GEOLOGY OF THE CAMP SAN SABA-WEST AREA,
MASON AND McCULLOCH COUNTIES, TEXAS

A Thesis

By

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ABSTRACT

The Camp San Saba-West Area is located on the northwestern flank of the Llano Uplift, about 6 miles south of the town of Brady. The area is most easily accessible by U.S. Highway No. 87, and covers approximately 30 square miles. Rock units of Late Cambrian, Early Ordovician, and Early Cretaceous age are present within the area. The Upper Cambrian strata have been divided into the Riley and Wilberns formations in ascending order.

The Riley formation is composed in ascending order of the Hickory sandstone, Cap Mountain limestone, and Lion Mountain sandstone members. The Hickory member consists of yellowish-brown to red, coarse-grained, nonglauconitic sandstones. These strata grade upward into the dark reddish-brown, arenaceous limestones of the lower portion of the Cap Mountain member. The middle and upper portions of the Cap Mountain limestones are gray to brown, silty, slightly glauconitic and fossiliferous, and grade upward into the coarse-grained, highly glauconitic Lion Mountain sandstone. The contact between the Riley and Wilberns formations is very sharp.

The Wilberns formation has been divided in ascending order into the following members: Welge sandstone, Morgan Creek limestone, Point Peak shale, and San Saba limestone. The Welge sandstone is yellowish-brown, medium-grained, and in most places nonglauconitic. This sandstone grades upward into the reddish-purple, arenaceous, glauconitic limestones

of the lower part of the Morgan Creek member. These limestones are gradually replaced upward in the member by greenish-gray glauconitic and fossiliferous limestone. The Morgan Creek member is transitionally succeeded by green, calcareous shales, limestones, and conglomerates of the Point Peak shale member. A thick zone of stromatolitic bioherms occurs at the top of this member. In most parts of the Llano region, these reef masses are considered to compose the upper portion of the Point Peak member. However, this writer has mapped them as the basal unit of the San Saba member, because in the central part of the thesis area the stromatolites occur interbedded with the San Saba limestones and in the southern portion of the area they are underlain by these limestones. The part of the San Saba member above the bioherms is termed the "calcitic facies", and is composed of brown to gray, granular, fossiliferous and sparingly glauconitic limestone.

The Cambrian strata are conformably overlain by Lower Ordovician limestones of the Ellenburger group. These limestones are light gray, sub-lithographic, and essentially nonglauconitic. They are succeeded upward in the section by darker gray, dense, saccharoidal dolomite. The Ellenburger group has been divided into formations in some areas, however, in the thesis area it has been mapped as a single unit.

Neither faulting nor folding of great magnitude has occurred in the thesis area. The faults, which are normal faults, have a general northeast trend and are almost restricted to the western and southern portions of the area. The displacements on the faults in the mapped area do not exceed 150 feet. Small folds of local occurrence have been formed as a result of differential compaction over bioherms and "reversed" drag along faults. The western limb of an anticline that plunges north probably is present in the eastern part of the area. Two collapse structures are present on the western bank of Katemcy Creek. Where undisturbed by faulting and folding the strata have an average regional dip of 4° N.52°W.

The most important resource in the area is the supply of ground water provided by the Hickory sandstone and Ellenburger limestone aquifers. The possibility of oil and gas production is very slight. Boulders of limestone and sandstone obtained from both the bedrock and from stream-transported deposits have been used for the building of homes and stone fences.

GEOLOGY OF THE CAMP SAN SABA-WEST AREA, MASON AND McCULLOCH COUNTIES, TEXAS

INTRODUCTION

PURPOSE OF INVESTIGATION

The primary aim of this paper is the detailed study of the geology of the Camp San Saba-West Area. The preparation of a geologic map of the area from field observations, and the study of the structure and stratigraphy of the Upper Cambrian rocks exposed in the area, are the two problems of primary interest. An attempt is made to interpret the geologic history of the area, and a resume' of the economic resources is included.

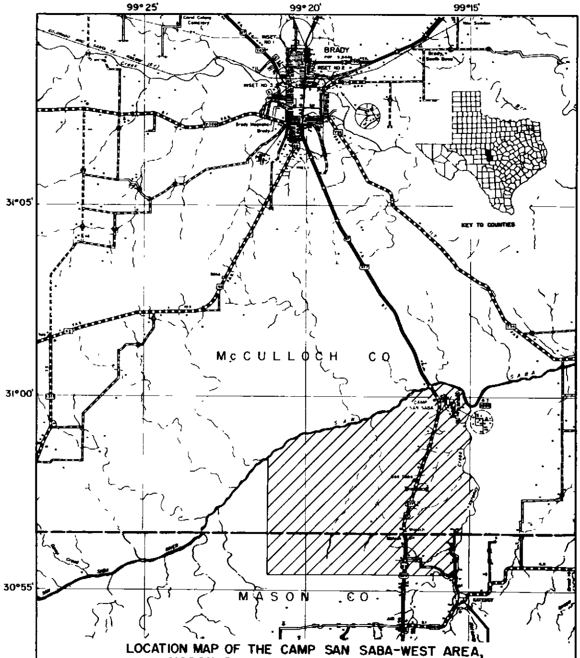
LOCATION

The Camp San Saba-West Area is located on the northwestern flank of the Llano Uplift, in Mason and McCulloch Counties. As shown in figure 1, the eastern and northern boundaries are natural geographic ones, i.e. Katemcy Creek and the San Saba River, respectively. The southern boundary extends 5.6 miles due west from the junction of Katemcy Creek and Katemcy Road, which forms the southeastern corner of the area. The western boundary extends due north from the western end of the southern boundary to the San Saba River.

ACCESSIBILITY

All but the extreme northwestern portion of the Camp San Saba-West Area is readily accessible by vehicle. The eastern half of the area is

Figure 1



LOCATION MAP OF THE CAMP SAN SABA-WEST AREA, MASON & McCULLOCH COUNTIES, TEXAS

Reproduced from highway maps of Mason and McCulloch Counties, Texas, prepared by the Texas State Highway Department, 1954

Scale 0 1 2 3 4 Miles

crossed by the north-south U.S. Highway 87. The area may be easily reached from the towns of Mason, to the south, and Brady, to the north, via this highway, which are respectively 13 and 8 miles distant.

Since a large amount of the central and eastern parts of the area are composed of small ranches and farms, many all-weather ranch roads and rocky ranch trails are present. The western portion of the area is made accessible by a ranch road connecting all the windmills on the Schmidt property, and by the Frank Kidd ranch road extending west from U.S. Highway 87. The northwestern region, where the topographic relief is greatest, is accessible only on foot.

METHODS OF FIELD WORK

The field work was done between July 3 and August 17, 1956. All mapping was done on acetate-covered contact prints of vertical aerial photographs prepared by the U. S. Department of Agriculture during December, 1939 and January, 1940. The scale of the photographs is approximately 1:20,000 or one inch equals 1667 feet. The thesis area is contained on photographs CJC 4 - 30 through CJC 4 - 34, CJC 23 - 138 through CJC 23 - 141, and CJC 4 - 131 through CJC 4 - 133. Most formational contacts and faults were traced in the field, and their locations were plotted on the acetate overlays during the process. Other less distinct contacts and faults were detected by a stereoscopic examination of the photographs. These observations were verified in the field, and their locations plotted.

All strikes and dips shown on the enclosed geologic map of this area were measured with a Brunton compass. Their localities were chosen for the purpose of illustrating the near-surface geologic structure of the area, and the values were determined by averaging several readings taken in the immediate vicinity of each point. A magnetic declination of ten degrees east was set on the compass.

All geologic data plotted on the acetate overlays of the individual photographs were transferred to an acetate base map of the thesis area. This map was drawn as an overlay of all the photographs used after they had been fitted together to form a mosiac of the whole area.

ACKNOWLEDGEMENTS

The author is grateful to Professor M. C. Schroeder of the Agricultural and Mechanical College of Texas, Chairman of the thesis committee, for suggestions made during field conferences and for the critical reading of this paper. Thanks are due to Professor H. R. Blank for aid in selecting the thesis area, and to Professors T. J. Parker and Peter Dehlinger, all of the Agricultural and Mechanical College of Texas, for critical reading of this paper. Also, the author's appreciation is extended to Professor J. L. Boone of Arlington State College for consultations concerning some of the field problems.

The writer is especially grateful to Verna N. Mounce for her aid in editing this work, and a general expression of thanks is extended to the ranchers in the thesis area for allowing him access to their property.

PREVIOUS INVESTIGATIONS

Review of Literature

Prior to this report, only the extreme northeastern corner of the Camp San Saba-West Area had been mapped in detail and published in the geologic literature. However, detailed work in the adjoining areas on the south and east was being done during the same time that this investigation was being carried on.

Dr. Ferdinand Roemer (1847) published the first descriptions of the rocks and fossils of the Llano region. While accompanying an exploring party of German colonists, he passed through the general locality of the thesis area. Although on the basis of information he received from others, Roemer made some erroneous speculations concerning the central portion of the Llano Uplift area, his own observations were confined to the southern and western periphery of the uplift. In a more extended investigation over a greater area, Roemer (1849, 1852) studied the formations, collected fossils, and published descriptions of these fossils in addition to an interesting account of his observations and travels. He was the first to announce the presence of Early Paleozoic, Carboniferous, and Cretaceous rocks in the Llano Uplift region. He described thirteen species of fossils from the Ordovician and Carboniferous systems with such accuracy that many of his descriptions have remained unchanged to this day.

While accompanying an expedition of Army engineers to explore parts of west Texas and New Mexico during 1865 and 1866, Dr. G. G. Shumard (1886) made brief geological notes along the return route from

Fort McKavett down San Saba River valley to Fort Mason and on to Fredericksburg.

B. F. Schumard (1861) varified much of Roemer's original work, and was the first to describe the rocks and fauna of the Potsdam group of Late Cambrian age. He first described the rocks composing the "Primordial Zone" of Texas, and also described nine new species of fossils of Cambrian age.

Jules Marcou (1855) compiled the first geologic map that showed the extent of Carboniferous strata in the Central Mineral region.

S. B. Buckley (1874), State Geologist of Texas in 1874, arbitrarily classified granites of the Llano region as being Azoic in age. He went on to state that these granites are younger than the metamorphic rocks with which they are associated.

Investigations of this region ceased until 1883 when C. D. Walcott (1884) visited the area, studied the rocks, and definitely established the Potsdam group as being Cambrian in age. Shortly thereafter, R. T. Hill (1887) briefly mentioned the Llano region in his review of the geology of Texas, noting the importance of Walcott's work. Two years later, Hill (1889) named and definitely established the correct age of the Carboniferous rocks at Marble Falls. Also, in the first of his two papers on the geographic features of Texas, Hill (1890) discussed the erosion of Upper and Lower Cretaceous strata from the central portion of the Llano region.

It was not until 1889 that a systematic geological survey of the Llano region was carried out. This investigation was done under the auspices of the newly created Geological and Mineralogical Survey of

Texas, with E. T. Dumble as State Geologist. Several publications resulted from this survey, including one by T. B. Comstock (1890) on the geology and mineral resources of the Llano region. He was the first to divide the Precambrian metamorphic rocks and granites of the Archean and Eparchean eras. In his discussion Comstock made the first reference to the names Valley Spring and Packsaddle series for the gneisses and schists occurring in the region. He also introduced the terms Hickory series, Riley series, and San Saba series. Comstock's Riley series included part of the rocks in the present Riley formation, and his San Saba series included all or a large part of the San Saba member as it is defined at present.

Other publications resulting from this investigation of the region were a report on the coal resources to the north and the drainage pattern of central Texas by R. S. Tarr (1890), one by J. A. Taff (1892) on the Cretaceous rocks, and two reports by W. F. Cummins (1890, 1891) on the stratigraphy of the Carboniferous rocks north of the region.

E. T. Dumble (1890) studied and described the Pennsylvanian rocks in the northern part of the region and gave them the name Bend for McAnnelly's Bend on the Colorado River. Some years later, Dumble (1898) published the geologic history of Texas and devoted a section of this work to the Central Mineral region. Dumble mentioned the Granite Highlands (1898, p. 402), which is the hilly region of Precambrian rocks fringed by Paleozoic strata that extends from Burnet County westward to the eastern part of Mason County.

In 1898, Sidney Paige (1912) compiled a detailed map of the Llano and Burnet quadrangles which are in the central part of the region.

Paige (1911) also named and described the Wilberns, Cap Mountain and Ellenburger "formations". He gave an excellent description of the Precambrian geology and discussed the economic resources of the Llano-Burnet area. Paige redefined the Valley Spring gneiss and Packsaddle schist, which he believed to be of sedimentary origin, and classified them as being of Algonkian age. In his discussion Paige refers to the Hickory sandstone instead of using Comstock's term "Hickory series".

The first comprehensive geologic map of Texas was compiled by J. A. Udden, C. L. Baker, and Emil Bose in 1916, and published by the Bureau of Economic Geology and Technology. It was drawn to a scale of 1:1,500,000. The Ellenburger group, Wilberns formation and Riley formation are shown as a combined unit, and the Precambrian rocks are undifferentiated. F. B. Plummer and R. C. Moore (1922) presented a new map of the Carboniferous formations of central Texas and differentiated the lower Bend shale as a separate formation having a distinctive fauna. The name Barnett was given to this new unit.

G. H. Girty and R. C. Moore (1919) discussed the age of the Barnett in a report on the Carboniferous rocks, and Girty concluded that it was of Late Mississippian age. Samples of crinoidal limestone collected by P. V. Roundy and K. C. Heald in 1919, were studied and found to be of Early Mississippian age by Roundy, Girty, and M. I. Goldman. The formation was referred to as "limestone of Boone age" until E. H. Sellards (1932) redescribed the strata and named them the Chappel formation.

The occurrence of algal limestone in the Wilberns shales in Mason County was mentioned by A. H. Deen (1931).

C. L. Dake and Josiah Bridge (1932) attempted the first zonation and faunal correlation of the Lower Paleozoic rocks in the area with similar strata in other states. Although a lithologic sequence was found to exist within the Ellenburger group, no formational boundaries were proposed at that time. However, after examining the Cryptozoan reef structure in the upper Wilberns formation of the Camp San Saba area, Dake and Bridge felt that these beds might be designated as a separate formation at some later date. They recommended that the old term "San Saba formation" be re-defined and applied.

H. B. Stenzel (1932) re-defined the Valley Springs gneiss and stated that it was of igneous origin and intruded the Packsaddle schist. In his report on the stratigraphy of Texas, Sellards (1932) briefly reviewed the Precambrian, Cambrian, and Ordovician systems of the Llano region. Sellards (1934) also discussed the deformation of the Central Mineral region during Paleozoic time in his report on the structural and economic geology of Texas. In this report, the Precambrian structural conditions of the Llano region were reviewed by Stenzel (Sellards, 1932). Later, Stenzel, (1935) reported on the Precambrian unconformities found in Llano County.

A new state geologic map (Darton, et al, 1937) was prepared by N. H. Darton after he had visited the area in 1933, collected unpublished data from geologists who had worked in the area, and checked certain formational contacts in the field. Darton plotted the outcrop areas of the Hickory sandstone, Wilberns limestone, Cap Mountain limestones, and Ellenburger limestone for the first time on this map.

Bridge (1937) studied the Lower Paleozoic rocks on the west side of the Llano Uplift, and named the Lion Mountain sandstone member of the Cap Mountain formation. He made many collections of fossils and relocated most of Roemer's original type localities. Roemer's Paleozoic fossils were redescribed by Bridge and Girty (1937) who also presented some excellent notes on the geology of the region.

V. E. Barnes and G. A. Parkinson (1939) first described the ventifacts which occur in the basal part of the Hickory sandstone of the Llano region. They regarded the Hickory as consisting, in part, of reworked eolian deposits, and included a map of Hickory sandstone outcrop areas showing ventifact localities in Mason, Llano, and Blanco counties in the report.

The larger bodies of Precambrian coarse-grained granites in the Llano-Burnet area were studied by D. Keppel (1940) with particular emphasis on their structure and texture.

An unpublished report concerning the stratigraphy of the Upper Cambrian strata in the Llano Uplift was given by Bridge and Barnes (1941) before the Geological Society of America meeting in Dallas, Texas, during December, 1941. They indicated that the Wilberns formation could be divided into four members; however, no names were proposed. These members were a basal sandstone, a glauconitic limestone, a green calcareous shale, and a limestone at the top. Later, Barnes (1944) named these units in ascending order the Welge sandstone, Morgan Creek limestone, Point Peak shale, and, as equivalent facies, the San Saba limestone and Pedernales dolomite. He assigned formational rank to all the pre-Wilberns units except the Lion Mountain sandstone, which he designated a member of the Cap Mountain limestone.

Plummer (1943) wrote a paper concerning the discovery of a white quartz sand near the middle part of the Wilberns formation in northwestern Mason County. This exceptionally pure sand was found on Leon Creek southeast of the town of Erna.

In a progress report on the stratigraphy of the Ellenburger group of central Texas, Cloud, Barnes, and Bridge (1945) revised the earlier nomenclature, introduced the term "Ellenburger group", and restricted this group so that it included only rocks of Early Ordovician age. The group was divided for the first time into three formations, which were named in ascending order the Tanyard, Gorman, and Honeycut. The authors also revised the stratigraphic classification of the Cambrian rocks. The Riley series was re-defined as a formation and was divided into the Hickory sandstone, Cap Mountain limestone, and Lion Mountain sandstone members. The top of the Cambrian system was placed at the upper boundary of the Wilberns formation.

