GEOLOGY OF THE LOYAL VALLEY-WEST AREA,

MASON COUNTY, TEXAS

A Thesis

By

JEROME GREGORY KMIECIK

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Approved as to style and content by:

Melvin C. Schroeder
(Chairman of Committee)

(Head of Department of Geology and Geophysics

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TABLE OF CONTENTS

ILLUSTRATIONS

GEOLOGY OF THE LOYAL VALLEY-WEST AREA, MASON COUNTY, TEXAS

ABSTRACT

The Loyal Valley-West area is located on the southwest flank of the Llano uplift in southeastern Mason County. The geology of the area is similar to that found elsewhere in the Llano region with outcrops of Precambrian, Paleozoic, Mesozoic, and Cenozoic rocks.

Gneiss, schist, and granite rock units compose the Precambrian rocks of the Loyal Valley-West area.

Rock units of Paleozoic age consist of Late Cambrian and Early Ordovician deposits. The Upper Cambrian deposits are divided into the Riley and Wilberns formations. The Riley is divided into three members. These members are (from oldest to youngest) the Hickory sandstone, the Cap Mountain limestone, and the Lion Mountain sandstone. The over-lying Wilberns formation is divided into four members. These members are (from oldest to youngest) the Welge sandstone, the Morgan Creek limestone, the Point Peak shale, and the San Saba limestone. Rocks of the Ellenburger group (Early Ordovician) conformably over-lie the Late Cambrian deposits. The Paleozoic rocks generally have a northeast-southwest strike and a southeast dip of 3 to 6 degrees.

An arkose conglomerate and reddish sandstone deposit, of probable Cretaceous age, represents the rocks of the Mesozoic Era.

Rocks of Cenozoic age are present in the form of stream and alluvial deposits, and are predominantly caliche conglomerates.

Of the numerous normal faults in the area, only two are classified as major faults. The major fault in the eastern portion of the area, the Loyal Valley fault, trends in a general north-south direction. The second major fault, the Squaw Creek fault, trends in a northeast-southwest direction and intersects the Loyal Valley fault in the northeastern part of the area. A small fold is present northwest of the intersection of the Squaw Creek and Loyal Valley faults.

The faulting and structural deformation of the area are attributed to compensatory movements which relieved anomalous stresses created by the excess loads in the depositional area. This depositional area included the Llano uplift area as well as the Llanoria geosyncline.

Grazing land is the most important natural resource of the area. The possibility for the development of other natural resources in the area is limited.

GEOLOGY OF THE LOYAL VALLEY-WEST AREA, MASON COUNTY, TEXAS

INTRODUCTION

LOCATION

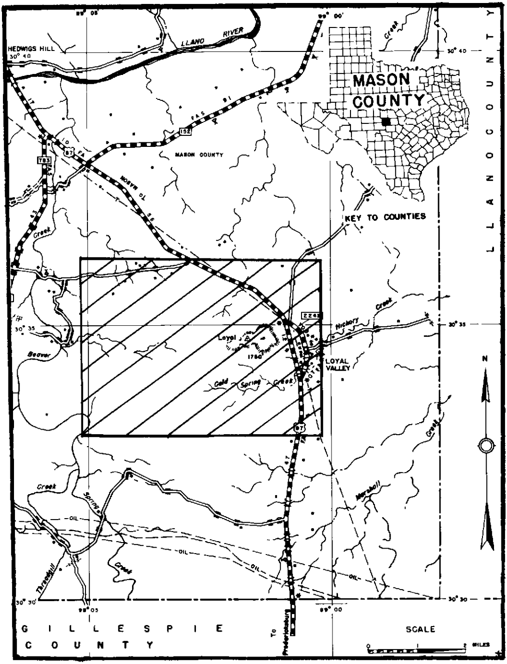
The Loyal Valley-West area is located approximately 16 miles southeast of Mason, Texas, in the southeastern corner of Mason County, Texas (Fig. I). This study area of about 20 square miles is bounded by latitudes 30°33' and 30°37'39" North and longitudes 99°30' and 99°05'06" West. The name for the area is taken from the small community of Loyal Valley which is located in the eastern part of the area.

ACCESSIBILITY

The Loyal Valley-West area is readily accessible via U. S. Highway 87 which crosses the area in a north-south direction. An unpaved county road that extends west from U. S. Highway 87, from a point 1.5 miles north of Loyal Valley, provides access to the northwestern portion of the area. Several private ranch roads extend south from this county road and give access to the midwestern portion of the area. A second unpaved road, intersecting U. S. Highway 87 three miles south of Loyal Valley, extends westward to the Reuben Evers residence. Several ranch roads, originating at the Evers residence, provide access to the southwestern part of the area.

Rough and ungraded roads are numerous throughout the area. Most of the ranch roads are passable only to jeeps or similar vehicles. Roads that may be traveled by automobiles in fair weather are indicated

Figure 1



Reproduced from Texas State Highway Department County Maps, revised to January 1959

LOCATION MAP OF LOYAL VALLEY—WEST AREA
MASON COUNTY, TEXAS

on Plate I.

METHODS OF FIELD WORK

The field work for this study was accomplished between July 15, 1958, and September 6, 1958. Data used in the preparation of the geologic map and cross sections accompanying this report were obtained by field observations. The field observations were supplemented by steroscopic study of aerial photographs covering the area. The mapping was recorded on acetate serial photographs. Aerial photographs used in the study of the area were obt ained from the U. S. Department of Agriculture and consisted of photographs 222, 224 of series DFZ-2P and 112, 124 of series DFZ-3P. These photographs were made in 1956.

The strikes and dips of the stratigraphic units were obtained by the use of a Brunton compass. A makeshift Jacob's staff and hand level were used in conjunction with the Brunton compass in the measurement of the described section.

Field notes on the topography, stratigraphy and structure were compiled during the mapping of the area and served as a basis for the preparation of this report.

REVIEW OF PREVIOUS GEOLOGIC INVESTIGATIONS

Considerable geologic literature relevant to the Llano Uplift of Central Texas is available. While many of the earlier publications have been supplanted by later investigations and revisions, most of the publications are of interest in a study of the region. Details concerning the development of stratigraphic nomenclature pertinent to the Llano region are given in the presentation of the geologic units.

Roemer's (1846) broad and general geological study of Central Texas is primarily of historical interest today.

Shumard (1861, p. 213-220) recognized that the Cambrian strata in the Llano Region is equivalent in age to the "Potsdam Group" of the eastern United States.

Walcott (1884, p. 431) states that rocks equivalent in age to the "Potsdam Group" are present in the Llano Region and proposed the name Llano group for the underlying schists, gneisses, and marbles.

Comstock (1890) introduced the terms Hickory and Riley series for the Cambrian strata of the Llano Region.

Tarr (1890) discussed the geomorphology of the Llano Region and observed that the present drainage system was developed on Cretaceous deposits that have since been removed by erosion.