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

Bridge, Barnes, and Cloud (1947) presented the stratigraphy of the Upper Cambrian rocks in the Central Mineral region in 1947. Their section consisted of seven members and two formations. These units were named and re-defined, and a detailed description of each was included in the paper.

Plummer (1947) published a summary of the classification of the Lower Pennsylvanian strata in central Texas. Later, Plummer's (1950) detailed analysis of the Carboniferous stratigraphy and paleontology in this region was published posthumously. This report included a brief report on the pre-Carboniferous strata of central Texas.

A basic study of the Ellenburger rocks of the Llano region was prepared by Cloud and Barnes (1948). Features having a possible significance in the search for petroleum were stressed in this report, and the pre-Ellenburger strata of several localities in the Central Mineral region were briefly described. H. R. Blank (1951) discussed and described degradational processes in operation on the granitic masses in the Llano Uplift area.

A. R. Palmer (1954) studied and described the fossils of the Riley formation of central Texas. Six trilobite zones were mentioned, the boundaries of which do not coincide with those of the members and submembers of the Riley formation.

Barnes and W. C. Bell (1954) compiled an excellent resume' of the Cambrian localities and measured sections in their guidebook for the San Angelo Geologic Society's Cambrian field trip to the Llano area. They stated that the previously mentioned term "Pedernales dolomite" had ceased to be used in favor of the name of its equivalent facies on the western side of the Llano area--the "San Saba limestone". The detailed geology of the extreme northeastern corner of the Camp San Saba-West area was also shown on a map prepared by Barnes and Bell (1954, p. 20).

Barnes (1956) presented a report on the lead and zinc deposits in the central Texas area. Dikes of diabase along the Marble Falls fault were recognized for the first time and found to be of Carboniferous or younger age.

In addition, several small sections of Mason County to the south of the thesis area were mapped and reported upon by W. L. Alexander (1952), T. P. Polk (1952), V. M. Duvall (1953), R. P. Parke (1953), J. F. Fritz (1954), and F. R. Grote (1954). Theses are being prepared by N. C. Scaife and W. E. Sweet on areas adjoining the Camp San Saba-West area on the south and the east.

Summary of Geologic History of the Llano Region

The large quantity of Precambrian gneiss, schist, quartzite, and marble occurring in the Llano region seems to indicate that a great series of sediments were laid down over the area during this time. At least the marble, and possibly a large part of the other metasediments were deposited under marine conditions. The variation of lithologic types occurring above the marble appears to indicate an influx of clastic material following a period of stability during which clastic deposition was not taking place. The graphite in some of the metasediments probably represents carbonaceous matter which was included within these rocks during deposition, and may indicate the presence of life.

As deposition continued the sediments were deeply buried and complexly folded and faulted with some attendant metamorphism. Extensive igneous intrusions followed, probably causing another phase of subsequent metamorphism. The coarse-grained texture of the Town Mountain granite seems to indicate deep-seated crystallization of its parent magma. However, the fine-grained Sixmile and Oatman granites appear to have crystallized under conditions of more rapid rates of cooling. It was pointed out by Sellards (1932, p. 35) that these granitic intrusions occurred before the deposition of Paleozoic strata, because at no place in the region did they penetrate the Paleozoic beds. A period of erosion followed the pronounced folding, and bared the Precambrian metamorphic rocks and granites to form a surface of considerable relief. This period of denudation probably occurred during the Early and Middle Cambrian epochs and part of Precambrian time.

The first Paleozoic sea entered the area during Late Cambrian time and reworked the existing eolian sediments to form the basal, coarse, cross-bedded sands of the Hickory member. This transgressive sea was rather shallow because hills as high as 800 feet did not receive sediments until Cap Mountain time. The ventifacts in the basal portion of the Hickory member appear to indicate that an environment suitable for eolian deposition still existed during early Hickory times. Barnes and Parkinson (1939) have found dreikanters as high as 4 feet above the base of the Hickory and concluded this indicated a continuation of ventifact formation after the deposition of the Hickory had begun. However, these materials may have been transported from a positive area from which the detrital material had not been removed. Also, a slight fluctuation of the early Paleozoic strand line in the area studied by Bridge and Parkinson could have caused reworking and redeposition of the relatively thin initial layer. It seems much easier to visualize the ventifact formation occurring over a very long period of time rather than during the relatively short interval required to deposit the initial four feet of sediments.

The presence of ripple marks and phosphatic brachiopods in the upper portion of the Hickory member indicates that shallow water conditions prevailed during this time. However, as the supply of coarse detritus was depleted, the marine sandstones graded into the glauconitic limestones of the Cap Mountain member. These limestones accumulated under relatively quiescent conditions in a shallow, cool, neritic environment. In late Riley and early Wilberns time, minor regional uplifting occurred and the lands again supplied sediments to the regressive-transgressive sand zones that compose the Lion Mountain sandstone and Welge sandstone sequence. The fact that these members were formed in marine waters is evidenced by the presence of glauconite and marine fossils. The sharp lithologic change between the two members may be the expression of a short hiatus, which would support the idea of minor regional uplift.

The close of Welge sedimentation was marked by a decrease in the supply of coarse material and the gradual transgression of marine waters. This marine invasion of the land areas is represented by the occurrence of granular arenaceous limestones in the lower portion of the Morgan Creek member. The abundant glauconite and marine fossils, including brachiopods and trilobites, in the middle and upper parts of the member indicate deposition in a neritic environment. The presence of stromatolitic bioherms in the upper portion suggest warm shoal waters and the shallowing of the sea.

During middle Wilberns deposition, argillaceous material was introduced into the sedimentary sequence in a very quiet sea. This is evidenced by the very well bedded silts and shales of the Point Peak member. The scattered limestone ledges and marine fossils within the member indicate that the waters were marine, and since most of these limestones occur as pebbles in intraformational conglomerates, the waters must have been very shallow. Paige (1912, p. 74) stated:

> Near the upper portion of the Wilberns thin alternating shale and limestone beds, numbers of shale pebble conglomerates, 'edgewise' (shale fragments) conglomerates, sun-cracked surfaces and fragments...all suggest the presence of widespread flats, alternately flooded by tide and dried by sun.

There must have been extensive shoaling and warming of the waters because of the large amount of stromatolitic growth occurring near the close of the deposition of the Point Peak and during the beginning of San Saba deposition.

A gradual deepening of the waters is represented by the silty, glauconitic limestones of the San Saba member in the northwestern and western parts of the Llano region. The occurrence of locally thick calcareous sands within the member has indicated to Cloud and Barnes (1946, p. 112) the continued or intermittent presence of a large island or land mass to the west. However, the increasing proportion of sub-lithographic limestone and dolomite within the San Saba member toward the eastern part of the Llano Uplift appears to indicate a general shoaling of the region in that direction. During latest Cambrian time the gradient of the sea floor was to the northwest and either tilting of the region in that direction or a lowering of sea level resulted in the emergence of the southeastern part of the Llano region and truncation of the highest Cambrian strata.

In the western part of the Llano Uplift, deposition was continuous across the Cambrian-Ordovician boundary. During Early Ordovician time the Llano region remained relatively stable, and the absence of clastics in the Ellenburger suggests that the western positive area had ceased to contribute sediments. The sea which covered the area during this time was warm, intermittently turbulent, and relatively shallow. Cloud and Barnes (1948, p. 32) have stated that these strata are:

> ...commonly although not generally stromatolitic, indicating at least a partial algal and generally a shallow water origin. Deposition in shallow water is also indicated by ripple marks and intraformational breccias... .

A wide gap in the geologic record follows the Lower Ordovician deposition. The conspicuous absence of Upper Ordovician and Silurian strata throughout the region indicates that generally emergent conditions with accompanying erosion prevailed during these intervals. This was probably the longest period of Paleozoic emergence of the Llano region before Devonian time according to Cloud and Barnes (1948, p. 113). Although maximum truncation of the Ellenburger group by erosion occurred in the western part of the uplift, the oldest Devonian strata are found in the east and the youngest in the west. From these data, Cloud and Barnes (1948, p. 113) concluded:

> ...one may provisionally infer that the region was tilted to the east and largely truncated before Devonian time, followed by an east to west Devonian marine invasion and continuing truncation of the emergent areas.

Irregularities in the Devonian overlap and temporary withdrawals of the sea are suggested by the occurrence of Devonian rocks as pocket- and crack-fillings.

Though locally discontinuous, beds of Mississippian age are widespread in the Llano region and are much more persistent laterally than beds of known Devonian age (Cloud and Barnes, 1948, p. 42). The Mississippian strata thin toward the center of the region, thus indicating gradual uplift of the Llano region during this period. Cloud and Barnes have stated that "It is known that marine invasions occurred at several times during Mississippian and Pennsylvanian time;..". A return to swamp-like conditions, according to Paige (1912, pp. 80), is indicated by the black shales that compose the top of the Pennsylvanian sequence.

Extensive faulting of the Llano region occurred during Early Pennsylvanian time. Most of these fault movements took place after the deposition of the rocks of the Bend group and prior to the deposition of the rocks of the Canyon group. The rocks of Canyon and younger ages are essentially free from faulting.

Widespread emergent conditions prevailed in the Llano Uplift after Pennsylvanian time, and the region persisted as a positive area in the Texas foreland during the Permian, Triassic, and Jurassic periods. Some re-elevation of the area probably accompanied this long hiatus. However, by Cretaceous time erosion had reduced the surface to a region of low relief and exposed all older strata in the area, including a large expanse of Precambrian rocks. As the Cretaceous sea invaded the region, basal sands and horizontal beds of limestone and clay were deposited throughout the area. After the early Cretaceous sedimentation, gentle, vertical uplift with no subsequent faulting and folding occurred. The resulting truncation by erosion again bared the ancient Paleozoic and Precambrian rocks.

The Llano region appears to have stood above sea level since Cretaceous time, for, with the exception of scattered stream deposits, no strata of younger age are present.

GEOGRAPHY

CLIMATE

A semi-arid climate prevails over the Llano region in which the Camp San Saba-West area is located. The average annual precipitation in Mason and McCulloch Counties is approximately 23.5 inches, however it may vary from a somewhat lower value up to about 45 inches. Although most of the rainfall occurs in the winter and spring, it is very unevenly distributed during these seasons. Often one-third of the annual precipitation comes within a single week, and the rains may be followed by many weeks of drought. For the past six years severe drought conditions have prevailed in the area.

The average annual temperature of the area is 70.5° F. During the winter months from November to April the daytime temperatures vary from 40° F. to 70° F. with frost frequent at night, especially when the wind is from the north. Through the hot and dry summers, the daytime temperatures range from 80° F. to 109° F. and average approximately 90° F. The prevailing southeasterly breeze tends to make the evenings and nights moderately cool during this season.

VEGETATION

The vegetation present in the thesis area belongs to the plant types which are adapted to moderate precipitation, rather severe temperature ranges, and rocky slopes. Mesquite, oak, elm, and cedar trees are found on most of the areas of higher elevations, while sycamore and pecan are most prevalent in the valleys. A few willows and elms are found along the more persistent streams in the area.

The distribution and relative abundance of plant life on a residual soil depends in part upon the type of bedrock. Accordingly, certain varieties of flora tend to grow more readily on certain stratigraphic units, and the contacts between some of these units are marked by obvious changes in vegetation. The limestone formations are characterized by an abundance of Mexican persimmon, Spanish bayonet, catsclaw, agerita, and prickly pear. Also, cedar, scrub oak, and live oak are found to grow abundantly in scattered clumps on the Lower Ordovician limestones. Mesquite, bee-bush, catsclaw, lady finger, and Mexican persimmon are more common to the sandstone and shale formations cropping out in the area. The grasses which occur throughout the area are buffalo, curly mesquite, crowfoot, tobosagrass, needle, sideoats and hairygrama, and several other varieties of lesser importance.

INDUSTRY

The major industries in Mason and McCulloch Counties are medium-scale ranching, stock farming, and farming. The most important product of the ranching industry is beef cattle, with the raising of sheep and goats assuming a secondary role. Peanuts, cotton, corn, hay, and watermelons are the principal agricultural products grown in this region. Most of the fields used for cultivation are rather small and limited to bottom land or slopes and benches associated with the less resistant sandstones and shales.

Prolonged drought conditions in all the southwest have caused a considerable decline in marketable products from this area. The cities of Mason and Brady serve as the shopping and trading centers for Mason and McCulloch Counties.

PHYSIOGRAPHY

PHYSICAL FEATURES

The Camp San Saba-West area lies on the northwestern flank of the Llano Uplift of central Texas. Although the Llano region has the topographic expression of a broad erosional basin, it is structurally a large domal uplift. Rocks of Precambrian age are exposed in the central part of the basin which is bordered by a higher area of more resistant Paleozoic and Cretaceous strata. The highest elevations in the region occur on the plateau between Mason and Fredericksburg, and are in excess of 2200 feet. Since the lowest point in the basin is at an elevation of 650 feet, the total relief is approximately 1600 feet. The Camp San Saba-West area is located in the outer portion of the high areas that form the rim about the Llano region. The uppermost part of this rim is composed of limestones of Early Cretaceous age and is located approximately three miles northwest of the San Saba River. The lowest point in the thesis area is about 1500 feet above sea level and occurs at the northeast corner where Katemcy Creek empties into the San Saba River. The highest elevation in the mapped area is approximately 1900 feet. Thus, the total relief in the Camp San Saba-West area is about 400 feet.

Three distinctly different varieties of physiographic expression are present in the area. The sandstones and shales of the Upper Cambrian sequence have been eroded in most localities to form low, relatively flat lands. These strata come to the surface in the eastern and southeastern parts of the area, and furnish most of the soil that is suitable for cultivation. The limestone portions of the Upper Cambrian series from prominent northeast-trending ridges and cuestas which exhibit steep escarpment slopes and gentle dip slopes. In the normal outcrop pattern these more resistant units are separated by the lowland flat areas formed by the previously mentioned softer units.

The Lower Ordovician limestones are exposed at the surface in the northwestern part of the area and form a rolling topography. Relief is greater in the outcrop area of the Ellenburger group than on the older strata in the thesis area, with the exception of an erosional remnant in the form of a hill composed largely of bioherms but capped by San Saba limestone. This hill is located due east of the C. Myrick farmhouse in the north-central part of the area (plate I).

EROSIONAL AGENCIES

The primary agent of erosion to which the rocks of the Llano region have been exposed is running water. After the concentrated but usually short-lived rains typical in this area, runoff waters in the portions of the drainage system with higher gradients attain velocities great enough to transport large amounts of sediment. These waters are especially effective in areas that support only sparse vegetation. With the exception of the cultivated areas, the effects of aeolian erosion are negligible.

Some of the topographic features present in the thesis area have been developed as a result of faulting which places less resistant strata against more resistant strata. Fracturing along some of the faults has further weakened the strata, making the rocks along these faults more susceptible to erosion.

DRAINAGE

The Llano region is drained by four principal streams, which are the Colorado River on the east, the San Saba River on the north, the Llano River in the central part, and the Pedernales River on the south. These streams have been superimposed upon the Paleozoic and Precambrian rocks of the region. As pointed out by Tarr (1890, p. 360), the pattern of the major stream courses was established during Tertiary time on an eastward-tilted plain of Cretaceous strata. The streams have been entrenched into the older rocks, and have held their general directions across the region without regard to the Precambrian core and encircling Paleozoic rocks. The numerous small tributary streams, however, are adjusted to local structure.

The San Saba River, which forms the northern boundary of the thesis area, drains all of the water from the area. Rainfall in the eastern and southeastern parts of the area is carried by small obsequent tributaries into Katemcy Creek which forms the eastern boundary and empties into the San Saba River at the northeast corner of the area. In the western and northwestern sectors waters are drained by way of small subsequent tributaries directly into the river.

All streams in the thesis area, except the San Saba River, are intermittent and flow only during periods of heavy rainfall. Katemcy Creek carries a heavy load of granite wash obtained from the granite masses through which it flows.

STRATIGRAPHY

GENERAL STATEMENT

Strata of the Cambrian, Ordovician, and Cretaceous systems are exposed in the Camp San Saba-West area. Although they do not crop out in the thesis area, Precambrian granites are exposed a short distance to the south. The only rocks younger than Early Ordovician consist of a very thin veneer of basal Cretaceous sediments occurring as an erosional remnant which caps a hill in the southwestern part of the area, and minor deposits of Recent alluvium. The gologic column of the area is as follows:

QUATERNARY

Recent

MESOZOIC ERA

Cretaceous System

Unidentified basal sand

PALEOZOIC ERA

Ordovician System

Lower Ordovician

Ellenburger group

Cambrian System

Upper Cambrian

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

CAMBRIAN SYSTEM

Rocks of Late Cambrian age crop out over all but the northwestern corner of the thesis area. These strata are composed of sandstones, limestones, and shales with stromatolitic bioherms occurring in the upper part of the sequence. The currently accepted division of the Upper Cambrian rocks into two formations and seven members is a result of the combined work of Bridge, Barnes, and Cloud, (1947, pp. 109-124).

Riley Formation

The term "Riley series" was first applied by Comstock (1890, p. 285) to part of the strata that compose the present Riley formation. This unit was reduced to formational rank and redefined by Cloud, Barnes, and Bridge (1945, p. 154) as including all of the Cambrian strata in central Texas beneath the Wilberns formation. It is composed, from base to top, of the Hickory sandstone, Cap Mountain limestone, and Lion Mountain sandstone members which are separated by gradational contacts.

The Riley formation was named for exposures in the Riley Mountains of southeastern Llano County where it is 780 feet thick. Because of the topographic irregularity of the overlapped Precambrian surface, the thickness in measured sections ranges downward to about 600 feet. Also, in southwestern San Saba County the Cap Mountain limestone member rests directly on Precambrian rocks, therefore at that place probably less than 200 feet of the Riley formation is present. The average thickness of the unit is given by Bridge, Barnes, and Cloud (1947, p. 110) as 660 feet. The lower 40 feet of the Riley formation is not exposed in the thesis area, and the estimated thickness of the remaining part of the formation that crops out in the area is 600 feet.

Hickory Sandstone Member

Definition and thickness--The term "Hickory" was first used as a series name by Comstock (1890, p. 285) and was applied to beds cropping out in the valley of Hickory Creek in Llano County. Later, Paige (1912, p. 42) renamed these rocks "Hickory sandstone" and placed the upper boundary of the unit at the highest dominately sandy beds in the basal Upper Cambrian strata. These boundaries were redefined and amended by Cloud, Barnes, and Bridge (1945, p. 154) when they reduced the Hickory to member status within the Riley formation.

The Hickory sandstone member is reported by Bridge, Barnes, and Cloud (1947, p. 112) to vary in thickness from the vanishing point to about 415 feet, and the average thickness is estimated as 360 feet. Although the base of the Hickory sandstone does not come to the surface in the thesis area, a thickness of approximately 525 feet of the member is exposed in the area. This unusually great thickness may be attributed in part to abnormal thickening of the member, or to the occurrence of several faults of such small displacements as to make them impossible to identify on the outcrop.

Lithology--The Hickory sandstone member overlies the Precambrian rocks with a marked unconformity, and is described by Bridge, Barnes, and Cloud (1947, p. 113) as noncalcareous, nonglauconitic, yellow, brown and red sandstones. In the thesis area, the lower portion of the Hickory is composed of reddish-brown to tan, very coarse-grained, nonfossiliferous sandstones. These strata are for the most part massively bedded. The shape of the quartz grains varies from subangular to rounded and their degree of sorting is poor.

The middle portion of the Hickory beds consists of alternating layers of light-colored sandstones and reddish silty shales. The sandstones are soft, gray to tan, friable, medium- to fine-grained, well-bedded and in many places intricately cross-bedded. The shales are somewhat darker in color, very fine-grained, and thinly to indistinctly bedded. These shales are persistent and do not appear to be laterally gradational into sandstones. Although some widely separated, coarse, quartz grains are present throughout this portion of the member, generally, the sorting is much better than that of the underlying lower Hickory sandstone. Where the sandstones are exposed in vertical stream banks, they tend to form prominent ledges which protrude outward over the undercut shale beds.

In the upper portion, the Hickory beds are reddish-purple, medium-grained, well-bedded sandstones containing a ferruginous cementing material, which tends to make the rocks moderately hard. It is well sorted and composed of rounded, quartz grains that are so coated with ferruginous material that they tend to give the rock an oölitic appearance. The residual soils resulting from this portion of the member have a characteristically dark red color.

Ripple marks are found at some places in the upper part of the Hickory member. Those shown in figure 1 of plate II are assymmetrical, but have rounded crests and troughs. They measure 2.5 inches from crest to crest, and the approximate depth of the troughs is three-eights of an inch.

Phosphatic brachiopods (plate II, figure 2) have been reported to occur in the middle and upper Hickory sandstones according to Parke (1953, p. 20). However, they appear to be almost completely restricted to the upper Hickory in the thesis area.

Topography and vegetation--The Hickory sandstone forms relatively flat, open fields in the topographically low, southeastern portion of the thesis area. Most of these fields are put under cultivation annually. A few gentle hills interrupt the almost flat terrain near Katemcy Creek. Outcrops of the Hickory sandstone that could be measured and described were not found in the mapped area.

Moderately dense vegetation consisting of scrub oak, mesquite, elm, Mexican persimmon, and several varieties of cacti and grasses is present on the uncultivated portions of the Hickory outcrop. Bee-bush and various grasses are usually found bordering the open fields.

PLATE II

Ripple Marks and Fossils in the Hickory Sandstone Member

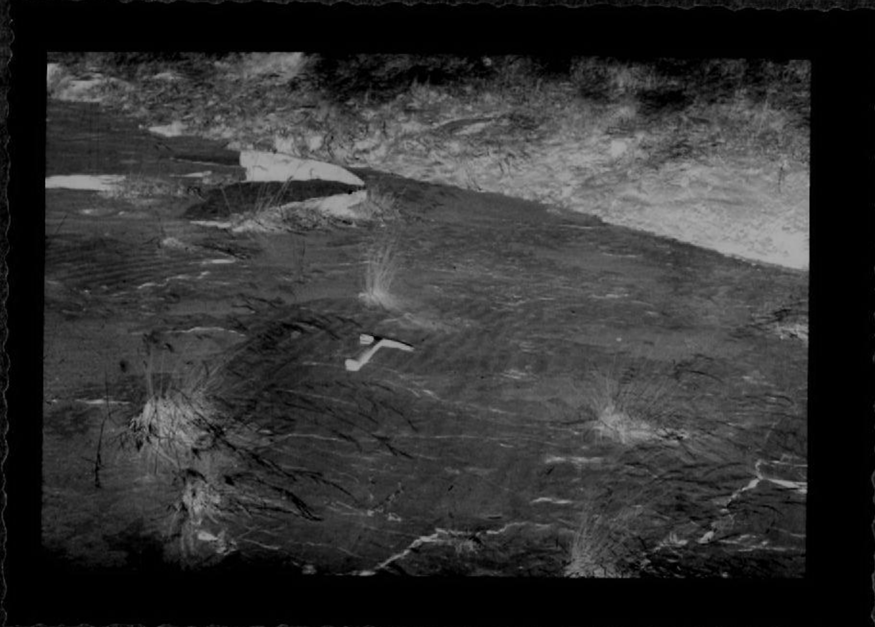


Figure 1.--Hickory sandstone ripple marks in stream bed two-thirds mile north of the M. Cohen ranch house.

Figure 2.--Hickory sandstone with phosphatic brachiopods three-fourths mile northwest of the M. Cohen ranch house.

Cap Mountain Limestone Member

Definition and thickness --The term "Cap Mountain" was introduced by Paige (1912, p. 45) as a formational name. This unit included all of the present Riley formation above Paige's Hickory sandstone, and was named for exposures on Cap Mountain in eastern Llano County. The Cap Mountain limestone was later re-defined by Cloud, Barnes and Bridge (1945, p. 154) and included as a member in the Riley formation.

The thickness of the Cap Mountain member throughout the region ranges from about 135 to 455 feet, and averages about 260 feet according to Bridge, Barnes, and Cloud (1947, p. 113). In the thesis area, the minimum thickness of this member is 225 feet. The abnormal width of the outcrop of the Cap Mountain (plate I) is caused by faulting.

Lithology--The contact between the Cap mountain limestone member is one of gradation, and is placed at a distinct topographic change in slope and a vegetational change which shows well on aerial photographs. In most places this change is at the base of the low escarpment of a Cap Mountain cuesta. More specifically, Bridge, Barnes, and Cloud (1947, p. 113) stated:

> This boundary is at the top of a noncalcareous sandstone zone beneath a zone of alternating impure, dark-brown limestones and calcareous sandstones which become more calcareous upward; finally grading into fairly pure, granular limestones that comprise the bulk of the member.

The lower beds of the Cap Mountain limestone exposed in the area are chiefly dark reddish-brown, medium-bedded and in part distinctly cross-bedded, calcareous sandstones of medium- to fine-grained texture, alternating with, and grading laterally into, grayish-brown, fine grained, arenaceous limestones. These beds grade upward into light-brown or gray, medium- to coarsely-crystalline, arenaceous limestones that contain many layers of yellowish-brown, fine-grained, noncalcareous sandstone (plate III, figure I). Cross-bedding is generally better developed than in the basal beds. The sandstone layers appear to persist over considerable lateral distances.

In the middle portion of this member, calcium carbonate is more abundant and the rocks consist of fairly pure, fine-grained, light gray limestones that contain some grayish-yellow dolomite. These strata are well-bedded, and contain thin layers and small cavity fillings of brownish-yellow siltstone.

The upper portion of the Cap Mountain member is composed of light-gray, medium- to coarse-grained, sparingly fossiliferous, glauconitic limestones. These limestone beds are very sandy near the top of the interval, and thick, shaly and silty beds are common (plate III, figure 2). Ripple marks and cross-bedding are well developed in some of the more sandy limestone layers (plate IV).

Topography and vegetation--In the Camp San Saba-West area the lower zones of calcareous sandstone and arenaceous limestone form cuestas along the contact of the Cap Mountain limestone and the Hickory sandstone. The sandy soils developed on the dip slopes of these cuestas are usually cultivated and used for the raising of crops. The thick limestone beds of the middle and upper portions of the Cap Mountain member form prominent ridges of moderate relief. However, an abundance of residual soil occurs on the member, and it is virtually impossible to measure the thickness of the unit accurately.

PLATE III

Upper and Lower Portions of the Cap Mountain Limestone Member

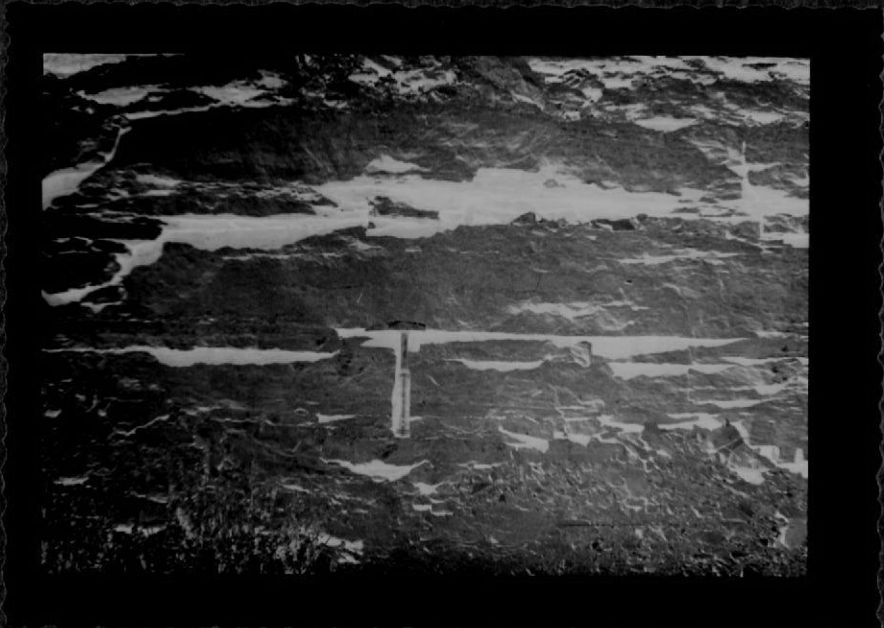


Figure 1.--Lower Cap Mountain limestones exposed in quarry 500 feet north of the junction of U. S. Highway 87 and the Katemcy road.

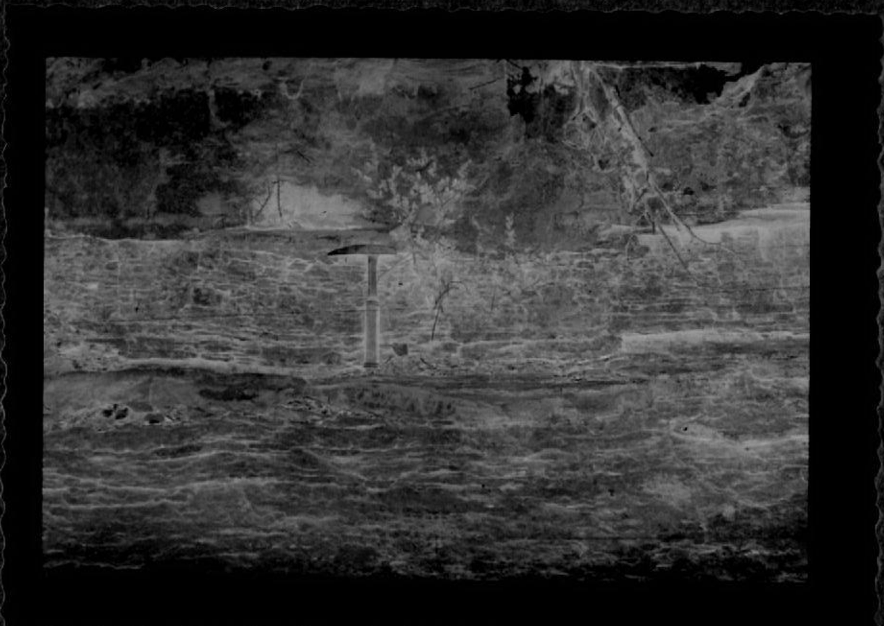
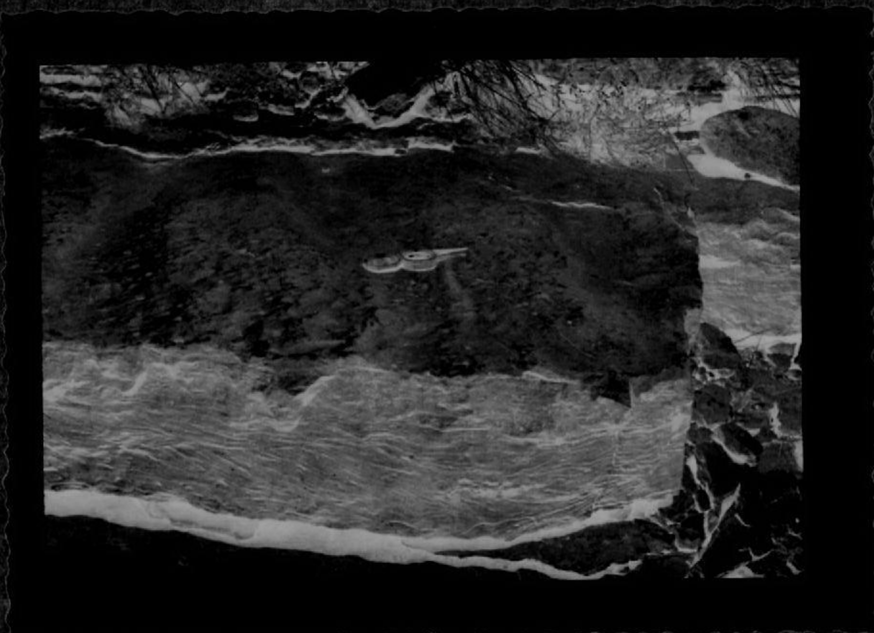


Figure 2.--Silty beds in the upper Cap Mountain limestones in the northeastern part of the thesis area.

PLATE IV



Cap Mountain limestone ripple marks exposed in a stream bed in the northeastern portion of the Camp San Saba-West area.

Vegetation growing on the Cap Mountain limestone is rather dense and evenly distributed. Scrub oak, mesquite, cedar, Mexican persimmon, prickly pear, turkey pear, catsclaw, Spanish bayonet, and numerous grasses grow on the weathered outcrops of these strata. However, some of the natural vegetation has been cleared by the ranchers.

Lion Mountain Sandstone Member

Definition and thickness--The Lion Mountain sandstone was originally defined by Barnes (1937, p. 234) as the top member of the Cap Mountain "formation", and was named for Lion Mountain in northwestern Burnet County. Later, Cloud, Barnes, and Bridge (1945, p. 154) included this sandstone as the upper member of the Riley formation in their reclassification of the Upper Cambrian strata of this region.

In the type section, according to Bridge, Barnes, and Cloud (1947, p. 114), the Lion Mountain sandstone is only about 20 feet thick. However, it attains a maximum measured thickness of 50 feet at other localities, and averages approximately 37 feet thick throughout the region. The thickness of the Lion Mountain sandstone in the Camp San Saba-West area is estimated to be 35 feet.

Lithology--The Lion Mountain sandstone member has a gradational contact with the underlying Cap Mountain limestone member. The contact is generally placed at a vegetational and slight topographic change that is visible on aerial photographs. The member is described by Bridge, Barnes, and Cloud (1947, p. 113) as a highly glauconitic sandstone containing thin lenses of limestone in its lower part.

In the thesis area, the Lion Mountain sandstone is principally a bright green, coarse-grained, distinctly cross-bedded, highly glauconitic sandstone. The only good exposure of these sandstones in the mapped area occurs in a creek bed along the south side of the Camp San Saba cemetery (plate I).

Lenses of limestone that are essentially composed of trilobites are common in the lower part of the Lion Mountain member (plate V). These limestones are light purplish-gray, very coarsely textured, and tend to occur in planes which are parallel to the prominent lines of cross-bedding. The trilobite fragments within them do not seem to have any particular pattern or arrangement, and consequently, these lenses have been termed "trilobite hash".