The geological investigations of Paige (1911, 1912) on the Precambrian and Cambrian stratigraphy of the Central Mineral Region of Texas are of interest; he noted the importance of the structural features of the area in his interpretation of the stratigraphic units.

The Texas Bureau of Economic Geology, under the direction of Udden, published a generalized geologic map of Texas in 1916.

A stratigraphic report on the pre-Paleozoic and Paleozoic systems in Texas by Sellards, Adkins, and Plummer (1932) includes the regional structure of the Llano region.

Sellards (1934) includes the Llano region in his report on the major structural features of Texas east of the Pecos River.

Bridge (1937) named the Lion Mountain sandstone as the uppermost member of the Cap Mountain formation of the Riley series.

Barnes and Parkinson (1939), in describing the origin of the dreikanters found in the Hickory sandstone member, concluded that an arid climate and eolian erosion were present during the deposition of the lower portion of the Hickory sandstone member.

Cloud, Barnes, and Bridge (1945) elevated the sequence of carbonate deposits known as the Ellenburger limestone formation to group status and restricted it to Ordovician age. They identified the recognizable units in the Ellenburger group, in ascending order as: the Tanyard formation, containing the Threadgill and Standebach members; the Gorman formation; and the Honeycut formation. The authors proposed that the deposits previously classified as the Riley series be re-classified as the Riley formation. The members, in ascending order, are listed as the Hickory sandstone, the Cap Mountain limestone, and the Lion Mountain sandstone.

Bridge, Barnes, and Cloud (1947) presented a detailed stratigraphic study of the Upper Cambrian rocks in the Central Mineral Region of Texas. Eight members of the two Upper Cambrian formations are described. Although the Pedernales dolomite is not now classified as a member, this paper is still recognized as the standard reference for the

Cambrian strata in the Llano Region.

Plummer (1950) discussed the Pennsylvanian and Mississippian deposits found in the Llano region.

Barnes (1952) described the Upper Cambrian, Ordovician, Cretaceous, and Quaternary deposits exposed in the Squaw Creek Quadrangle of Mason and Gillespie Counties, Texas. This locality is about seven miles southwest of the thesis area.

Rogers (1955) described Cretaceous (?) age arkosic conglomerate beds of possible terrestrial origin found at numerous places in Mason County.

Woolsey (1958) mapped and described an area that overlaps the southern portion of the Loyal Valley-West area. In the overlap area, the writer is not in complete agreement with the structure and outcrop pattern as mapped by Woolsey. The interpretation of the structure and outcrop pattern of the overlap area as presented on Plate I is thus different from that mapped by Woolsey (1958).

Peterson (1959) mapped and described an area that overlaps the Loyal Valley-West area on the western border. The area of overlap was jointly mapped by Peterson and the author.

ACKNOWLEDGEMENTS

This thesis was prepared under the guidance of Dr. Melvin C. Schroeder, Chairman of the Committee, and Messrs. Clay L. Seward and Fred E. Smith, Members of the Committee. Sincere appreciation is accorded them for their assistance.

Additional assistance from Mr. Shirley A. Lynch, Head of the Department, and other faculty members of the Geology and Geophysics Department of the A. and M. College of Texas is acknowledged and appreciated. The generous help of Mrs. Margaret Adams in the final typing of this manuscript is assented and valued.

PHYSIOGRAPHY

CLIMATE

The Loyal Valley-West area has a semi-arid to sub-humid climate. The average annual rainfall for Mason County is reported as 22.5 inches by the Texas Almanac (1958). According to the residents of the area, extreme variations from the average annual rainfall are common.

The approximate average annual temperature is 70 degrees Fahrenheit. The temperature varies with seasonal changes from a low of 5 degrees below zero in the winter season to a high of 110 degrees in the summer months.

VEGETATION

Vegetation in the Loyal Valley-West area is similar to that found elsewhere within the Llano uplift. The vegetation is adapted to the semi-arid to sub-humid climate and the poor soil development common to the Llano uplift. The type and abundance of plant growth found on the area is primarily controlled by the different type soils that develop from the various stratigraphic units. Perennial vegetation found within the area includes cacti, Spanish dagger, mesquite, Mexican persimmon, bee brush, catsclaw, post oak, scrub oak, and live oak. Buffalo, Curly mesquite, Bermuda, and Texas needle are grasses most common to the area. Additional discussion of the vegetation is given in the individual descriptions of the stratigraphic units.

GEOMORPHOLOGY

The Llano uplift has the topographic expression of a basin, although structurally the region is a dome. It is drained by the Colorado River and its tributaries. The major tributaries of the Colorado River in this area are the San Saba River, the Llano River, and the Pedernales River. All of these rivers apparently formed as consequent streams on the Cretaceous strata. As erosion progressed, these major streams became superimposed and incised into the Paleozoic and Precambrian rocks.

The Loyal Valley-West area, in the southern portion of the Llano uplift, is drained by tributaries of the Llano River, which is located about six miles north of the area. Beaver Creek, which makes a meander into the western part of the thesis area, is the only perennial stream. Intermittent streams, originating within the thesis area, serve as primary drainage units. The intermittent westerly flowing streams of the area empty into Beaver Creek, a tributary of the Llano River. The intermittent streams that drain the eastern half of the area drain northeast toward the Llano River.

The Loyal Valley-West area has valleys, hills, and cuestas whose slopes show varying degrees of steepness. This topography is attributed to the structural and stratigraphic relationships of the various rock units that are exposed to the erosional effects of the intermittent and perennial streams of the area. The beds more resistant to erosion are the Paleozoic limestones whose topographic expressions include hills, cuestas, and sloped areas. The more easily eroded

Precambrian rocks and the Hickory sandstone member generally form lowlands and valleys. The maximum and minimum elevations of the area are 1750 feet and 1375 feet, respectively, giving an approximate total relief of 375 feet.

The most effective erosional agent in the thesis area is running water from the sporadic concentrations of rainfall. This erosion is aided in the area by the clearance of vegetation from large expanses which allows an easier removal of the soil covering. Wind erosion is negligible.