Numerous black, round hematite nodules which have a metallic appearance are found on the weathered outcrop of this member. In most exposures the relative abundance and size of these nodules increase toward the top of this member. These nodules are believed to be derived from the chemical alteration of glauconite.

Topography and vegetation--The Lion Mountain sandstone member weathers to produce a narrow bench or open field, which is usually cultivated. Vegetation on the parts of the outcrop that are not plowed is rather sparse, primarily consisting of mesquite, scattered clumps of scrub oak, needle grass, lady finger, and turkey pear.

The contact between the evenly distributed vegetation on the Cap Mountain member, and the characteristically sparse vegetation of the Lion Mountain beds is very apparent at many places on the aerial photographs.

PLATE V

Lenses of "trilobite hash" in the Lion Mountain sandstone member exposed in a stream bed 300 feet southeast of the Camp San Saba cemetery.

Wilberns Formation

Sidney Paige named the Wilberns formation in 1911 (p. 23) for Wilberns Glen in northeastern Llano County, and later described the unit in detail (1912, p. 46-51). Present usage retains the lower boundary as established by Paige, but the upper limit was re-defined by Bridge, Barnes, and Cloud (1945, p. 140) to coincide with the Cambro-Ordovician boundary.

The Wilberns formation is divided into four members, and these were first described in detail by Bridge, Barnes, and Cloud (1947, p. 109-124).

Through most of the Llano region the Wilberns formation ranges from 540 to 610 feet thick. In the Camp San Saba-West area the Wilberns formation is estimated to be 615 feet thick.

Welge Sandstone Member

Definition and thickness--The Welge sandstone member was named by Barnes from the Welge land surveys between Threadgill and Squaw Creeks in northern Gillespie County (Bridge, Barnes, and Cloud, 1947, p. 114). At this locality the member is 27 feet thick. It is persistent throughout the Llano Uplift, averaging 16 and ranging from 9 to 35 feet thick. The thicker sections occur along the northern and western sides of the uplift. The thickness of the Welge sandstone in the mapped area is about 32 feet.

Lithology--The contact of the Welge sandstone member with the underlying Lion Mountain sandstone member is abrupt and may be unconformable. In their study of the region, Bridge, Barnes, and Cloud (1947, p. 114) described the Welge member as a brown, mostly nonglauconitic sandstone, and noted the sharp contact at its lower limit. This contact is well exposed in the thesis area in the creek bed (plate VI, figure 1) a short distance upstream from the previously mentioned Lion Mountain locality.

The Welge sandstone is well exposed only in the northeastern corner of the mapped area, and is a yellowish-brown to reddish-brown, mostly nonglauconitic, poorly sorted sandstone. At the better localities it is thickly bedded to moderately cross-bedded, and composed of medium- to coarse-grained, subrounded to well rounded quartz grains, some of which sparkle in the sunlight because of the presence of secondary crystal growth. The basal part of the member consists of a thin zone of yellowish-orange to white, very thinly bedded, fine-grained siltstone that grades upward into the overlying sandstone.

The base is marked by a sharp change from the greenish, highly glauconitic, cross-bedded sandstones of the Lion Mountain member to the thin, light-colored laminae of the lower Welge siltstone. This contact is exposed at only a few places however, and since it is not marked by a topographic or vegetational change in the thesis area, it is difficult to determine accurately in the field.

Topography and vegetation--Except in the northeastern corner of the mapped area, there is little variation between the topography of the Welge sandstone and the underlying Lion Mountain sandstone. In almost all localities the Welge is represented by a very gentle rise in slope, and in most localities it weathers to form a slightly darker

PLATE VI

Basal Contact and Ledges of the Welge Sandstone Member

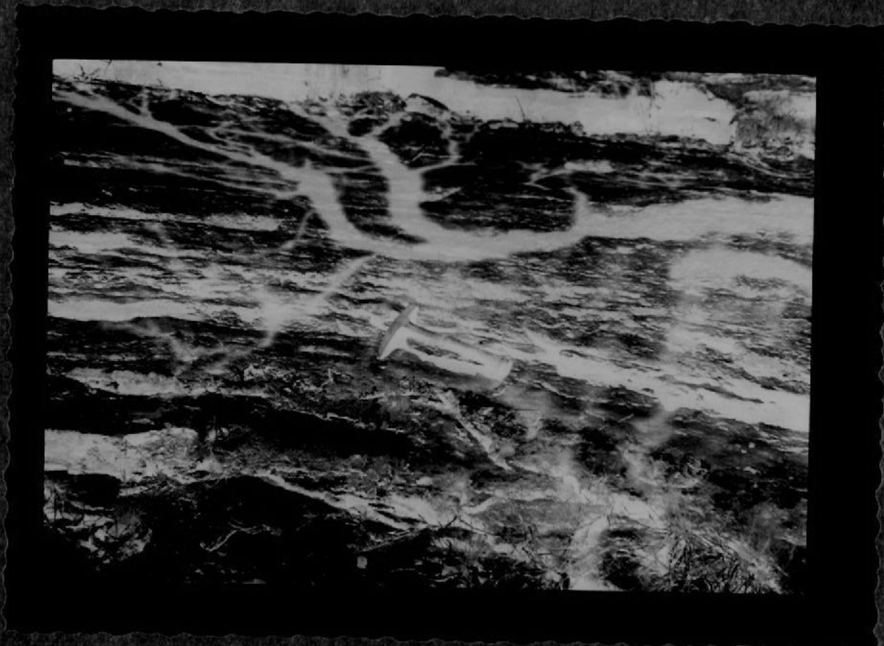


Figure 1.--Lion Mountain--Welge contact exposed in a stream bed 200 feet south of the Camp San Saba cemetery.

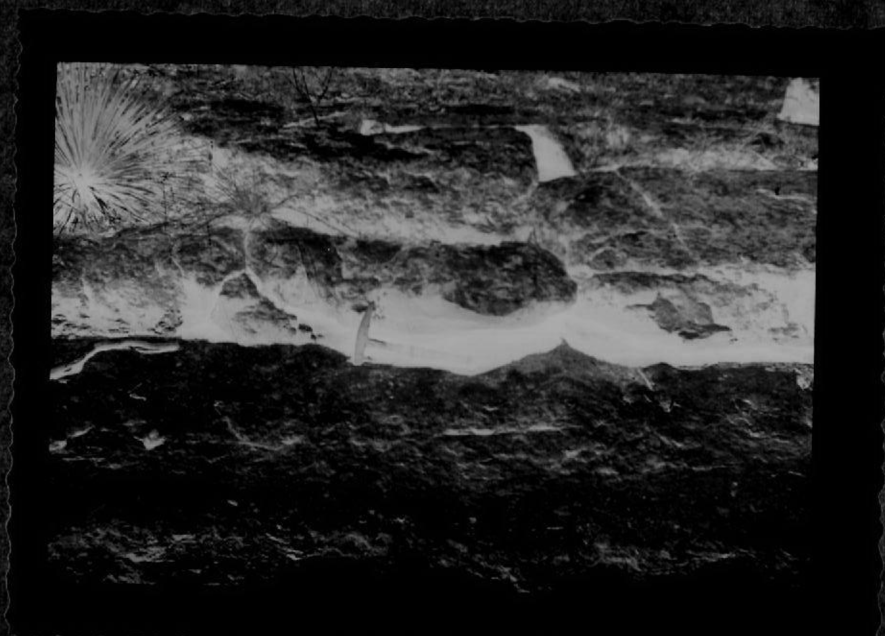


Figure 2.--Welge sandstone ledges exposed 400 feet upstream from the locality described in Figure 1 above.

soil than does the underlying Lion Mountain sandstone. Where exposed in a vertical stream bank, it weathers to form massive ledges (plate VI, figure 2).

Similarly, there is very little difference in the vegetation growing on the Welge and Lion Mountain sandstones. Mesquite, scrub oak, turkey pear, lady finger, and various grasses are common to both.

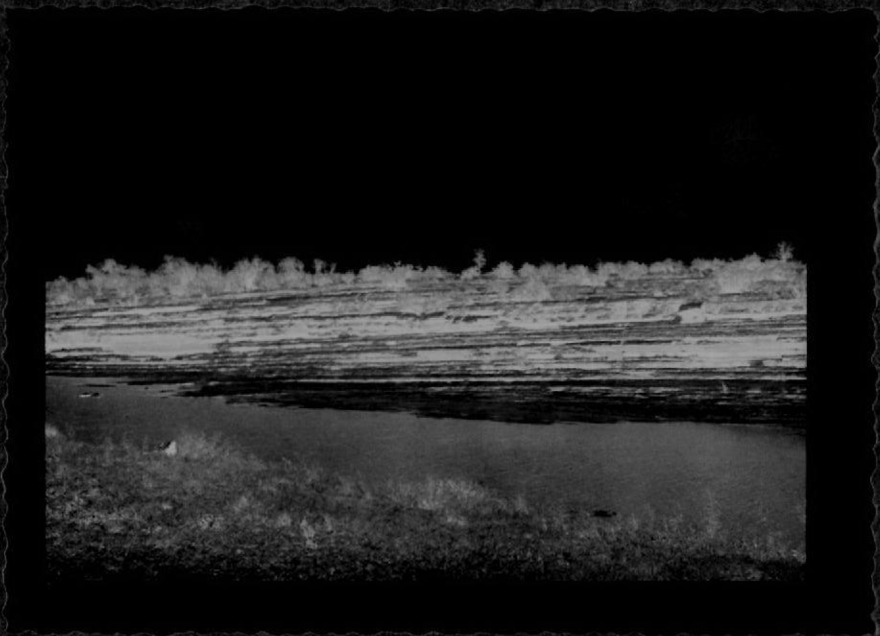
Morgan Creek Limestone Member

Definition and thickness--The Morgan Creek limestone member was named by Bridge from exposures on both the north and south forks of Morgan Creek in northwestern Burnet County (Bridge, Barnes, and Cloud, 1947, p. 115). In the type section, which is exposed on the point just north of the junction of the two forks, it is about 110 feet thick. The Morgan Creek limestone ranges from 70 to 160 feet thick and averages 120 feet. A thickness of 114 feet was measured on the north bank of the San Saba River in the vicinity of Flatrock Crossing (plate VII) one-half mile northeast of Camp San Saba by Barnes and Bell (1954, p. 57).

Lithology--The Morgan Creek member overlies the Welge member conformably. The contact is gradational and in most areas it is placed at a topographic and vegetational change that is normally represented by a Morgan Creek escarpment. The contact is at the base of the first reddish-purple, arenaceous limestone bed. As a unit, the member is a medium- to coarse-grained, abundantly glauconitic, well-bedded limestone according to Bridge, Barnes, and Cloud (1947, p. 115).

The limestones of the Morgan Creek member are exposed throughout the length of the thesis area. In the lower part of the member, the

PLATE VII



Morgan Creek limestones exposed on the San Saba River one-fourth mile downstream from Flatrock Crossing limestones are reddish-purple, coarse-grained, granular, slightly glauconitic, and very sandy. These medium-bedded layers erode into indistinct ledges and gradually grade upward into gray to greenish-gray, medium-grained, glauconitic fossiliferous limestones. The fossils within this interval consist of trilobites, cystoids, and conaspids. The conaspid fauna, according to Bridge, Barnes, and Cloud (1947, p. 115), is divided into the Eoorthis and Billingsella subfaunas, with Eoorthis occurring in abundance 44 feet above the base. Elvinia, Pterocephalia, and other trilobites, according to Barnes and Bell (1954, p. 40) occur just below the Eoorthis zone, and thumb-nailed-shaped Billingsella commonly occurs within the interval from just below this zone to several feet above it.

Isolated stromatolitic reefs consisting of dense, gray limestone occur near the top of the Morgan Creek member. These masses range up to 18 inches in thickness, are 20 to 25 feet in diameter, and are about 100 to 200 feet apart. The bedded limestones surrounding the reefs appear to be arched over them. Some of the interreef layers are silty or argillaceous, and cross-bedding is common within them.

Topography and vegetation--A distinct topographic and vegetational change occurs between the Morgan Creek limestone and Welge sandstone members. The limestones form a prominent ridge of considerable relief along the up-dip margin of the Welge sandstone benches. The Morgan Creek member erodes to form distinct northeast-trending ridges in the area, and does not form tillable areas.

Vegetation on the member is abundant and rather uniformly distributed. Scrub oak trees are the most abundant, but Mexican persimmon, turkey pear, agerita, Spanish dagger, and various grasses are also common.

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, which is an isolated hill about four miles northeast of Lone Grove in Llano County. In the type section, located on the south slope of the hill, the member is about 270 feet thick. The average thickness of the Point Peak shale is estimated as 160 feet, and it thickens from the southeastern to the northeastern part of the Llano region.

As originally defined, the upper portion of the Point Peak member was composed of a thick zone of stromatolitic bioherms. However, Bridge, Barnes, and Cloud (1947, p. 117) closed their discussion of the Point Peak-San Saba boundary by stating:

> Most of these zones of stromatolitic bioherms are large enough to be mapped separately and should be so mapped to obtain more information about their vertical and lateral distribution.

In the Camp San Saba-West area, the author has mapped these stromatolites as a separate zone that composes the lower portion of the San Saba limestone member. To facilitate the discussion, the reasons for this departure from the standard stratigraphic division of the Wilberns formation will be explained in that portion of the text devoted to the bioherm zone.

The thickness of the Point Peak shale member, excluding the bioherm zone, was measured at Camp San Saba to be 94 feet.

Lithology--The lower contact of the Point Peak member is transitional with the upper Morgan Creek limestone, but is easily recognized by a distinct vegetational and somewhat less pronounced topographic change. The lithology of the member is described by Bridge, Barnes, and Cloud (1947, p. 115) as consisting of well-bedded, soft, greenish, calcareous shales containing subordinate amounts of fine-grained dolomite, medium- to fine-grained glauconitic limestone, and intraformational conglomerates.

Although the outcrop of the Point Peak shales traverses the length of the Camp San Saba-West area, they are better exposed in the northern part. The member is mainly composed of well-bedded, brownish- and greenish-gray, fine-grained siltstones interbedded with soft, thinly bedded, very fine-grained, calcareous shales. Some of these shales are micaceous and most of them occur as films or thin-layers between the somewhat thicker siltstone beds. Thin layers of light gray, fine- to medium-grained limestones which contain some glauconite occur in the basal portion of the member, and closely resemble the upper Morgan Creek limestones.

Small individual reef colonies of gray to pinkish-gray, very dense, sublithographic limestone are scattered through the upper portion of the member. The thin shale beds curve smoothly over and around these inclusions.

Approximately 40 feet above the base of the Point Peak member, scattered layers of intraformational, edgewise conglomerate begin to appear. These edgewise conglomerates are crowded with yellowish-green, flat pebbles of fine-grained limestone in a matrix of brown, fine-grained limestone. In the upper portion of the member, the conglomeratic layers occur mostly at, or a few inches below, the base of the reef masses, and appear to have been formed in an environment in which conditions of shoaling predominated.

Topography and vegetation--The Point Peak member consistently forms a flat open bench bordering the dip slope of a Morgan Creek cuesta. However, a few hills capped by the more resistant bioherms and composed almost totally of Point Peak shales (plate VIII, figure 1) occur in the northern part of the area.

Vegetation on the Point Peak is limited, consisting primarily of scattered mesquite, along with grasses, and cacti. The contrast between the light colored soils and sparse vegetation on the Point Peak member and the dense growth supported by the Morgan Creek member is very distinct on aerial photographs.

San Saba Limestone Member---Bioherm Zone

Definition and thickness--Although the zone of stromatolitic bioherms was originally considered to belong to the San Saba member, Bridge, Barnes, and Cloud (1947, p. 117) included these reef masses with the Point Peak member in their subdivision of the Upper Cambrian series in the Llano region. The basis for this reclassification was that the zone is not continuous over the whole region and that the boundary between the Point Peak member and the San Saba member had been previously established at the top of the highest significant shale in areas where the stromatolites were absent. Additional evidence for

PLATE VIII

Exposures of the Point Peak Shale Member

Figure 1.--Hill composed of Point Peak shale and capped by bioherms, one-sixth mile northwest of the junction of U. S. Highway 87 and the F. Kidd ranch road.

Figure 2.-- Point Peak shale in road cut one-half mile south of the highway bridge over the San Saba River on U. S. Highway 87.