STRATIGRAPHY

GENERAL STATEMENT

Exposures of rocks ranging in age from Precambrian to Recent are exposed in the Loyal Valley-West area. The Precambrian exposures consist of both igneous and metamorphic rocks. The Paleozoic strata are represented by outcrops of Upper Cambrian and Lower Ordovician rocks. The Mesozoic Era is represented by a thin veneer of Lower Cretaceous deposits. Alluvium, conglomerates, and caliche deposits of probable Recent age are the only deposits of the Cenozoic Era. The stratigraphic column for the area is as follows:

CENOZOIC ERA

- Quaternary System
  - Recent alluvium
  - Recent conglomerate
  - Recent caliche deposits

MESOZOIC ERA

- Cretaceous System
  - Lower Cretaceous (Comanchean) Series
    - Cretaceous Sandstone Unit

PALEOZOIC ERA

- Ordovician System
  - Lower Ordovician Series
    - Ellenburger group

CAMBRIAN SYSTEM

- Upper Cambrian Series

Wilberns formation

San Saba limestone member

Point Peak shale member

Morgan Creek limestone member

Welge sandstone member

Riley formation

Lion Mountain sandstone member

Cap Mountain limestone member

Hickory sandstone member

PRECAMBRIAN ROCKS

Igneous rocks

Granite

Metamorphic rocks

Gneiss and schist units

PRECAMBRIAN ROCKS

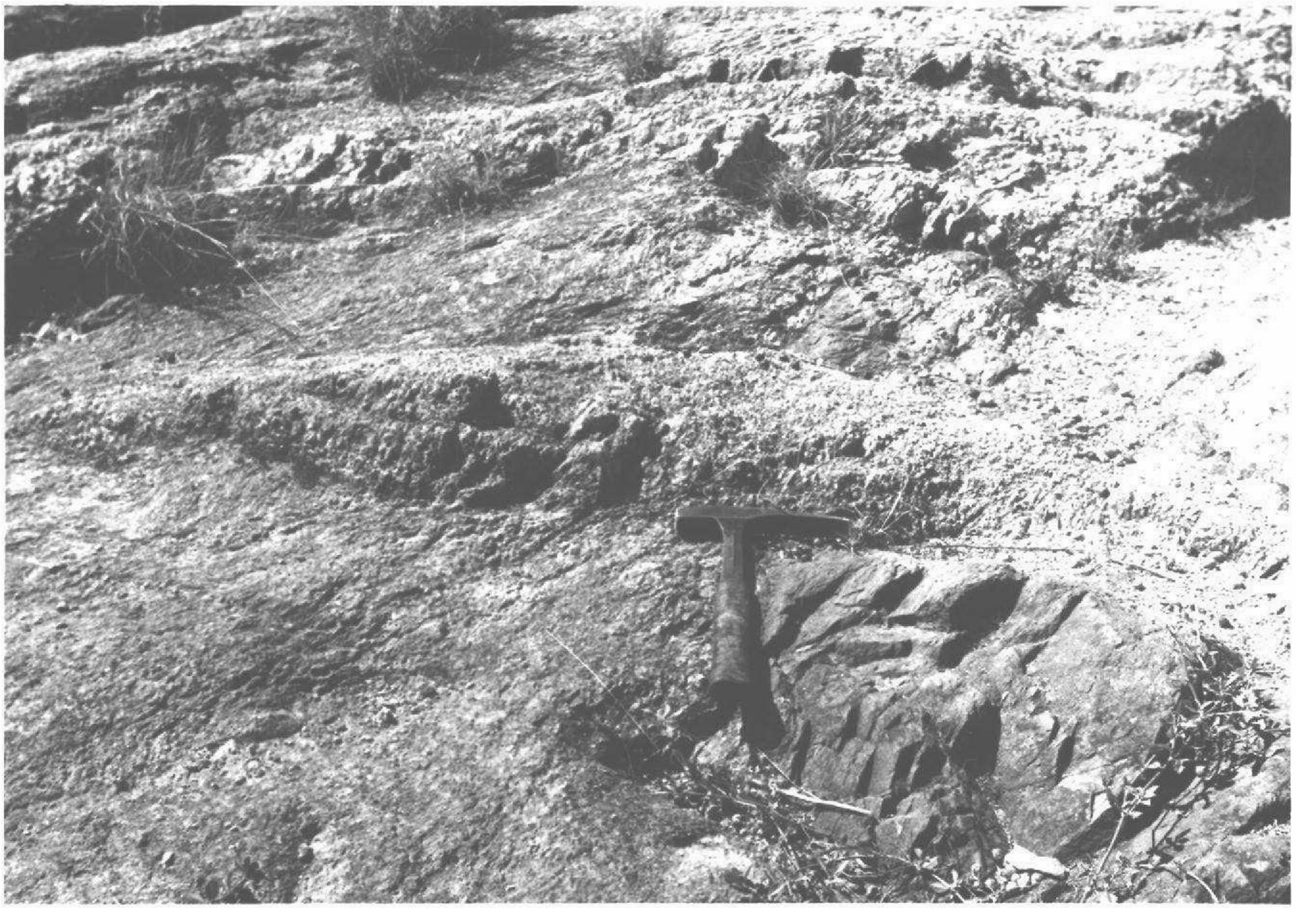
Precambrian rocks are exposed at three different places in the Loyal Valley-West area. It is difficult to obtain an accurate surface contact between the igneous and metamorphic rock units because of the soil cover, the complex character of the relationship between the units, as shown on Plate II, and the small areas of exposure. Stenzel's (1934, p. 78) description of Precambrian rocks adequately describes the outcrops found within the Loyal Valley-West area:

> "----- In this zone, the crumpled schists or gneisses are welded together by tortuous granite stringers but pegmatites cut straight through stringers and all."

Thus, where igneous or metamorphic outcrops are shown on Plate I, it is a designation of only the dominant rock type.

PLATE II

Contact of Precambrian Metamorphic and Igneous Rocks



Complex Precambrian stratigraphic relationship with granitic and aplitic intrusives in lower right, schist unit in lower left and gneiss unit in upper right. East of U. S. Highway 87, Location 1, Plate I

METAMORPHIC ROCKS

Walcott (1884, p. 431) used the term "Llano series" in his general description of the rocks of the Llano area, grouping both sedimentary and metamorphic rocks in this unit. Comstock (1890) differentiated the metamorphic rocks of the region into the Valley Springs gneiss and the Packsaddle schist. Paige (1912, p. 26) redefined these units and stated that the Packsaddle schist is younger than the Valley Springs gneiss. Stenzel (1932, p. 143) stated that the Valley Springs gneiss is igneous in origin and intruded the Packsaddle schist. Sellards, et al, (1932, p. 33) described the Packsaddle schist as metamorphosed sediments intruded by basic igneous rocks. Barnes (1945, p. 56) defined the Big Branch gneiss as igneous in origin and the predominant Precambrian outcrop of northeastern Gillespie County and northwestern Blanco County. This unit is regarded as younger than the Valley Springs gneiss and Packsaddle schist.

Gneiss Unit

Exposures of roughly foliated metamorphic rocks are present in the northwestern and eastern parts of the Loyal Valley-West area. The color, mineral grain-size, and foliation of the gneissic rocks found within the area have been used to differentiate this general metamorphic rock into two types, namely, the banded foliated gneiss and the lenticular foliated gneiss.

The pink-to-gray lenticular gneiss is coarse-to-medium grained. Foliation patterns are not developed as well as those present on the banded gneiss. The principal minerals identifiable megascopically are pink feldspar, smoky quartz, and biotite.

The dark-gray banded gneiss has a fine-to-medium grained texture and lacks the pink color of the lenticular gneiss. Foliation patterns are more pronounced on the banded gneiss than on the lenticular gneiss. Feldspar, smoky quartz, and biotite are the principal minerals.

Deep weathering of both the banded and lenticular gneiss prevented a comparison of the hardness of the rock types. Where determinable, the strike of the foliation patterns of both rock types is in a general north-south direction with easterly dips of about 20 degrees most common.

Schist Unit

Metamorphic rocks exhibiting well developed foliation are present in two locations in the Loyal Valley-West area. Two different schist types, a biotite schist and a hornblende schist, are present in both outcrop areas. The best exposures of the biotite schist are present in the small creek beds that cross U. S. Highway 87 near the community of Loyal Valley. The best exposures of the hornblende schist are present in the metamorphic outcrop north of the intersection of the Loyal Valley and Squaw Creek fault (Plate I).

The dull-gray, biotite schist is primarily composed of biotite and milky quartz. A poor rock cleavage occurs parallel to the orientation of the flaky biotite crystals. In all exposures, this rock type is loosely consolidated due to weathering.

The hornblende schist, in contrast to the dull biotite schist, has a silky luster. The black, slender crystals of hornblende are oriented parallel to the foliation pattern. Smoky quartz is also identifiable megascopically. The hornblende schist is apparently more resistant to weathering than the biotite schist.

IGNEOUS ROCKS

Intrusive granitic rocks in the form of batholiths, sills, and pegmatite dikes predominate in the Llano region, although basic igneous rocks such as diorite are also present.

Numerous descriptions of the igneous rocks of the Llano region have been published by various authors. Early investigators who described igneous rocks of the Llano region include Roemer (1846), Walcott (1884), and Comstock (1889). Paige (1912) mapped and described a large exposure of fine-to-medium grained granite east of the Loyal Valley-West area. Stenzel (1932, p. 75) divided the granite batholitic intrusions into three types, namely, the fine-grained Six-Mile granite, the medium-grained Oatman Creek granite, and the coarse-grained Town Mountain granite. He also states that each of the above intrustions has its own system of aplite and pegmatite dikes. Other references of interest on the igneous rocks found within the Llano region include Stenzel (1934), Keppel (1940), Goldich (1941), Barnes, et al (1950), and Flawn (1956).

Igneous Unit

The granite found in the southeastern portion of the Loyal Valley-West area is believed to be a continuation of the large exposure of granite that Paige (1912) described and mapped east of the thesis area. The contact between the large mass of granite and metamorphic rocks in the Loyal Valley-West area is generally obscured by soil cover.

Where granitic material was observed in contact with metamorphic rocks, the question arises as to whether this granitic material is part of a dike, a large pegmatite vein, or part of a batholithic intrusion, as both abrupt and transitional contacts are present. Paige (1912), Wilson (1957), and Woolsey (1958) have all previously indicated that the contacts between granite and metamorphic rocks in nearby areas are both abrupt and transitional.

The granite present in the Loyal Valley-West area is medium-grained. Pink microcline appears to be the most abundant mineral. Other minerals identified by megascopic inspection are biotite and smoky quartz. The mineral grains in this pink-gray granite are generally between 4 and 6 millimeters in diameter.

Numerous aplite, pegmatite, and quartz dikes cut both the igneous and metamorphic rocks in the area. The principal minerals in the porphyritic pegmatite dikes are microcline, biotite, and smoky quartz. Smoky quartz is the only mineral identifiable in the quartz dikes. The principal minerals in the aplite dikes are feldspar and quartz.

Topographic and Vegetational Characteristics of the Precambrian Rocks

There are no significant topographic and vegetational differences between the igneous and metamorphic outcrops in the Loyal Valley-West area. No differentiation is made for individual unit discussions of the topographic and vegetational characteristics of the Precambrian rocks.

The Precambrian outcrops weather more easily than the sedimentary Paleozoic strata. A lowland type of topography with small hills is the general surface expression of the Precambrian outcrops. Brown, sandy soils develop on the Precambrian outcrops and are generally characterized by the presence of pebble-sized feldspar and quartz fragments.

Vegetation is generally well-developed on the Precambrian exposures except where erosion has removed most of the soil. The principal plants are mesquite, post oak, scrub oak, cactus, and native grasses.

PALEOZOIC ERA

CAMBRIAN SYSTEM

In the Loyal Valley-West area, as elsewhere in the Llano region, there is an absence of Lower and Middle Cambrian deposits. Upper Cambrian deposits exposed in the thesis area include the three members of the Riley formation and the four members of the Wilberns formation.

Riley Formation

The Riley formation, as re-defined by Cloud, Barnes, and Bridge (1945, p. 154), is recognized as the oldest Paleozoic deposit present in the Llano region. This Late Cambrian formation is presently divided into three members. Listed in descending order, they are:

3. Lion Mountain sandstone
2. Cap Mountain limestone
1. Hickory sandstone

The contact between the Riley formation and the underlying Precambrian complex in unconformable. The contact with the overlying Wilberns formation, which is probably unconformable, is recognized by lithologic changes between the Lion Mountain sandstone of the Riley formation and the overlying Welge sandstone of the Wilberns formation.

The type locality for the Riley formation is the Riley Mountains in southeastern Llano County where the formation is 780 feet thick. According to Bridge, Barnes, and Cloud (1947, p. 109) this formation may vary from 200 to 780 feet in thickness. This variation in thickness is attributed to the irregular Precambrian surface upon which the Riley formation was deposited.

The Riley formation is estimated to be 750 feet thick in the Loyal Valley-West area.

Hickory Sandstone Member

Definition and thickness:

The lowest Cambrian sandstones in the Central Mineral Region were initially termed the Hickory series by Comstock (1890). Paige (1912) classified the lowest Cambrian sandstones as the Hickory Formation. Cloud, Barnes, and Bridge (1945, p. 154) later defined the Hickory sandstone as the basal member of the Riley formation. Goolsby (1957) proposed that the Hickory sandstone should be classified as a formation. This proposal was in accordance with information derived from a detailed stratigraphic study of the unit which indicates that the Hickory sandstone contains three mappable units. This proposal has not received widespread acceptance.

According to Cloud, Barnes, and Bridge (1947, p. 112), the average thickness for the Hickory sandstone member is 360 feet. The thickness of the member in the Llano region may vary from zero to 400 feet. This variation in thickness is attributed to the irregular Precambrian surface on which the member was deposited, to the unequal rates of deposition, and to the lateral gradation of sandstones into limestones in the upper part of the member.

A measured thickness of the member was not obtained in the thesis area due to poor exposures and faulting. Palmer (1954, p. 785) reports a measured thickness of 364 feet approximately 7 miles southwest of the thesis area. Within the thesis area, the member is believed to be about the same thickness as that reported by Palmer.

Lithology and stratigraphic relationship:

The Hickory sandstone member's unconformable contact with the underlying Precambrian complex is best exposed in the extreme northwestern portion of the thesis area. In the above location (Location 2, Plate I), about two feet of the lower most basal beds of the Hickory sandstone are exposed where the underlying Precambrian rocks have been removed for road metal. Elsewhere in the area of investigation, the contact between the Hickory sandstone and the underlying Precambrian rocks is totally or partially obscured by soil cover.