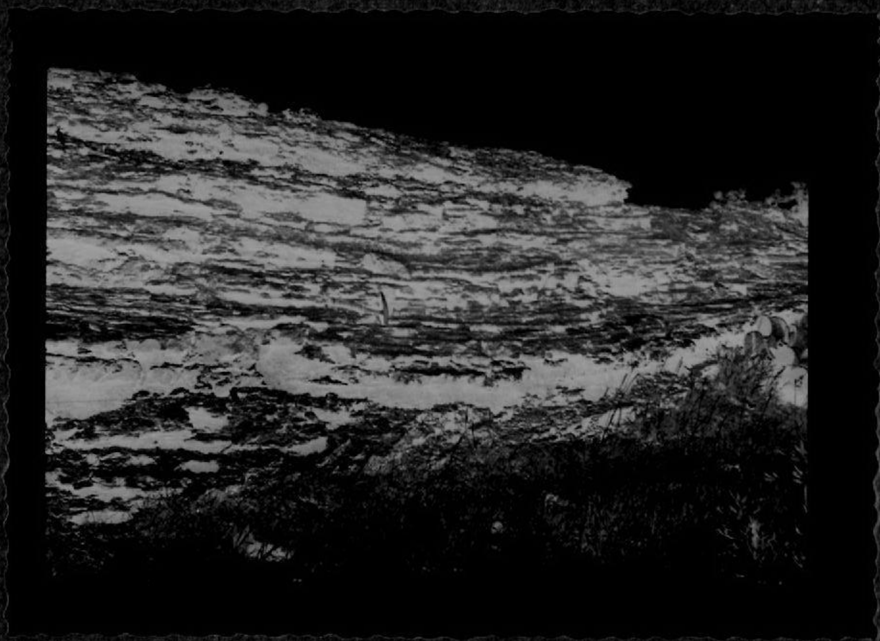
the placing of the bioherm zone with the Point Peak member is the presence of shale above the bioherms and below well-bedded, granular limestones of the San Saba member in the area west of the Mason-Brady highway near the San Saba River. South of Mason the bioherm masses are well exposed in the south bank of the Llano River above one-fourth of a mile downstream from White's Crossing. At this locality, they occur as large, discontinuous reef masses and are overlain by Point Peak shale.

In a later study of the Upper Cambrian series in the immediate vicinity of Camp San Saba, Barnes and Illinwood (see Appendix) placed the bioherm zone in the lower portion of the San Saba member in their measured and described section near Camp San Saba. In this section, according to Barnes and Bell (1954, p. 25) the stromatolites have been placed with the San Saba member because they extend high into this member.

In the area adjoining the Camp San Saba-West area on the east, Sweet (1957) has placed the bioherm zone in the base of the San Saba member. This was done because the zone is composed of a thick continuous sequence of reef limestones that occur at the top of the shale sequence and are overlain by limestones of the San Saba member.

During the mapping operations, a careful study was made of the bioherm zone exposed in the area. The overlying shales (plate IX) were found to be present in the northern part of the area, and good exposures were common along the upper limit of the stromatolites. These shales are somewhat similar to those of the Point Peak member

PLATE IX



San Saba shale overlying the bioherm zone due west of the C. Myrick ranch house.

with the exceptions that they are poorly bedded and do not appear to contain thin films of shale between the layers of siltstone. However, in the central portion of the area the shales pinch-out, and well-bedded, granular limestones of the San Saba member occur as interreef limestone and as beds overlying the reef masses. In the southern part of the area, limestone of the San Saba member actually occurs below the bioherm zone and above shales of the Point Peak member. This relationship, according to N. C. Scaife (personal communication), is well exposed about two-thirds of a mile south of the thesis area. Some of the interreef limestones (plate I) contain marble-sized, subspherical stromatolites that have been termed "Girvanella". Girvanella bearing beds are reported by Bridge, Barnes, and Cloud (1957, p. 119) to occur mainly in the San Saba member. In the vicinity of Point Peak, about 150 feet of these beds are present within the member, and in a section north of Fall Creek, Girvanella beds constitute the entire San Saba limestone member.

Since the zone of stromatolitic masses occurs partially or totally within the San Saba member in the thesis area, the lower boundary of this member has been placed at the base of the bioherm zone. Thereby, the reef zone is mapped separately and composes the basal portion of the San Saba. These conclusions seem to be in agreement with Barnes and Ellinwood, (Barnes and Bell, 1954, p. 20) who have placed the bioherm zone in the base of the San Saba member in their geologic map of the area about Camp San Saba.

The bioherm zone occupies a different space relationship in different parts of the western half of the Llano region. This zone transgresses from the upper part of the Point Peak member in the area south of Mason to the lower portion of the San Saba member north of Mason. Since the deposition of the Upper Cambrian series in the Llano region was predominately controlled by diastrophic movements and the resulting oscillations in the strand lines of the Late Cambrian seas, it follows that the formational and member boundaries transgress lines of time equivalence. However, the transgression of the bioherms across the boundary between the Point Peak and San Saba members does not appear to be the result of the way this boundary was defined. Because the range of environmental conditions under which the growth of reefs may occur is very limited, the more likely explanation for the change in the stratigraphic position of the biohermal masses is that they were gradually moving northward following a change in environment. Therefore, the bioherm zone would not serve as a good time marker.

The thickness of the bioherm zone ranges from a maximum of about 230 feet in the northern part of the mapped area to a minimum of about 115 feet in the southern part, and has an average thickness of about 175 feet. The abnormal width of the outcrop in the northern part of the area is primarily due to the more or less gentle slopes formed by the weathering of the bioherm zone.

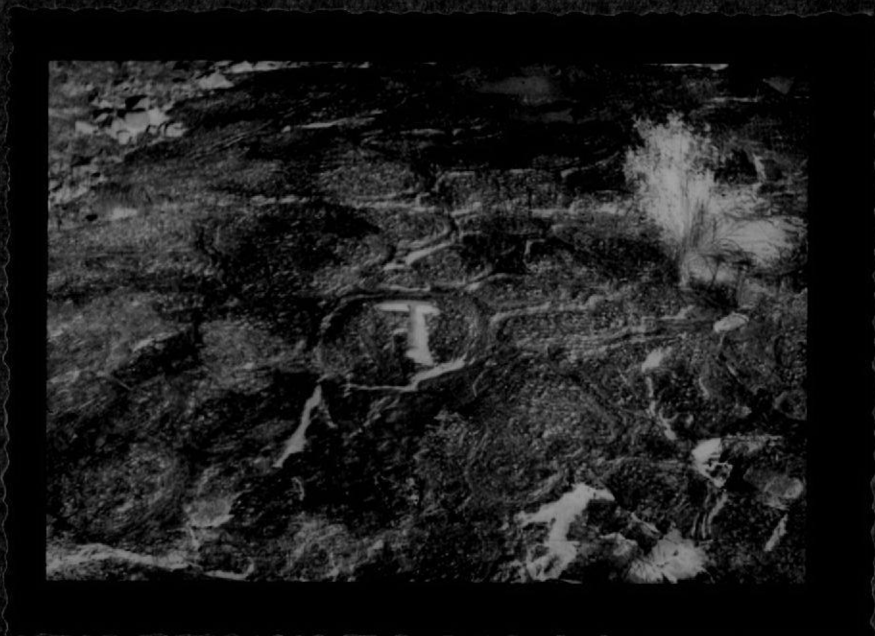
Lithology--The bioherm zone is primarily composed of stromatolitic bioherms and interreef limestone. The stromatolites in the Camp San Saba vicinity were briefly described by Bridge, Barnes, and Cloud (1947, p. 117) as bluish-green, sublithographic to microgranular limestones. The bioherms exposed in the thesis area generally conform to this description, and weather to form a rugged terrain of small boulders and closely spaced, low hummocks. Most of these hummocks exhibit "cabbage head" structures on the weathered surfaces (plate V) and locally coalesce to form biostromes. A somewhat raised, reticulate pattern of yellowish-brown, silty, dolomitic limestone is also common on the weathered surfaces.

Varying degrees of dolomitization occur in many places and seem to be almost completely restricted to the stromatolitic masses. In some bioherms only the outermost portion has been altered to light gray saccharoidal dolomite, and in others pinkish-gray patches of dolomitic material are scattered throughout the rock. A few have been almost completely dolomitized and are very hard and brownish-yellow in color. In the southernmost part of the area, the complete zone has been altered to a light gray, saccharoidal to microgranular, dolomite.

The interreef limestones are brown to brownish-gray, fine- to medium-grained, well-bedded limestones, which in some parts of the area contain lentils of intraformational conglomerate and dark gray limestone.

Topography and vegetation--There is a distinct topographic and vegetational change between the bioherm zone and the Point Peak member. In many places the resistant bioherms cap escarpments that extend along the upper limit of the Point Peak bench, and tend to form a rugged, dissected terrain. The vegetation on this zone is very dense and evenly distributed. It consists primarily of scrub oak with some mesquite, and an abundance of catsclaw, Mexican persimmon, and Spanish bayonet.

PLATE X



Stromatolitic bioherm with "cabbage heads" one-eighth mile south of C. Myrick ranch house.

San Saba Limestone Member--Calcitic Facies

Definition and thickness--The San Saba limestone member was named by Bridge (Bridge, Barnes, and Cloud, 1947, p. 117) from exposures along and near the San Saba River, northwest of Camp San Saba in McCulloch County. The type section is exposed along both sides of U. S. Highway 87, beginning at the highway bridge across the San Saba River on the north boundary of the Camp San Saba-West area and extending northward for 0.7 mile.

The name San Saba was originally used as a series term by Comstock (1890, p. 301) who applied it to all or some part of these beds. Later, Dake and Bridge (1932, p. 729) called these beds "Post Wilberns", correlated them with the Fort Sill and Signal Mountain formations of the Arbuckle and Witchita mountains, and suggested that Comstock's name San Saba might well be revived for a part of them.

The thickness of the San Saba member in the type section is about 280 feet, and in the thesis area it is approximately 200 feet.

Lithology--The contact between the calcitic facies of the San Saba member and the underlying bioherm zone is a gradational contact and has been placed at the base of the first bed of granular, more or less glauconitic limestone occurring above the bioherms. A distinct vegetational change is easily discernible on aerial photographs along this boundary, and aids in defining it in the field.

In their classical description of the San Saba member, Bridge, Barnes, and Cloud (1947, p. 120) noted that its lithology was variable and that marked changes of facies occurred from one locality to another.

For the purpose of securing an accurate area-wide description of the lithology of the calcitic portion, the better exposures have been described and their locations shown on the geologic map of the area. The lower portion is well exposed at and around localities 1 and 2, (plate I) and consists of hard, light brown to brownish-gray, medium-grained to granular, well-bedded, glauconitic limestone containing scattered streaks and mottles of dark orange, silty limestone. However, the basal beds at locality 1 show a marked difference from those exposed at locality 2. Several of these beds contain lenses of light gray, very coarse-grained, silty limestone which is crowded with a large number of small brachiopod shells, and could be termed a "brachiopod hash". Other beds within this interval consist of greenish-gray, coarse-grained, intraformational limestone conglomerate which contains reworked particles of greenish-gray, sublithographic limestone, lense-shaped particles of gray limestone, and small, brown, tightly coiled gastropods. These beds grade laterally into the previously discussed granular limestones which compose the greater part of the lower portion.

In locality 2, the lower limestones of the San Saba member appear to contain less arenaceous material and are more coarse-grained than those exposed at locality 1. For the most part, the intraformational conglomerates and lateral variations that commonly occur at locality 1 are not present in the sequence of beds exposed at locality 2. The strata in the latter are of much more uniform lithologic character.

The lithology of the middle part of the San Saba limestone is essentially uniform throughout the thesis area, and this part of the member is very well exposed in and about locality 5. These strata consist in their lower part of light gray to brownish- and purplish-gray, well-bedded, medium- to fine-grained, essentially non-glauconitic, silty limestones. A few beds of intraformational limestone conglomerate occur within this interval. These conglomerates are composed of large flat pebbles of brownish-gray, sublithographic limestone embedded in a matrix of finely crystalline, light brown limestone. Many of the bedding planes have an undulating appearance and may have been formed by interfering wave action. Globular particles of glauconite are more abundant where these strata grade upward into greenish-brown and gray, fine-grained, well-bedded, silty limestones which compose the upper interval. The relative distribution of the glauconite varies from one layer to the next, with some layers containing up to 50 percent glauconite. Solution cavities are common in this part of the member and many of them have been filled or lined with secondarily deposited calcite.

The upper portion of San Saba calcitic facies is composed of limestone in the central and southern portions of the area, however, in the northern part these limestones grade into dolomite. The latter is well exposed in the area about location 5, and the former about location 4. The limestones within this interval are mostly hard, light gray to brownish-gray, fine-grained to sublithographic limestones. A few of the beds contain scattered globules of glauconite, and a small number of fossils. Zones of irregular intercalations or mottlings of yellowish-brown, slightly dolomitic, silty limestone are common within this interval. This silty material appears to be more resistant than the more nearly pure limestone because it forms raised, reticulate patterns on the exposed surfaces. Many of the bedding planes within this interval have an irregular, rippled appearance.

The dolomite within the upper San Saba interval is very hard, light gray to white, and has a saccharoidal texture. Scattered small solution cavities and cavity fillings are visible on the freshly broken surfaces. Most of these features are lined or filled with calcite, and the dolomite immediately surrounding them has a light orange color. These strata weather to form more or less smooth cobbles and small boulders which are generally strewn over partially covered slopes. The areas underlain by dolomite are easily distinguished from those underlain by the limestones of the member, because of the lack of vegetation on the dolomite beds.

There is little similarity between dolomite of the San Saba limestone and the dolomite of the overlying Ellenburger group. The Ellenburger dolomite is generally darker in color, and in most places weathers to form a highly vugular rock that has a "sponge-like" appearance. Quartz druse and chert, which occur in minor quantities in the Ellenburger dolomite sequence, are totally absent in that of the upper San Saba. However, the dolomite within the San Saba member appears to be a local variation because it is absent at the type section a few miles to the northeast and at the Calf Creek section a few miles to the west.

Topography and vegetation--In general the San Saba member forms a rolling topography with no appreciable local relief. In the northern part of the area, a low, almost vertical escarpment is formed by the shale interval at the base of the calcitic facies, and this escarpment causes a distinct change in slope between the overlying San Saba limestones and the stromatolites of the bioherm zone.

Vegetation on the San Saba is scattered and consists of clumps of scrub oak and cedar along with Mexican persimmon, Spanish bayonet, prickly pear, and turkey pear. A distinct vegetational change is visible between the San Saba limestones and the underlying San Saba bioherm zone.

ORDOVICIAN SYSTEM

Ellenburger Group

Definition and thickness--The "Ellenburger limestone" was first named by Paige (1911, pp. 51) from the Ellenburger Hills in southeastern San Saba County. This term remained unchanged until 1945, when it was revised to Ellenburger group and restricted to include beds of Early Ordovician age by Cloud, Barnes, and Bridge (1945, p. 133). They divided the group into the Tanyard, Gorman, and Honeycut formations in ascending order.

The maximum thickness of the Ellenburger group of the Llano Uplift is approximately 1620 feet in the southeastern corner of the uplift. From there it thins both northward and westward by truncation of the upper beds, being only 970 feet thick along the Llano River in western Mason County and slightly over 800 feet thick in McCulloch County. Only the lower 225 feet of the group is present in the Camp San Saba-West area. A study of the Highway 87 section as described by Cloud and Barnes (1948, p. 140) seems to indicate that the Ellenburger strata in the Camp San Saba-West area are wholly within the Tanyard formation.

Lithology--In the thesis area, the Cambrian-Ordovician boundary is transitional and is difficult to establish within the limits of a few feet. This contact was determined by striking a mean between the last occurrence of glauconite in the San Saba member and the first occurrence of the uncoiled form of the gastropod *Lytospira gyroceras*. The strata that compose the lower portion of the Ellenburger group are described by Cloud and Barnes (1948, p. 36) as gray, sublithographic, thickly to thinly bedded limestone and gray, fine-grained, irregularly bedded dolomite.

Ellenburger limestone and dolomite crops out in the northwestern part of the thesis area. The limestones are mostly thick-bedded, light gray to ivory in color and very hard. They have a sublithographic texture. Many intervals of more thinly bedded limestone occur in the upper portions of the section, and a small amount of brownish-gray chert is present. These limestones weather to a flat gray color, and form large slabby blocks which are usually lower in the centers than on the edges. Small rosettes of reddish-tinged quartz druse occur sporadically on the weathered surface. In many places where they are exposed in stream cuts, the basal strata have a very vuggy appearance.

The limestone sequence grades upward into light to medium gray, saccharoidal dolomite, which also exhibits shades of yellowish- , brownish- , and pinkish-gray. Some light tan to nearly white chert nodules and lenses occur within these strata, and minor amounts of quartz druse are present on a few of the beds. The dolomite weathers to form slopes strewn with blocks which are fairly smooth to pitted or so highly vugular as to be "sponge-like" in appearance.

Topography and vegetation--The Ellenburger consistently forms a rolling type of topography with rounded hills separated by relatively deep valleys. Some of the highest hills in the area are either capped by, or composed entirely of Ellenburger beds.

These strata exhibit a very characteristic vegetational pattern that consists of numerous, more or less isolated clumps of trees separated by grassy, open areas. The clumps of trees are mainly composed of cedar, scrub oak, and live oak, while growths of prickly pear, catsclaw, Spanish dagger, Mexican persimmon, and bee-bush predominate in the open areas. In addition to their characteristic vegetational expression, the Ellenburger beds also appear lighter in color on aerial photographs than do the underlying San Saba limestones.

CRETACEOUS SYSTEM

General Statement

Rocks of Early Cretaceous age are present only in the extreme southwestern part of the thesis area. In this locality they occur as an erosional remnant capping a hill which is composed mainly of Point Peak shale. The Cretaceous strata consist of only a thin veneer of basal sand and conglomerate, and are expressed on the surface by reddish soils containing numerous pebbles of chert, quartzite, and quartz. The age of these deposits was determined by a comparative study with the exposures of the basal Cretaceous strata occurring on adjacent hills to the south of the thesis area.