The most basal deposits of the member observed in the thesis area consist of approximately 2 feet of brown-colored, conglomeratic, sandstone beds as shown on Plate III. The milky quartz pebbles, incorporated in the matrix of poorly sorted sand-sized particles, have a maximum approximate diameter of 8 centimeters. The pebbles are predominantly sub-rounded and exhibit frosted surfaces. Although the pebbles show some faceting, they do not possess as high a degree of faceting as those described and illustrated by Barnes and Parkinson (1939, p. 666). The thickness of the conglomeratic sandstone beds was not determined because of soil cover; however, it probably does not exceed five or six feet.

With the exception of the basal beds described above, the lower portion of the member consists of massively bedded, reddish-brown, cross-stratified, non-fossiliferous, non-calcareous, coarse-grained

PLATE III

Basal Beds of the Hickory Sandstone Member

Conglomeratic basal beds of the Hickory sandstone member exposed in a road metal pit in northwest part of thesis area. See Location 2, Plate I sandstone. Quartz is the only mineral that can be megascopically identified. The cement appears to be silica and ferruginous material.

Above the reddish-brown, massive beds, the member is a gray-to-tan, coarse-to-medium sandstone. This coarse-to-medium grained sandstone sequence lacks the ferruginous material that is common in the lower portion of the member. The quartz particles of this portion of the member are sub-rounded to rounded. Reddish, slightly raised, stellate shaped structures, approaching three inches in diameter are found within this sequence in the northwestern portion of the area (Location 20, Plate I). These slightly raised structures are probably due to differential weathering. The reddish color of the stellate structures suggests that iron and silica are combined to form a cement that is more resistant to weathering than silica cement alone.

The lithology of the beds that comprise the upper portion of the member is varied. Olive-green and brown siltstone beds are interspersed between yellow and beige, fine-grained sandstone beds, as shown on Plate IV. Ripple marks and intraformational conglomerate, as shown on Plate V, are commonly present on the upper surface of the fine-grained sandstone beds. These sandstone and siltstone beds grade vertically into massively bedded, dark red-to-brown, medium-grained sandstone beds. A more noticeable amount of ferruginous material is present in the uppermost portion of this member than is present in the middle portion of the member. Hematitic nodules, noticeably lighter in weight than those present in the Lion Mountain sandstone member, are found within the weathered portion of these massive beds. These beds grade upward into the calcareous Cap

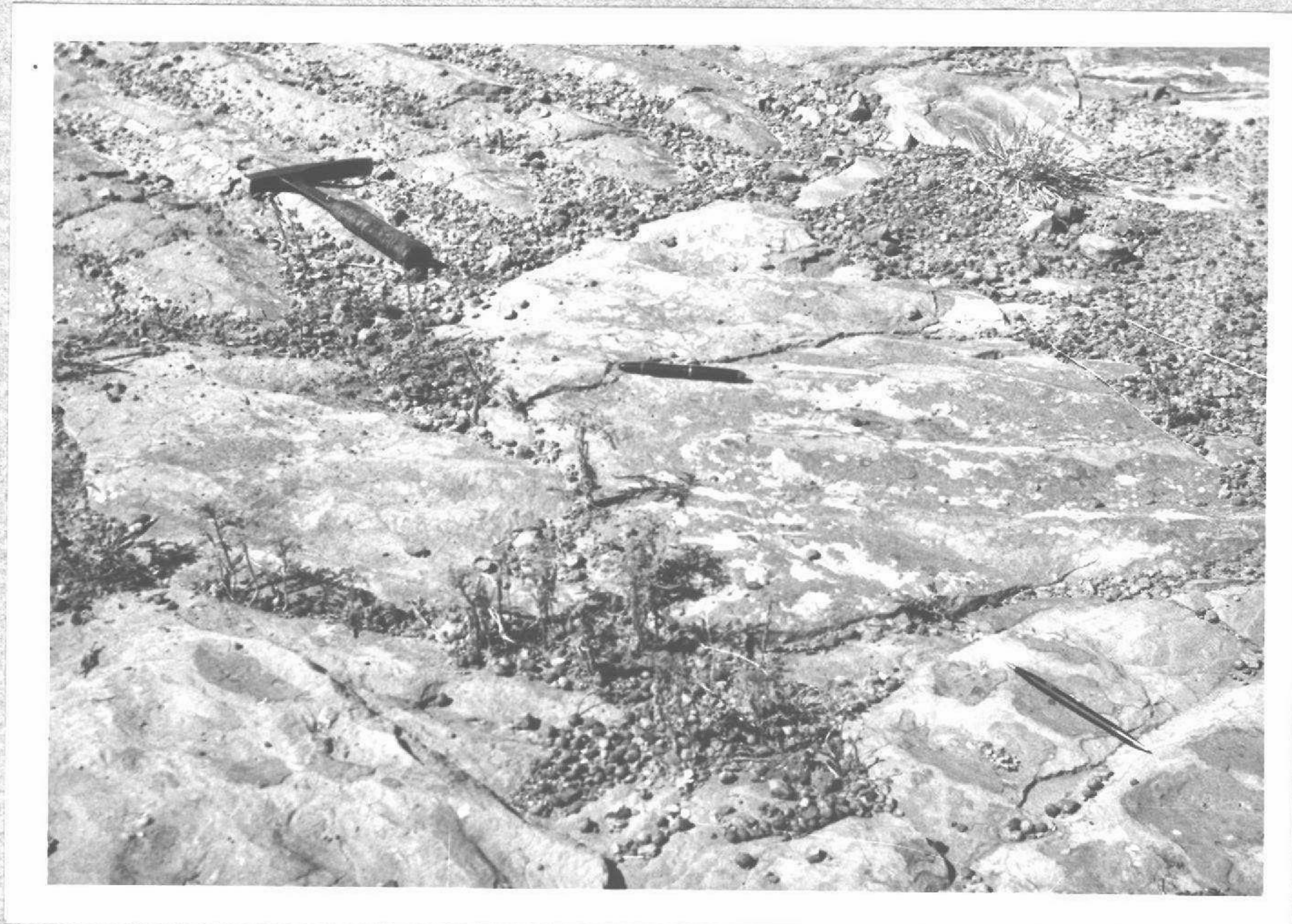
PLATE IV

Shaley Beds in the Hickory Sandstone Member

Shaley portion of Hickory sandstone member cut by minor fault. See Location 3, Plate I

PLATE V

Ripple Marks in the Hickory Sandstone Member



Three distinct sets of ripple-marks on different beds in middle portion of the Hickory member east of U. S. Highway 87. Pencil, pen, and hammer parallel to the troughs of the ripple-marks. See Location 4, Plate I

Mountain limestone member.