QUATERNARY SYSTEM

General Statement

Quaternary sediments are limited to stream alluvium which consists of sands and gravels derived from rocks of Precambrian, Paleozoic, and Cretaceous age. These deposits occur in isolated patches along the banks of the San Saba River and Katemcy Creek, and cover a considerable part of the area in the vicinity of Camp San Saba.

STRUCTURAL GEOLOGY

GENERAL STATEMENT

The Llano region is a structural dome which has been truncated by subsequent erosion so that the Paleozoic and Precambrian rocks have been exposed in its central portion. The Lower Cretaceous beds, however, are flat-lying and appear to have originally covered the entire area. The greater portion of these strata have since been removed by erosion, and thereby an inlier exposing pre-Mesozoic rocks has been formed. These older rocks dip gently away from the center of the uplift. The area of exposure of the pre-Mesozoic strata is more or less elliptical in shape. The long axis trends in a west-northwest direction and is about 70 miles in length. The length of the short axis is approximately 40 miles. From subsurface information, the total uplift of the Central Mineral region was estimated as 6000 feet on top of the Precambrian surface by Sellards (1932, p. 30).

The Paleozoic rocks of the Llano Uplift have been extensively disrupted by faults. They are normal and range in dip from about 60 to 90 degrees. Displacements along these fractures range from a few feet up to 3000 feet. Generally, the faults of major displacement trend in a northeast-southwest direction; however, those of minor magnitude are not always in agreement with this alligament. Many of the latter occur in complicated zones which appear to be caused by the disintegration of larger faults, by two major faults merging or passing within a short distance of one another, or by abrupt changes in the strikes of major faults. There are no faults of major displacement within the thesis area. Where undisturbed by faulting, the Paleozoic strata in the mapped area have an average regional dip of 4^{o}, N.52°W.

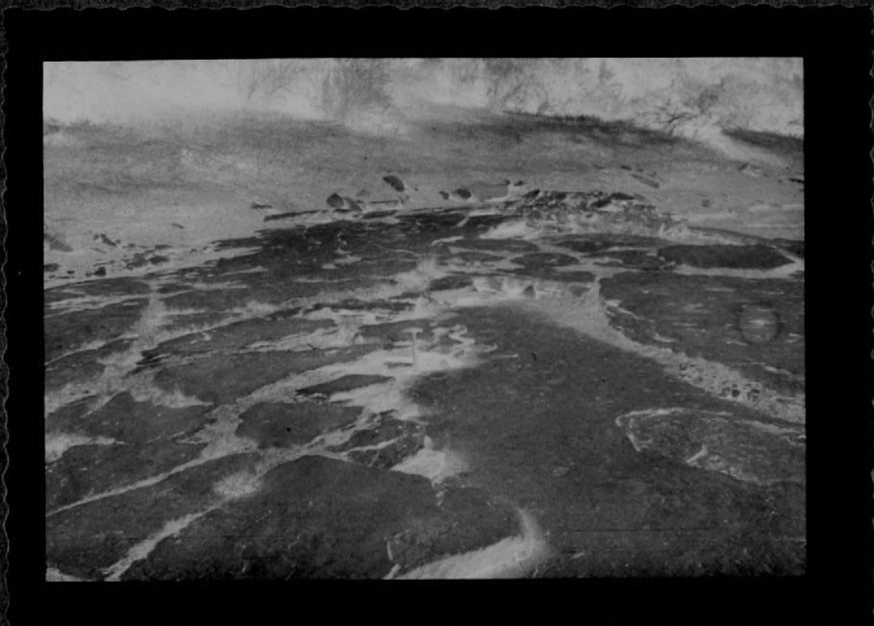
The Paleozoic rocks of the Llano region have been only gently folded. The only folds of considerable extent that are present consist of possible broad warps which occur at scattered localities. Local folds that have been formed by slumping into limestone sinks, compaction over and around irregularities of hard limestone, and drag along faults are present. The only Paleozoic folds present in the thesis area are of a very minor nature, and are due to "reversed" drag along faults and differential compaction above and below bioherms (plate XI). The western limb of a northward plunging anticline may be present in the eastern portion of the area.

FAULTING

Detection of Faulting

Although some of the faults in the thesis area were detected directly from field observations, the majority were discovered by investigating allignments or abrupt offsets in the vegetational pattern, which were observed on aerial photographs. Since the units that crop out in the mapped area vary in their lithologic characteristics and, to a lesser degree, in their respective flora, many faults are evident somewhere along their traces as a change in vegetation. All observations of possible faults on the photographs were carefully investigated in the field to determine their existence. The field indications that were used to detect faulting were distinctive variations in the normal

PLATE XI



Folding of San Saba limestone over a bioherm one-fourth mile upstream from the large stock tank in the northern part of the C. Myrick ranch.

strike and dip of the strata, repetition and omission of strata, abrupt termination of beds or key horizons along their trends, and the actual observation of the fault surface in localities where it has been exposed by erosion.

Description of Faulting

The majority of the faulting in the thesis area occurs in the southern and western parts of the region. The faults in the western portion form a northeastward trending, narrow zone that enters the area in the southwest corner and dies out in the immediate vicinity of the Frank Kidd ranch house. The southern portion of this zone is composed of two nearly parallel faults that are downthrown toward each other to form a graben. Since the displacement of the fault that forms the eastern boundary of this structure is about 120 feet and the displacement of the fault that forms the western boundary is approximately 145 feet, it appears that these faults do not compensate one another. However, the throw of both faults increases to the south. These faults merge about halfway along the extent of the zone. At the northern end, another graben is formed on the eastern side of the zone. In this portion, "reversed" drag is conspicuous along the fault that composes the eastern boundary of the zone, with anomalous dips as high as 32°NW not uncommon. The faults in this zone are confined to rocks of the San Saba member and the lower portion of the Ellenburger group at the surface.

The western zone of faulting appears to terminate at the long, east-west trending fault that is located one-half mile north of the fault movements had ceased prior to Cretaceous sedimentation for nowhere did they extend up into the Cretaceous strata. Cloud and Barnes (1948, p. 120) have reported seeing "...rocks of the Strawn formation in fault contact with Marble Falls limestone". In the vicinity of Calf Creek, about seven miles west of the northwestern corner of the area, faulted rocks of the Ellenburger group are overlapped by unfaulted beds of Canyon age. The major late Paleozoic faulting is thereby indicated to have been a pre-Canyon event, and according to Sellards (1934, p. 35) is of Bend and probably Strawn age.

Origin of Faulting

In their discussion of the geologic structure of the Llano region, Cloud and Barnes (1948, p. 118) stated that the Llano Uplift comprised a relatively resistant mass that was bordered on its eastern and southern sides by the Ouachita geosyncline (Llanoria geosyncline of Sellards, 1932). Active compression originating from the late Paleozoic folding of the geosynclinal area was believed to have developed "tensional couples" that would cause fractures alligned dominately in the northeast quadrant. However, the existence in the earth of the theoretical "tensional couples" postulated by Cloud and Barnes is difficult to visualize.

Stress distributions associated with normal faulting have been postulated after the well-founded Mohr-Coulomb theory of fracture by E. M. Anderson (1945, p. 7), M. K. Hubbert (1951, p. 359), W. Hafner (1951, p. 387), and others. For homogeneous conditions, typical normal faults occur when the maximum principal stress direction is vertical, the minimum principal stress direction is horizontal and perpendicular to the strike, and the intermediate stress direction is horizontal and parallel to the strike. The dips of the faults in the Llano area are somewhat higher than the dips of most normal faults, and therefore this simple stress distribution does not apply completely.

Stress directions involved in the faulting of the Llano area were apparently more complicated, although they are not believed to be a result of "tensional couples" or other "tension" as suggested by Cloud and Barnes. Rather, it appears that inhomogeneities in the Llano region resulted in modified stress distributions so that a resultant regional maximum principal stress direction was not vertical, but was close to the vertical. The corresponding intermediate stress direction was nearly horizontal and trending northeasterly, and the minimum principal stress direction was nearly horizontal and trending northwesterly.

It appears that the Late Paleozoic uplifting of the Central Mineral region was the predominate factor in the faulting of the Llano Uplift. The stress distribution postulated for the Llano area is quite different from that of the folding in the Ouachita geosyncline. Presumably the two features were not formed by a common stress distribution.

The Camp San Saba-West area lies between two major faults, the Blockhouse Ranch fault on the west, as shown by Barnes and Bell (1954, p. 28), and the Katemcy Creek fault, mapped by Sweet (1957), on the east. The faulting in the thesis area may have been caused by more or less regional adjustments attendant to the formation of the major faults.

FOLDING

As previously mentioned, folding of a minor nature only is present in the thesis area. Gentle undulations or domal structures of local occurrence are common in the upper portion of the Point Peak member and the lower portion of the calcitic facies of the San Saba member (plate XI). These features have been formed as a result of differential compaction both above and below the hard bioherms.

The small folds formed as a result of "reversed" drag along a fault are restricted to the western fault zone. Cloud and Barnes (1948, p. 118) stated:

> Along several of the faults of the Llano region the rocks immediately adjacent to the faults dip in a direction opposite to that of the normally expectable drag. The reason for the 'reversed' drag is not apparent from field observations, but it is conjectured to be caused either by a noncompensatory movement opposite to the original displacement, or possibly by slumping or pitching of the strata toward openings along the zone of displacement. The 'reversed' drag seems to be mostly associated with the steeper faults.

On the surface exposures in the Camp San Saba-West area, only limestones of the calcitic facies of the San Saba member have been affected by the "reversed" drag phenomena. In this instance, these spurious dips seem to be more easily explained by the presence of a broad depression in the upper surface of the bioherm zone. This shallow, low area was assymmetrical toward the northwest and was formed prior to the deposition of the calcitic facies.

The western limb of an anticline that plunges north probably is present in the eastern part of the thesis area. The mapped units in this portion of the area dip gently to the northwest and form an outcrop pattern of northeastwardly trending bands of strata (plate I). However, these units are truncated by a fault that is generally parallel to the eastern boundary of the thesis area, and for the most part is located a few tens of feet east of the area. On the eastern side of this fault, in the Katemcy-Voca area that has been mapped by Sweet (1957), the outcrop pattern is very similar to that previously described in the thesis area, with the important exceptions that the mapped units exhibit a northwestward trend and dip gently to the northeast. The structural relationships between the units exposed on opposite sides of the fault may indicate the presence of an anticline that is interrupted by a fault. The axis of this structure is in general probably parallel to the southern one and one-half miles of the eastern boundary of the Camp San Saba-West area. This structure would adjoin the northward plunging syncline that is located in the Katemcy-Voca area and has been described by Sweet (personal communication). He has stated that the synclinal structure is probably a tectonic fold, and the indication of an anticline adjoining the syncline would definitely strengthen that conclusion.

COLLAPSE STRUCTURES

There are two collapse structures present in the Camp San Saba-West area. The northernmost of these structures is located on the west bank of Katemcy Creek, approximately 300 feet south of the San Saba River. This structure forms a conspicuous hill that rises to a height of about 15 feet out of the relatively flat terrain of the Welge sandstone member, and is composed of recognizable blocks of limestone from the Morgan Creek member and San Saba member that are embedded in a matrix of Welge sandstone. The dimensions of the limestone blocks vary from a few inches up to several feet, and the larger, slabby pieces are oriented in many different directions. Some of the limestone blocks appear to be bedded, whereas others indicate no traces of bedding whatsoever.

The more southerly collapse structure is also located on the west bank of Katemcy Creek, and is approximately three-fourths of a mile north of the M. Cohen ranch house (plate XII). At this locality, a hill that is about 20 feet high rises abruptly out of the upper Hickory sandstone. In most respects, this structure is very similar to the one described above. However, the blocks of limestone that compose the greatest part of this structure more closely resemble the limestones of the Cap Mountain member than those of the Wilberns formation. Also, these rocks appear to have been more strongly deformed than were those in the previously described collapse structure, and they are embedded in upper Hickory sandstone.

Two collapse structures that are located approximately one and one-half miles west of Streeter on Bluff Creek have been described by Barnes (Barnes and Bell, 1954, p. 17). Both of these structures occur within the Hickory sandstone member. In the first of these structures, recognizable blocks of limestone from the calcitic facies and the bioherm zone of the San Saba member were present, whereas in the second, limestones from the Marble Falls formation have been identified. In neither of these structures has a hill of any appreciable height been

PLATE XII

Collapse structure in the upper Hickory sandstone three-fourths mile northeast of the M. Cohen ranch house.

formed, and for the most part the blocks of limestone do not reach the large dimensions of many of the blocks that compose the collapse structures in the thesis area. Barnes has postulated that the solution of the Precambrian marble that underlies the Hickory sandstone in the Streeter area has allowed the overlying rocks to collapse. Since no Precambrian rocks are exposed in the Camp San Saba-West area, it is not known whether significant masses of marble exist in this area. An alternate explanation might be that the undercutting of the more resistant limestones by stream action may have resulted in their collapse.

COMPARISON OF LOCAL TO REGIONAL GEOLOGIC HISTORY

Although the regional geologic history of the Llano Uplift has been discussed beginning on page 15, this portion of the text is included to call attention to certain geologic features in the Camp San Saba-West area that have a bearing upon the interpretation of the geologic history of the region. Some of these features are in accord with the regional interpretations, but others suggest that slight modifications of the regional interpretations might be made. The absence of Precambrian rocks in this area limits the discussion to events of Paleozoic age.

With the exception of a few instances, the series of geologic events inferred by the stratigraphic sequence exposed in the thesis area are in very good agreement with those of the Llano region. The deposition of the Hickory member appears to have occurred under the same type of conditions in the mapped area as it did elsewhere in the region. Along the littoral zone and the shallower parts of the neritic zone of the Early Cambrian seas that transgressed the area, pre-existing eolian deposits were reworked to form coarse, cross-bedded beach sands. The prevalence of shallow waters throughout the span of Hickory sedimentation is indicated by the presence of phosphatic brachiopods and ripple marks to within a few feet of the top of the Hickory sandstone member. The gradation of the marine sands of the upper Hickory into the calcareous sandstones and arenaceous limestones of the lower portion of the Cap Mountain member in the thesis area is also in accordance with the regional history.

The first significant deviation of events in the thesis area from those typical to the region as a whole appears to have occurred during the deposition of the upper Cap Mountain limestones. An abnormally large amount of silt occurs in this portion of the member, and possibly indicates that the regressive-transgressive oscillations of the Late Cambrian seas, that is recorded by the Lion Mountain sandstone and Welge sandstone sequence, had begun at an earlier time in the vicinity of the Camp San Saba-West area than in some of the other parts of the Llano Uplift. Further evidence for this presumption is the fact the Welge sandstone is thicker in the northern and western parts of the region than it is in the eastern and southern portions. This would indicate that the latter areas were farther from the source area than were the former. Therefore, the thesis area was probably not inundated by the transgressing sea that deposited Morgan Creek limestone until a later time than were the areas on the south and east.

The deposition of the Morgan Creek limestone in the mapped area appears to have occurred under conditions that prevailed throughout the Llano region during the time of deposition of this member. A neritic environment and the presence of shallow, warm waters during the deposition of the middle and upper portions of the member respectively, are indicated by the presence of glauconite and marine fossils in the middle part of the member, and stromatolitic bioherms in the upper part. In the thesis area, lower Point Peak sedimentation was very similar to that of the previous regional determinations. However, the bioherm zone that occurs in the top of the member in the southern part of the region, is located in the basal portion of the San Saba limestone member in the thesis area. The transgression of the reef masses across the boundary separating the two members appears to be the result of the bioherms moving northward due to a changing environment. This would indicate that the stromatolites occurred at a later time in the Camp San Saba-West area than they did to the south of the area. Throughout the remainder of San Saba deposition and the lower portion of the Ellenburger sedimentation the events occurring in the thesis area seem to have been very similar to those occurring in the rest of the Llano region. The San Saba member received some silty material from a continuous or intermittent source area to the northwest. Deposition was continuous across the Cambrian-Ordovician boundary, however the absence of arenaceous material in the Ellenburger limestone indicates that the western source area had ceased to supply sediments.

ECONOMIC GEOLOGY

The most important geologic resources of the Camp San Saba-West area are an abundance of general-purpose ground water and a moderate amount of tillable soil. A large percentage of the gound water is obtained from the Hickory sandstone, and lesser amounts are furnished by the San Saba and Ellenburger limestones. The Hickory is one of the most important aquifers in Texas and is an invaluable asset to farmers during the long dry summers and the present drought. Some irrigation wells have been drilled in the area and equipped with pumps which enable them to produce several hundred gallons per minute. During seasons of normal climatic conditions, numerous springs occur in the San Saba and Ellenburger limestones, however, the prolonged drought conditions of the past few years have caused them to cease to flow.

The Hickory, Lion Mountain, and Welge sandstones, lower Cap Mountain limestone, and Point Peak shale all form slopes, benches, or low, flat areas of sandy soils suitable for cultivation. With the exception of the large area underlain by the Hickory member in the southeastern portion, the tillable areas are of relatively limited extent.

Some of the resistant sandstone in the upper portion of the Hickory has been used locally for building stone and road metal. Also, in clearing land for cultivation, many of the early settlers used limestone and sandstone obtained both from the bedrock and from stream-transported deposits to build houses and rock fences; most of which are still being used at the present time.