Topography and vegetation:

The rolling lowland topography developed on the member is both structurally and stratigraphically controlled. Where the dip of the member is less than 5 degrees, flat lowland topography is developed. In most instances, hilly topography is developed on this member where the dip is greater than 5 degrees. The most resistant beds are in the upper portion of the member and often form gentle cuestas in the thesis area. These beds are characterized by the presence of intraformational conglomerate and ripple marks on the upper surfaces of the individual layers.

Loamy and sandy soils develop on the exposures of the member and support a well-developed and variegated vegetative growth. The greater portion of the member's exposure in the thesis area has been cleared of trees and underbrush growth for use as improved pasture and farm land. The dominant type of vegetation on the uncleared exposures of the member include scrub oak, mesquite, bee brush, and varied grasses. Lesser amounts of Mexican persimmon, live oak, and cactus are also present.

Cap Mountain Limestone Member

Definition and thickness:

The term Cap Mountain limestone was formally used for the first time by Paige (1911, p. 23) in describing the sequence of limestone and glauconitic rocks above the Hickory sandstone in Llano County. At that time, the Cap Mountain was classified as a formation and the upper boundary was the present contact between the Riley and Wilberns formation. Bridge (1937, p. 234) named and defined the Lion Mountain sandstone as the uppermost member of the Cap Mountain formation. The Cap Mountain limestone is presently defined as the middle member of the Riley formation by Cloud, Barnes, and Bridge (1945, p. 154).

The type locality for the Cap Mountain limestone member is at Cap Mountain in Llano County. According to Bridge, Barnes, and Cloud (1947, p. 113), the thickness of the member varies from 135 feet to 455 feet. The average thickness of the member is 280 feet.

The thickness of the Cap Mountain limestone member in the thesis area is estimated to be 350 feet. This estimate is similar to the estimated 400 feet thickness reported by Peterson (1959) for the member in the adjacent Middle Beaver Creek area. Woolsey (1958) reported an estimated thickness of close to or greater than the average thickness of 280 feet for the southerly overlapping Squaw Creek-Marshall Creek area.

Lithology and stratigraphic relationship:

The contact between the underlying Hickory sandstone member and the Cap Mountain limestone member is gradational. The contact between these two members may be recognized by the following criteria: (1) the distinct topographic change from the flat lowland of the Hickory sandstone to the small scarp formed by the more resistant basal beds of the Cap Mountain limestone and, (2) the dense vegetational band supported by the basal beds of the Cap Mountain limestone.

The lowest portion of the Cap Mountain limestone is composed of reddish-brown, massive, slightly glauconitic, arenaceous limestone beds. Very irregular weathering patterns, as shown on Plate VI, are common.

In the middle part of the member, an increase in the amount of arenaceous material is noticeable. An exceptionally thick bed with a higher than usual content of fine-grained arenaceous material is shown on Plate VII.

The upper portion of the Cap Mountain limestone is composed of gray, massive, glauconitic limestone beds and beige, silty limestone beds. The glauconite content of the limestone beds is greatest near the contact of the Lion Mountain sandstone.

Topography and vegetation:

Where exposures of the Cap Mountain limestone have a dip of less than 5 degrees, a rolling topography is developed. Pronounced cuestas are developed where the dip of this member is greater than 5 degrees over a large areal extent.

The vegetation on the Cap Mountain limestone is very dense near its contact with the Hickory sandstone. Scrub oak is the dominant plant with lesser amounts of catsclaw, mesquite, and prickly pear.

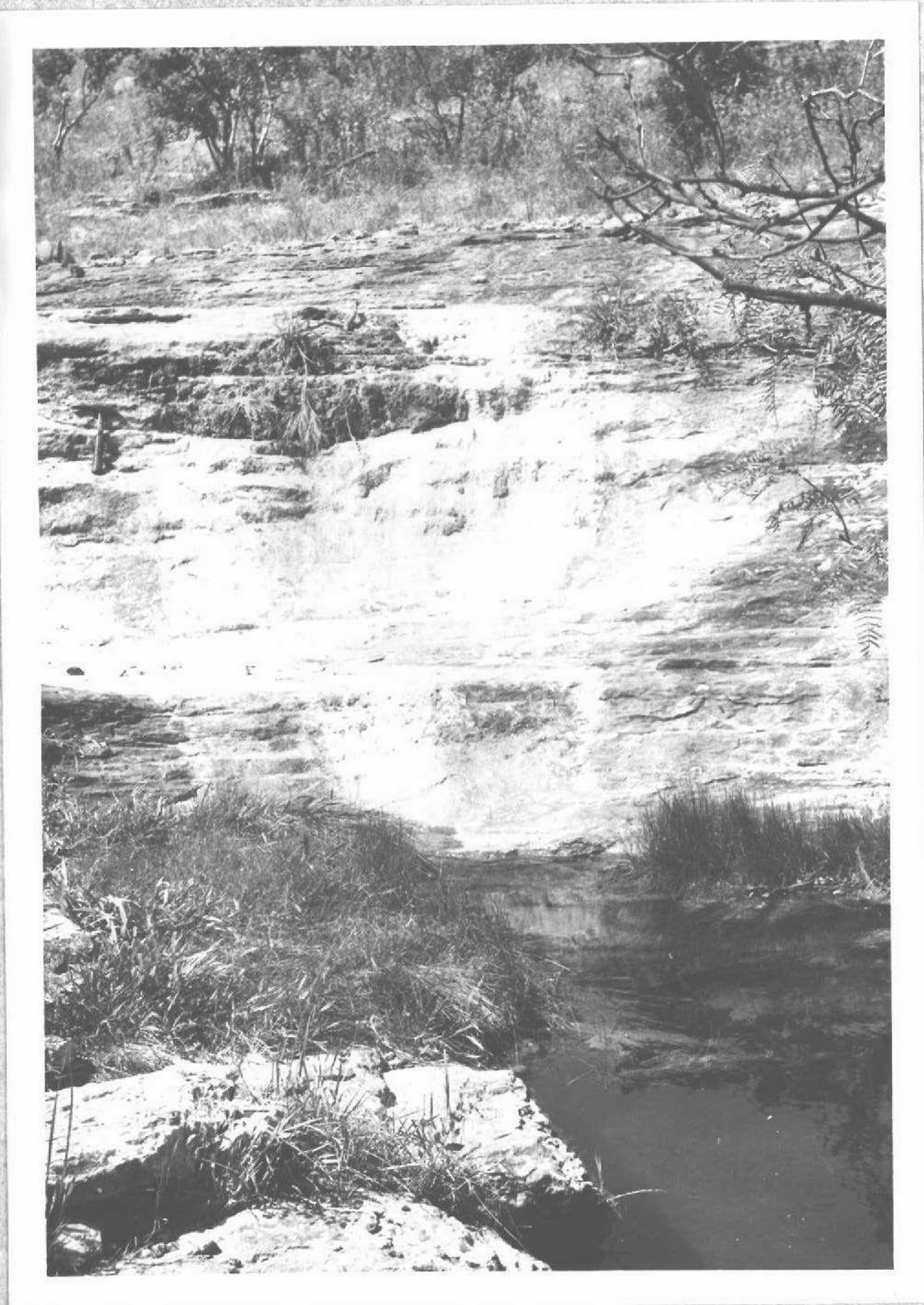
PLATE VI

Weathered Surface of the Cap Mountain Limestone Member

Cap Mountain limestone member showing extreme development of very irregular weathering pattern. See Location 5 in south central portion of Plate I

PLATE VII

Sandstone Bed in the Cap Mountain Limestone Member



Massive sandstone bed in middle part of Cap Mountain limestone member. See Location 6 in east-central portion of Plate I.