The discovery of petroleum in the area appears highly improbable. Cloud and Barnes (1946, p. 33) have stated:

> Petroleum will probably not be found by drilling in the Llano region because of the complex faulting of the potential source beds and their present exposure to the atmosphere.

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APPENDIX

Camp San Saba Section, McCulloch County, Texas

The Camp San Saba Section is principally exposed on the north bank of the San Saba River. All but the upper 179 feet of the measured thickness occurs in the vicinity of Flatrock Crossing, which is half a mile northeast of Camp San Saba. The upper interval occurs on a hill about 4500 feet N. 62^{o} W. from the highway bridge over the San Saba River. The Camp San Saba Section was measured and described by Barnes and Ellinwood during the fall of 1949 (Barnes and Bell, 1954, p. 45) and is quoted in its entirety below:

	Thickness in feet	Feet above base
Ellenburger group:		
Tanyard formation:		
Threadgill member:		
1. Limestone--sublithographic, beds mostly 4 to 6 inches thick, some beds are slightly dolomite mottled, trails are scarce, and quartzose chert is rare. Fossils are _Lytospira_ and _Ophileta_ throughout the section and _Finklenburgia helleri_ at 579 feet	15	577-592
2. Limestone--mostly sublithographic, some fine to very fine grained, yellowish gray, some beds mottled pale to dark yellowish orange, and trails and other bedding marks are common, but not nearly so abundant as in equivalent rocks in the southwestern part of the Llano uplift.		

From 516 to 519 feet, mostly covered, probably nodular; 519 to 521 feet, thin bedded; 521 to 522 feet, one bed slightly dolomite mottled; 522 to 524 feet, mostly covered; 524 to 525 feet, medium bedded, small pebble intraformational conglomerate at top; 525 to 527 feet, prominent dolomite mottled bed with Ophileta on top surface; 527 to 529 feet, poorly exposed; 529 to 530 feet, medium bedded, patches of intraformational conglomerate on top surface; 530 to 537 feet poorly exposed, some dolomite mottling; 537 to 538 feet, one bed with Ophileta and nodules of limonite pseudomorphic after pyrite on top surface; 538 to 550 feet, poorly exposed but appears to be thin bedded, in part dolomite mottled, and intraformational conglomerate float is common; 550 to 554 feet, medium bedded, considerable dolomite mottling, and small marble-size nodules of quartzose chert near middle; 554 to 555 feet, one bed, some quartzose chert along trails (?); 555 to 558 feet, poorly exposed; 558 to 567 feet, beds mostly 6 to 12 inches thick, a few markings on bedding surfaces; 567 to 577 feet, poorly exposed, thin bedded . . . 61 516-577

Wilberns formation:

San Saba member:

The top of the Wilberns formation is arbitrarily chosen using lithologic characteristics, the limestone beneath the boundary being predominantly sublithographic. The choice of the boundary was also influenced by the highest occurrence of glauconite.

3. Limestone--mostly very fine grained, some fine and medium grained, mostly somber hues of pale yellowish brown and when glauconitic having a greenish cast, limonite common, pale to dark yellowish orange dolomite common as mottles and patches, and beds mostly 6 to 12 inches thick. Ordovician trilobites are common in some beds; the lowest such occur at the base of this unit.

   From 490 to 496 feet, glauconitic, trilobitic, and at 492 feet involute gastropods; 496 to 497 feet, fine grained, mottled by dolomite; 497 to 503 feet, fine to very fine grained, the latter being thin bedded; 503 to 505 feet, covered; 505 to 507 feet, very fine grained, nodular, thin bedded, and Ordovician-type gastropod outlines are on surface at 505 feet; 507 to 508 feet, very fine grained; 508 to 509 feet, fine grained, mottled by dolomite; 509 to 510 feet, covered; 510 to 511 feet, fine grained, mottled by dolomite; 511 to 514 feet, mostly covered, a bed at about 512 feet contains many trilobites; 514 to 516 feet, lower portion very fine grained, middle portion fine grained, mottled by dolomite, and upper part fine to very fine grained and glauconitic 26 490-516

4. Limestone--alternating zones of thin-bedded, very fine grained to sublithographic, yellowish gray limestone, and beds of fine grained limestone which are mostly intraformational conglomerate. Dolomite mottles and patches are common. No trilobites have been found.

From 470 to 471.5 feet, very fine grained, with a 3-inch intraformational conglomerate at 470 feet; 471.5 to 472.5 feet, fine grained, with grayish orange dolomite patches; 472.5 to 476.5 feet, poorly exposed, mostly very fine grained; 476.5 to 477.5 feet, two beds of intraformational conglomerate; 477.5 to 480 feet, not exposed, probably very fine grained; 480 to 480.5 feet, one bed of intraformational conglomerate; 480.5 to 481.5 feet, poorly exposed, very fine grained; 481.5 to 482.5 feet, fine grained, one bed; and from 482.5 to 490 feet, poorly exposed, some beds are pelleted, some are intraformational conglomerate; at 485 feet, a coarse grained bed contains many Ordovician (?) gastropods; at 486 feet a 3-inch bed contains glauconite which is being replaced by dolomite, and at

about 487 to 488 feet, fine grained and mottled by abundant dark yellowish orange dolomite	20	470-490

SHIFT about 50 feet eastward and continue down in section.

5. Limestone--zones of very fine grained, thin-bedded shaly limestone, alternating with thicker beds of mostly fine to medium grained limestone. The very fine grained limestone is between yellowish gray and light olive gray and is mottled by grayish yellow dolomite. Ripple marks and intraformational conglomerate indicate shallow water deposition. No trilobites have been found.

    From 437 to 437.5 feet, intraformational conglomerate or breccia is composed of very small fragments; 437.5 to 438 feet, fine grained; 438 to 439 feet, very fine grained; 439 to 439.5 feet, coarse grained, glauconitic; 439.5 to 440 feet, very fine grained; 440 to 440.5 feet, fine grained, dark yellowish orange bedding plane patches of dolomite; 440.5 to 441.5 feet, medium grained, slightly glauconitic, top surface has large ripple marks; 441.5 to 442 feet, very fine grained, recessive argillaceous; 442 to 445 feet, fine to medium grained, bottom bed has dark yellowish orange dolomite patches followed upward by intraformational breccia, top bed is mostly a small-pebble, intraformational conglomerate, and at 445 feet, a small, medium spired, gastropod coquinite is replaced by dolomite; 445 to 451.5 feet, very fine grained to sublithographic; 451.5 to 452 feet, very fine grained, one bed; 452 to 461 feet, very fine grained to sublithographic; 461 to 461.5 feet, one bed of intraformational conglomerate; 461.5 to 464 feet, very fine grained, 2-inch intraformational conglomerate at 462.5 feet; 464 to 466.5 feet, mostly intraformational conglomerate; 466.5 to 467 feet, fine grained, one bed; 467 to 470 feet, mostly fine grained and heavily mottled by dark yellowish orange dolomite 33 437-470

6. Limestone--mostly fine and medium grained and some very fine and coarse grained, mostly pale yellowish brown and yellowish gray mottled by minute specks of grayish orange and dark yellowish orange dolomite, and beds mostly 6 to 12 inches thick. Dark yellowish orange dolomite patches are common on several bedding surfaces. No trilobites have been found 7 430-437

SHIFT down Flat Branch about 400 feet and continue down in section.

7. Limestone--fine grained, very fine grained, sub-

lithographic, and medium grained, mostly pale yellowish brown minor splotchings of dark yellowish orange and moderate yellowish brown in a few beds, some beds are pelleted, glauconite is absent, and some beds contain pebble-like objects and are probably intraformational conglomerates. No trilobites have been found.

From 416 to 429 feet, the rock in the line of section forms a resistant ledge but laterally the rock is thin bedded. From 422 to 423 feet, the limestone is nodular caused by irregular shale films. A few beds elsewhere in the interval have the same type lithology. An intraformational conglomerate extends from 427 to 427.5 feet 14 416-430

8. Limestone--mostly very fine grained to sublithographic, some medium grained; pale yellowish brown; beds are of irregular thickness being mostly 1 to 2 inches thick. Small gastropods are abundant in top bed. Highest Cambrian trilobites so far found occur in this unit 3 413-416

SHIFT about 1 mile eastward to Hudson Creek, using the hyolithid bed to make the shift and the overlying thin bedded sublithographic to very fine grained light gray weathering limestone as a check.

9. Limestone--mostly coarse grained, some medium grained, and a very small amount of fine grained, mostly yellowish gray to darker and mottled by pale yellowish orange and grayish orange dolomite which appears to be replacing fossil fragments and other objects. Glauconite and oolites are common and mudballs are present in some beds. The coarse grained beds are mostly trilobite shell debris. Owenella are common and the top bed is composed of hyolithids 22 391-413

10. Limestone and shale--the limestone is coarse grained, glauconitic, light olive gray mottled grayish orange, oolitic, mudballs common, dolomitic, and beds are 1 to 6 inches thick. The dolomite is minute patches as if replacing fossil debris and other objects. Trilobites and Owenella are common.

The shale is silty, grayish yellow, and contains thin glauconitic streaks and thin fine grained limestone beds. From 377 to 383 feet, mostly limestone; 383 to 384.5 feet, mostly shale; 384.5 to 385.5 feet, mostly limestone; 385.5 to 386 feet, mostly shale; 386 to 391 feet, limestone with thin shale partings 14 377-391

11. Limestone--coarse to medium grained, mostly glauconitic, mudballs and oolites common, beds mostly 6 to 12 inches thick, and dolomite prevalent throughout as minute mottlings, mostly as replacements of objects. An intraformational conglomerate at 371 feet contains highly glauconitic pebbles. Trilobites are abundant, many beds being highly fossiliferous; they correlate with the upper Trempealeauan of the standard section.

From 365 to 368 feet, covered, except for one 6-inch bed near middle. This interval can be seen along face of bluff 125 feet to the north 24 353-377

12. Limestone--sublithographic to very fine grained, yellowish gray, massive, and slightly rough weathering. Hudson Creek is crossed at 341 feet in section.

From 330 to 341 feet, pelleted; 341 to 342 feet, non-pelleted; 342 to 348 feet, pelleted; 348 to 350.5 feet, nodular, mottled, greenish shaley material in lower part, and moderate yellowish brown dolomite which appears to follow burrows is in upper part; from 350.5 to 353 feet, sublithographic limestone mottled by light brown dolomite, one bed.

A sharp change in lithologic character at the

	top of this interval appears to coincide with the top of a reef 100 yards to the east.	15	338-353
13.	Covered	2	336-338
14.	Dolomite--fine grained, in part mottled, grayish orange, in part very pale orange and in part a color between pale and dark yellowish orange. Some of the dolomite is calcitic, it is in part smooth weathered and in part weathers rough. Bedding is indistinct but beds appear to be about 6 to 12 inches thick	6	330-336

SHIFT downstream about 500 feet and continue down - in section along east bank of Hudson Creek.

15. Limestone--microgranular to fine grained and coarser, well bedded in beds mostly 1 to 12 inches thick, some beds highly glauconitic, and others are non-glauconitic.

From 300 to 302 feet, very fine grained, thin bedded, and nodular with shale films about the nodules; 302 to 306 feet, very fine grained, yellowish gray mottled by pale yellowish orange dolomite, massive, and rough weathering; 306 to 308 feet, medium grained, oolitic in upper part, coarse glauconite common, mottled by minute specks of pale yellowish orange dolomite, weathers smooth, and bedding indistinct; 308 to 310 feet, very fine grained, yellowish gray, nodular with shale films about nodules, thin bedded, and recessive; 310 to 313 feet, same as above except more massive and rough weathering; 313 to 314 feet, medium grained, smooth weathering, and mottled by minute specks of very pale yellowish orange dolomite which appears to be replacing fossil fragments; 314 to 323 feet, very fine grained, nodular, mottled by pale yellowish orange dolomite, and massive in bluff but thin bedded away from bluff; 323 to 324 feet, medium grained, slightly glauconitic, dolomitic, and smooth weathering; 324 to 330 feet, very fine grained, rough weathering, and mottled by pale yellowish orange dolomite 30 300-330

16. Covered in line of section. Laterally appears to be interreef limestone 5 295-300

The stromatolitic biohermal portion of the San Saba member is crossed, using an average of the dips from below and above the reef. The thickness of the reef, therefore, may be in error. The top of the reef is very irregular, fluctuating through at least 30 feet of section within one-half mile of the line of section.

17. Limestone and some dolomite--intervals of reef and interreef beds are as follows: from 247 to 251 feet, dark yellowish orange interreef dolomite; 251 to 259 feet, reef with individual stromatolites

about 1 foot across, which are yellowish gray and have a concentric structure brought out by incipient dolomitization, the dolomite being pale yellowish orange; 259 to 270 feet, light brown to grayish orange dolomite interreef beds; 270 to 276 feet, reef with foot-sized stromatolites which are about one-third dolomite causing the concentric structure to be well displayed; 276 to 277 feet, light brown to dark yellowish orange interreef dolomite; 277 to 280 feet, dolomite mottled reef and interreef beds on a dip slope; 280 to 285 feet, pale red to light brown interreef dolomite beds; 285 to 295 feet, dolomitic reef as above, and some interreef dolomite beds at about 290 feet. 48 247-295

18. Limestone and covered-lower 5 feet very fine to coarse grained and dolomitic. Rest of interval covered. Local folding of beds suggests that shale is present in the covered interval 16 231-247

19. Limestone--coarse grained, mostly pale yellowish orange to grayish orange, and thick bedded, the bottom bed being 7 feet thick, followed by a 1-foot bed, a 4-foot bed, and a top 2-foot bed. Large ripple marks on top bed are indistinct. Ten inches of intraformational conglomerate forms the basal portion of the interval 14 217-231

Eastward the rock in this interval changes to stromatolitic reef so if section had been continued before offset, this interval would be logged as reef.

Point Peak Shale member:

20. Siltstone, intraformational conglomerate, and shale--the siltstone is mostly yellowish gray to darker in color, slightly micaceous, and in beds 1/4 to 1 inch thick separated by shale films.

    Intraformational conglomerate is at the following levels: 206 feet, of variable thickness averaging about 2 inches in thickness; 207.5 feet, 1 to 6 inches thick with two doughnut-shaped stromatolites at same level; 208 to 209 feet; 211 to 211.5 feet; and 215 to 215.5 feet 13 204-217

SHIFT downstream eastward about 1200 feet and continue section down bluff.

21. Limestone--in the line of section the interval consists of stromatolitic reefs and interreef coarse grained limestone. As this interval is traced laterally upstream the limestone is replaced by shale and the reefs are sporadically distributed. Silicified brachiopods at 204 feet belong to the genera Billingsella and Plectotrophia 3 201-204

22. Siltstone, intraformational conglomerate, and shale--the siltstone beds are mostly one-quarter to 1 inch

thick with a few as much as 2 inches thick alternating with light brownish gray shale.

From 188 to 188.5 feet, shale; 188.5 to 189 feet, intraformational conglomerate; and from 189 to 201 feet, siltstone, thin shale films, and four intraformational conglomerates, 2-inch ones at 192 feet and 193 feet, a 3-inch one at 195.5 feet, and a 6-inch one from 197.5 to 198 feet 13 188-201

23. Limestone--microgranular to sublithographic, stromatolitic reef limestone, coarse grained interreef limestone beds, and intraformational conglomerate. The reef is pale red, mottled light brownish gray and light olive gray; and the coarse grained limestone is light olive gray, in part mottled by dark yellowish orange. Plectotrophia cross sections are abundant but only very poor material breaks out 2 186-188

24. Siltstone, shale, and intraformational conglomerate--the siltstone is yellowish gray to darker, micaceous, in beds mostly 1 to 4 inches thick, and each bed composed of many closely spaced laminae. Trails are common but not abundant.

The shale is light brownish gray, slightly micaceous, and occurs as beds and films between siltstone beds.

From 169 to 171.5 feet, siltstone; 171.5 to 172 feet, shale; 172 to 174 feet, siltstone and considerable shale; 174 to 177 feet, mostly 1 to 6-inch beds of siltstone; 177 to 182.5 feet, mostly 1 to one-quarter inch beds of siltstone with shale films between, trails abundant, and a 2-inch intraformational conglomerate at 178 feet; 182.5 to 183 feet, intraformational conglomerate; 183 to 186 feet, thin bedded siltstone and shale, somewhat slumped 17 169-186

SHIFT 500 feet eastward using interval from 186 to 188 feet for making the shift.

25. Siltstone, shale, and intraformational conglomerate--from 160 to 180 feet, mostly siltstone in one-quarter to 4-inch beds, alternating with thin shale films, trails uncommon, some minute interference ripples, and at about 162.5 feet and 179 feet, 4-inch intraformational conglomerates; from 180 to 186 feet, very poorly exposed siltstone contains some poorly preserved orbiculoids 26 160-186

CONTINUE downstream along foot of bluff.

26. Siltstone and shale--the siltstone is in beds, mostly between 1 and 4 inches in thickness separated by thin films of shale, trails are uncommon, and a trilobite found as float is probably from this interval . . . 5 155-160

27. Siltstone and limestone--from 136 to 149 feet, silty limestone or calcareous siltstone, mostly

thinly bedded and alternating with shale films; exposures are sporadic except for top 5 feet.

— CROSS fence at this point.—

From 149 to 155 feet, the rock is similar and mostly thinly bedded except for some 2 to 3-inch beds in upper part. Trails and minute interference ripples are common. In the lower 4 feet, exposures are sporadic and in the upper 2 feet, exposures are good 17 138-155

28. Limestone and shale--mostly fine grained, silty limestone separated by thin greenish gray shale films. The limestone is medium light gray, mostly weathers to pale olive, and contains very fine grained glauconite and mica.

From 123 to 126.5 feet, fine grained, nodular but massive, furrowed, and a few inches of coarse grained limestone at 125.5 feet; 126.5 feet, alternations of paper-thin shale beds and one-half inch limestone beds; 128.5 to 130 feet, fine grained, nodular, much burrowed, and fairly well bedded; 130 to 131 feet, fine grained, and beds 1 to 2 inches thick; 131 to 134 feet, fine grained limestone and shale alternations, very thinly bedded and shaly in lower part becoming less shaly upward and containing beds up to an inch in thickness; 134 to 135 feet, medium grained limestone forming a resistant ledge;

135 to 138 feet, fine grained limestone in beds mostly 1 to 2 inches thick separated by thin shale films along irregular bedding planes	15	123-138

Morgan Creek limestone member:

29. Limestone--coarse and fine grained. The coarse grained limestone is glauconitic, mostly 6 to 12 inches thick, some 3 feet thick, mostly yellowish gray with a light olive gray cast and the remainder is mostly light brownish gray. Small pale to dark yellowish orange dolomite specks up to 1/8 inch in size are common.

The fine grained limestone is mostly pale olive, glauconitic, burrowed, nodular, and silty to aregillaceous.

Upper Franconian trilobites occur throughout this unit.

From 90 to 90.5 feet, fine grained; 90.5 to 94.5 feet, coarse grained, abundant oolites in the middle; 94.5 to 95.5 feet, fine grained; 95.5 to 98 feet, coarse grained, 98 to 99 feet; fine grained; 99 to 100 feet, coarse grained, moderate yellowish brown weathering dolomite patches on top surfaces, and dolomitized objects throughout; 100 to 103 feet, coarse grained, and many Billingsella and a few oolites in top bed; 103 to 103.5 feet, fine grained;

103.5 to 104.5 feet, coarse grained and slightly oolitic; 104.5 to 106 feet, fine grained; 106 to 109 feet, coarse grained, pisolitic (?), and moderate yellowish brown weathering dolomite patches on top surface; 109 to 110 feet, coarse grained, oolitic, small dolomite patches on top surface, and trilobitic; 110 to 111 feet, fine grained limestone, coarse grained limestone, and stromatolites. The coarse grained limestone is oolitic, cross-bedded, and forms lower portion of interval. The fine grained limestone is greenish gray, has mica along its bedding surfaces, and is in thin beds separated by shale films. The reefs are up to 18 inches thick, 20 to 25 feet in diameter, and about 100 to 200 feet apart. The beds arch over the reefs and some girvanella are associated with them.

From 111 to 112 feet, coarse grained, mottled by dusky yellow dolomite, and some Billingsella; 112 to 113 feet, fine grained, recessive; 113 to 119 feet, coarse grained, much dolomite mottling, fossil material is replaced by dolomite rhombs, and Billingsella are common at several levels; 119 to 120.5 feet, fine grained; 120.5 to 122 feet, coarse grained, dolomite mottles and replacements common, and upper surface has interference ripples on it; 122 to 122.5 feet, fine grained, recessive; 122.5 to 123 feet, coarse grained, light brownish gray, and dolomite replacements common 33 90-123

30. Limestone--mostly microgranular to fine grained, yellowish gray and light olive gray, stromatolitic reef heads separated by medium to coarse grained septa. The reef is about 18 inches thick and in places rests on fine grained limestone 1 89-90

31. Limestone--alternating coarse and fine grained beds. The coarse grained limestone is stylolitic, mostly glauconitic, mostly between yellowish gray and light olive gray and some is pale red but much less abundant than in interval below. Cross-bedding is detectable in many beds but in many if present cannot be seen because of stylolites. Beds are mostly 6 to 12 inches thick but thicker ones are common. Calcareous brachiopods are abundant in many beds in the lower part of the interval.

The fine grained limestone is glauconitic, silty, argillaceous, mostly pale olive and light olive gray to pale yellowish brown, and extensively burrowed, giving it a nodular appearance.

From 43 to 43.5 feet, a coquinite of small calcareous brachiopods; 43.5 to 45 feet, coarse grained with 4-inch fine grained bed in middle, top bed contains abundant Irvingella; 45 to 45.5 feet, fine grained; 45.5 to 46 feet, a coarse grained Eoorthis coquinite; 46 to 48 feet, an alternation of coarse and fine grained beds, the coarse grained ones being mostly a coquinite of Eoorthis in lower part and Billingsella in upper part; 48 to 50.5 feet, fine grained, nodular, slightly argillaceous, acrotretids abundant near middle of bed, and some Billingsella; 50.5 to 51.5 feet, coarse grained, coquinite of Billingsella; 51.5 to 54.5 feet, fine grained, nodular, argillaceous, and some corneous brachiopod fragments; 54.5 to 55 feet, coarse grained; 55 to 56 feet, fine grained, argillaceous; 56 to 56.5 feet, coarse grained; 56.5 to 57.5 feet, fine grained; 57.5 to 58 feet, medium grained, and many grayish orange to dark yellowish orange mudballs; 58 to 59.5 feet, fine grained; 59.5 to 60.5 feet, coarse grained, light brownish gray, oolitic, and contains Billingsella; 60.5 to 61.5 feet, fine grained; 61.5 to 62 feet, medium grained, contains pale yellowish orange dolomite patches, and near bottom mudballs; 62 to 62.5 feet, grayish olive green greensand, and coarse grained limestone crossbeds; 62.5 to 63 feet, shale, recessive; 63 to 66 feet, coarse grained, slightly oolitic limestone, streaked light brownish gray; 66 to 67.5 feet, medium grained, mottled; 67.5 to 69 feet, coarse grained, sandy cross-bedded, and highly glauconitic; 69 to 71 feet, fine grained; 71 to 71.5 feet, coarse grained, oolitic; 71.5 to 73 feet, fine grained, 73 to 76 feet, coarse and medium grained, somewhat sandy, cross-bedded, and contains many Billingsella and cystid plates and columnals; 76 to 77.5 feet, fine grained; 77.5 to 78.5 feet, coarse grained, grayish red and contains cystid plates; 78.5 to 79.5 feet, fine grained, thin bedded, contains numerous trails but is little burrowed; 79.5 to 80 feet, coarse grained; 80 to 81 feet, medium and fine grained, light olive gray mottled by dark yellowish orange, and more argillaceous towards top; 81 to 85.5 feet, coarse grained, and a minor amount of medium to fine grained, bottom bed highly oolitic; 85.5 to 86 feet, fine grained; 86 to 87.5 feet, coarse grained, and some fine grained at top; 87.5 to 89 feet, coarse grained and contains a number of moderate yellowish brown dolomite specks 46 43-89

32. Limestone--mostly coarse grained, stylolitic, sandy, glauconitic, and in beds mostly 6 to 12

inches thick. Some of the limestone is fine grained.

From 15 to 15.5 feet, fine grained, between yellowish gray and light olive gray, glauconitic, silty, and highly burrowed; 15.5 to 19 feet, coarse grained, grayish red; 19 to 20 feet, fine grained, highly burrowed; 20 to 22 feet, coarse grained, grayish red to light brownish gray, and contains pale yellowish orange mudball conglomerate, the mudballs of which in the top 2 inches are rimmed by dark yellowish orange; 22 to 24 feet, fine grained, between greenish gray and light olive gray, highly burrowed and with a layer of mudball-like material on top surface; 24 to 25 feet, coarse grained, pale red to light brownish gray, somewhat cross-bedded, and contains some rimmed mudballs; 25 to 25.5 feet, recessive, not exposed; 25.5 to 28 feet, coarse grained, pale red to light brownish gray, and contains some rimmed mudballs; 28 to 31.5 feet, fine grained and burrowed, except for 5 inches of coarse grained cross-bedded limestone at 29 feet and about 3 inches at 30.5 feet; 31.5 to 32.5 feet, coarse grained, pale red to light olive gray, and contains a few mudballs; 32.5 to 33 feet, fine grained, silty, light olive gray, argillaceous, burrowed, and weathers to moderate yellowish brown;

33 to 34 feet, coarse grained, pale red to light olive gray, and contains a few mudballs; 34 to 34.5 feet, fine grained, silty, argillaceous, burrowed, light olive gray weathering to medium yellowish brown; 34.5 to 35.5 feet, coarse grained; 35.5 to 36.5 feet, mostly fine grained, some coarse grained; 36.5 to 37 feet, coarse grained; 37 to 37.5 feet, 38 to 38.5 feet, fine grained; 38.5 to 39 feet, coarse grained, except for 2 inches of fine grained, dark yellowish orange dolomite patches are common, two beds, the lower one 3 feet and the upper one 1 foot thick and serving as a ford . . . . 28 - 15-43

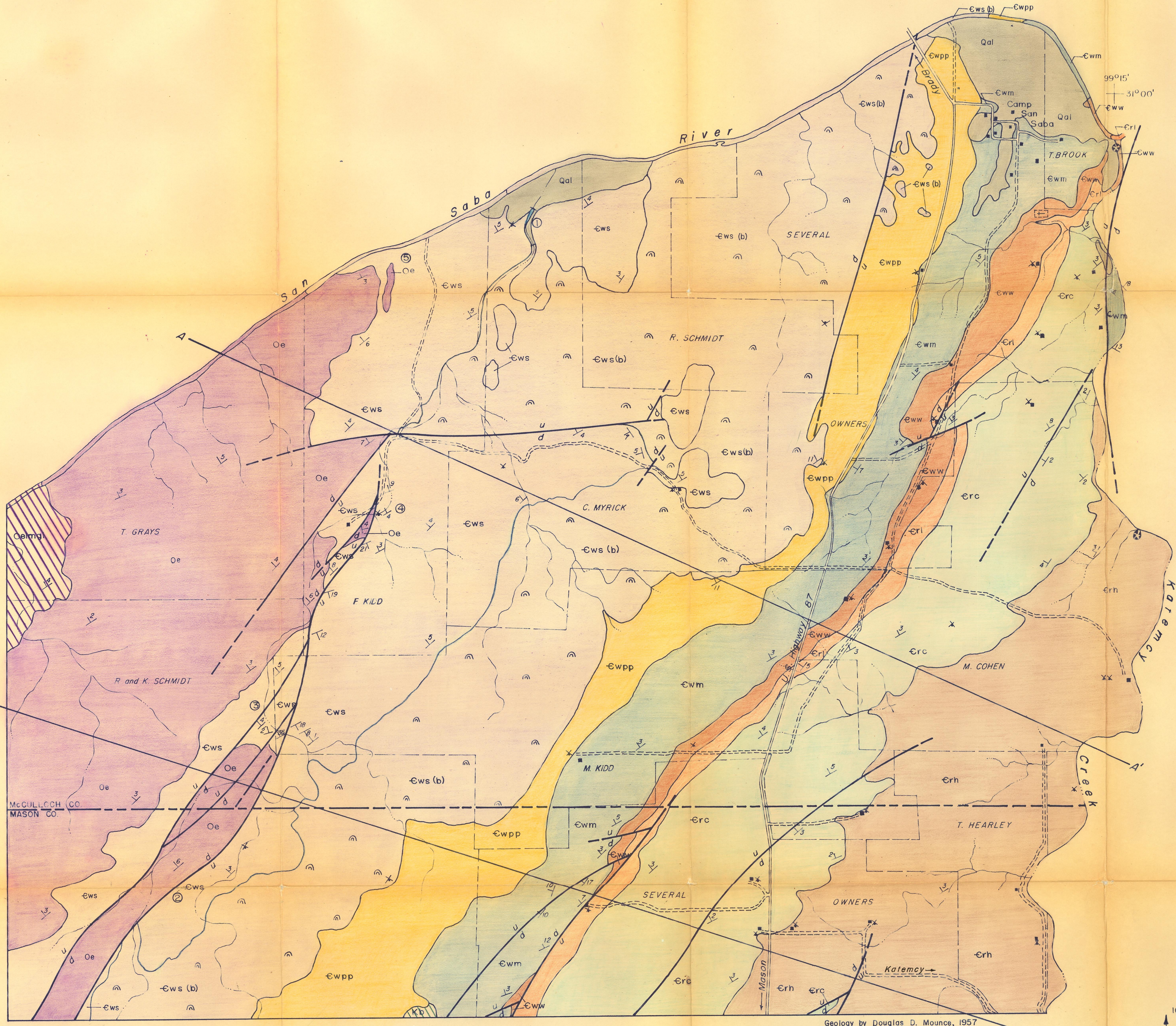
33. Limestone--coarse grained, highly sandy with bottom few feet possible more than 59 percent sand, mostly grayish red and a small amount of light brownish gray, glauconite common, and beds mostly between 4 and 10 inches in thickness 6 9-15

Welge sandstone member:

34. Sandstone--medium to coarse grained, coarsening toward top where granules are up to one-quarter inch in diameter. Some beds contain scattered glauconite and the sandstone is massive and calcareous toward the top. Light olive gray where glauconitic, otherwise yellowish brown and pale to dark

yellowish orange except for top bed which is pale yellowish brown. The sand grains are well rounded, mostly rough and poorly sorted	9	0-9
Total thickness measured	592	

The base of the section is located on the north bank of the San Saba River about 1000 feet downstream from Flatrock Crossing. The section starts at the lowest exposed bed at the edge of a boulder-strewn alluvial plain.



Base from U.S. Department of Agriculture, Soil Conservation Service, Aerial photographs, 1939-40

Geology by Douglas D. Mounce, 1957

99°15'
30°55'

EXPLANATION

GEOLOGIC COLUMN

Qal	Recent Alluvium			Quaternary
Kb	Unnamed basal sands			Cretaceous
	UNCONFORMITY			
Oe(mg), Oe	Oe (mg), Ellenburger dolomite; Oe, Ellenburger limestone	Ellenburger Group	Lower Ordovician	Ordovician
€ws, €ws(b)	San Saba limestone member, with basal bioherm zone	Wilberns Formation	Upper Cambrian	Cambrian
€wpp	Point Peak shale member	Wilberns Formation	Upper Cambrian	Cambrian
€wm	Morgan Creek limestone member	Wilberns Formation	Upper Cambrian	Cambrian
€ww	Welge Sandstone member	Wilberns Formation	Upper Cambrian	Cambrian
€rl	Lion Mountain sandstone member	Riley Formation	Upper Cambrian	Cambrian
€rc	Cap Mountain limestone member	Riley Formation	Upper Cambrian	Cambrian
€rh	Hickory sandstone member	Riley Formation	Upper Cambrian	Cambrian

LEGEND

Normal fault
u, upthrown side
d, downthrown side

Inferred normal fault

Observed and inferred contact

Strike and dip of strata

San Saba limestone description locality

Property line fence

Intermittent stream

Following stream

A——A'
Structure section line

Collapse Structure

Windmill

Stock tank

Ranch house

All Weather road

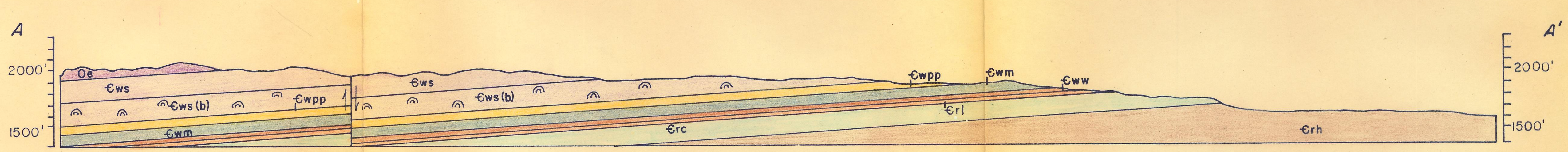
Graded earth road

10°
N

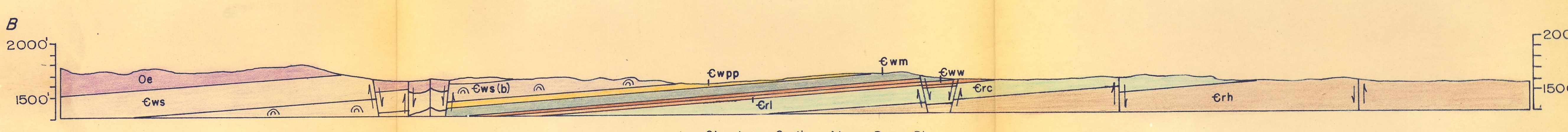
SCALE 1:20,000

0 1/2 1 2miles

0 850 1700 3400 5100 6800 8500 10200 feet



Structure Section Along A — A'
(All Elevation Approximate)



Structure Section Along B — B'
(All Elevation Approximate)

GEOLOGIC MAP AND SECTIONS OF THE CAMP SAN SABA-WEST AREA, MASON & McCULLOCH CO. TEXAS