Lion Mountain Sandstone Member

Definition and thickness:

Bridge (1937, p. 234) defined the Lion Mountain sandstone as the upper member of the Cap Mountain formation. The Lion Mountain sandstone is presently defined by Cloud, Barnes, and Bridge (1945, p. 154) as the uppermost member of the Riley formation.

The type locality is Lion Mountain, Burnet County, Texas, where the member is 20 feet thick (Bridge, 1937, p. 234). The member, within the Loyal Valley-West area, is estimated to be 45 feet thick.

Lithology and stratigraphic relationship:

The contact of the Lion Mountain sandstone and the underlying Cap Mountain limestone is gradational. The first glauconitic sandstone beds encountered above the Cap Mountain limestone member were used as the criteria in placing the lower boundary of the Lion Mountain sandstone member.

The Lion Mountain sandstone consists of alternating massive, coarse-grained, glauconitic, calcareous sandstone beds and glauconitic, arenaceous limestone beds. Lenses of "trilobite hash" are common. Purplish-black, hematite nodules, ranging in size from 1/4 to 4 inches in diameter are present on the weathered surface.

Topography and vegetation:

The Lion Mountain sandstone forms a flat-to-gentle sloping bench in the thesis area with numerous hematite nodules and slabs of "trilobite hash" present on the weathered surface.

Scrub oak is the most abundant plant. Isolated, slightly dwarfed bushes of Mexican persimmon, turkey pear, and tasajillo are also present on the outcrop of this member.

Wilberns Formation

The Wilberns formation, as defined by Paige (1912, p. 47), included 220 feet of sandstone, shale, and intraformational conglomerate beds. The limits of the formation as described by Paige (1912, p. 47) are as follows:

> "The base of the formation is well defined by the top of the glauconitic sandstone which forms the upper member of the Cap Mountain formation. Its upper limit is at the base of the overlying massive chert-bearing beds."

Cloud, Barnes, and Bridge (1945, p. 155), redefined the Wilberns formation and listed four members of the formation. In ascending order, they are the Welge sandstone, the Morgan Creek limestone, the Point Peak shale, and the San Saba limestone members. Bridge, Barnes, and Cloud (1947, p. 114) listed the above four members and the Pedernales dolomite member. Subsequent investigations by Barnes and Bell (1954, p. 35) indicate that the San Saba limestone and the Pedernales dolomite occupy the same relative stratigraphic position and interfinger laterally. Thus the Pedernales dolomite member is not recognized as a member of the Wilberns formation.

According to Bridge, Barnes, and Cloud (1947, p. 114), the Wilberns formation is 540 to 610 feet thick throughout most of the Llano region. In the Loyal Valley-West area, the Wilberns formation is estimated to be 580 feet thick.

Welge Sandstone Member

Definition and thickness:

Barnes (1944, p. 37) introduced the term Welge sandstone in his description of the Wilberns formation. The name Welge was taken from the Welge land surveys in Gillespie County. The formal definition of the Welge sandstone member, as the basal sandstone member of the Wilberns formation was made in 1947 by Bridge, Barnes, and Cloud (1947, p. 114). The type locality is located one-half mile north of the Gillespie County line.

According to Bridge, Barnes, and Cloud (1947, p. 114), the thickness of the member ranges from 9 to 35 feet throughout the Llano region. The author and Peterson (1959) measured 16.4 feet of the Welge sandstone member on the western border of the thesis area. The thickness of the member is believed to be nearly constant throughout the area of investigation.

Lithology and stratigraphic relationship:

The contact between the Welge sandstone member and the Lion Mountain sandstone member was placed at the point where the highly glauconitic beds of the Lion Mountain are abruptly succeeded by orange-brown, non-glauconitic and non-calcareous beds of the Welge sandstone member. This contact, as shown on Plate VIII, is often characterized by the Welge sandstone member forming a small ledge in contrast to the easily eroded Lion Mountain sandstone member.

The Welge sandstone member is an orange-brown, massive, medium-grained, quartzose sandstone. It is non-calcareous, non-

PLATE VIII

Contact Between the Lion Mountain and Welge Members

Contact between the Lion Mountain sandstone member and the overlying Welge sandstone member with typical ledge development formed by the Welge sandstone member. See Location 7, Plate I, east of U. S. Highway 87 fossiliferous, and non-glauconitic in the Loyal Valley-West area. Individual beds within this member may be white or buff. Many of the quartz grains that compose this member glitter in the sunlight. Bridge, Barnes, and Cloud (1947, p. 114) attribute this to recomposed faces on the quartz grains.

Topography and vegetation:

The Welge sandstone member generally forms an easily definable ledge. This ledge development is often limited to the upper one-half of the member with the lower one-half of the member weathering to form a flat or gently sloping bench.

Vegetation present on the outcrops of the Welge sandstone is relatively dense in relation to that present on the outcrops of the Lion Mountain sandstone and the Morgan Creek limestone. The member supports an assemblage of plant growth that is dominated by scrub oak and Mexican persimmon trees. Other plants present on outcrops of the Welge member are turkey pear, tasajillo, and various grasses.

Morgan Creek Limestone Member

Definition and thickness:

Bridge (1937, p. 236) named and described the Morgan Creek limestone from exposures north of the junction of the north and south forks of Morgan Creek in Burnet County, Texas.

According to Bridge, Barnes, and Cloud (1947, p. 115), the thickness of the Morgan Creek limestone varies from 70 to 160 feet. The average thickness is 120 feet. In the Loyal Valley-West area, the measured thickness of this member is 112.5 feet (appendix, section 1). This measured interval may be in error as several small faults are in the measured section. Correlation between beds, in the measurement of this faulted section, was established by lithologic similarity of beds and fossil zones.

Lithology and stratigraphic relationship:

The contact between the Morgan Creek limestone member and the underlying Welge sandstone member is gradational. The boundary between these units is placed where the first purplish-red, arenaceous, limestone beds of the Morgan Creek member are encountered above the Welge sequence of orange-brown, non-calcareous sandstone beds. The contact between these two members is expressed topographically by a small escarpment formed by the calcareous beds of the Morgan Creek member which are more resistant to weathering than the non-calcareous sandstone beds of the Welge member.

The most basal part of the Morgan Creek member is composed of purplish-red, arenaceous limestone beds. These beds grade upward into greenish-gray, medium-grained, glauconitic limestone beds. The beds in the basal part of the member vary in thickness from a fraction of an inch to greater than three feet.

The middle portion of the member is composed of highly fossiliferous gray limestone beds. The fossils consist of cystoid stems, calcareous braciopods, and trilobite fragments. Approximately 45 feet above the base of the member, a persistent 5 feet thick zone of coquina-like limestone, containing an abundance of the brachiopod Eoorthis texanna, is present. Other fossils present in this zone include brachiopods and trilobite fragments. According to Barnes (1952) and Barnes and Bell (1954, p. 59), the brachiopod Eoorthis texanna does not occur lower in the stratigraphic section and may be used as a marker zone.

Argillaceous material is more abundant in the upper portion of this member although limestone is still the dominant material. Calcareous siltstone and shale beds are commonly interspersed with greenish-gray limestone beds as shown on Plate IX. In the uppermost 20 to 30 feet of the member, small purplish-to-greenish-gray stromatolitic bioherms range in size from 6 inches to 5 feet. Bioherms of the Morgan Creek limestone member are shown on Plate X.

For a more detailed lithologic description of the Morgan Creek limestone member, reference is made to the measured section (appendix, section 1).

Topography and vegetation:

The limestone beds of the Morgan Creek member form a steep slope that is marked by a series of small step-like benches. The top

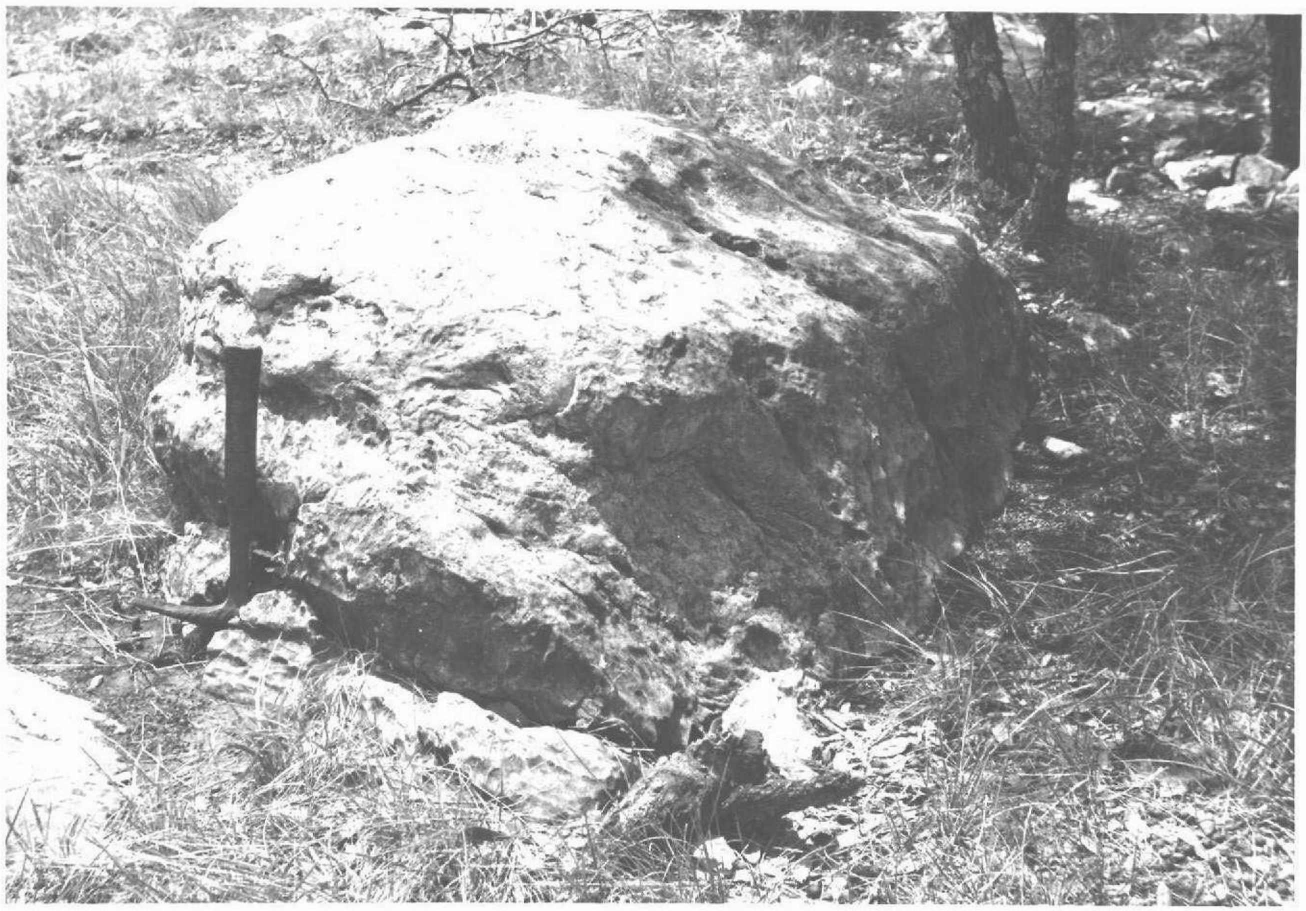
PLATE IX

Weathered Morgan Creek Limestone Member

Weathered Morgan Creek limestone member, mined for road-metal and possessing a "caliche-like" appearance. See Location 8, west of U. S. Highway 87, Plate I

PLATE X

Bioherms of the Morgan Creek Limestone Member



Unusually large bioherms in upper Morgan Creek limestone member. See Location 9 in south central portion of Plate I of the member in the thesis area is often capped by a layer of small stromatolitic bioherms that is very resistant to weathering.

The vegetation present on the Morgan Creek member is perhaps as abundant as that found on the Welge sandstone member but is noticeably less robust. This dwarfed characteristic of the vegetation growing on the Morgan Creek member makes the vegetational growth, when observed on aerial photographs, appear less dense than that on the Welge sandstone member. Mexican persimmon is the most common plant. Scrub oak, tasajillo, Spanish dagger, and native grasses are also present.

Point Peak Shale Member

Definition and thickness:

The Point Peak member was named by Bridge (1937, p. 236) from exposures on Point Peak, an isolated hill located 4 miles northeast of Lone Grove, Llano County. A complete description of this member at the above type locality is given by Bridge, Barnes, and Cloud (1947, p. 115).

The thickness of the member at the type locality is 270 feet. According to Barnes and Bell (1954, p. 237), the average thickness of this member is 130 feet. In the western portion of the thesis area (appendix, section I), this member is 160 feet thick. Two reef zones are included in this section and were mapped as separate units within the Point Peak shale member.

Lithology and stratigraphic relationship:

The contact of the Point Peak shale member with the underlying Morgan Creek limestone member is gradational. The basal contact of the Point Peak m mber was arbitrarily placed at the top of the small bioherm zone in the Morgan Creek limestone member. There the small bioherm zone of the Morgan Creek limestone member is not present or completely covered, the more prounounced argillaceous content and the more gentle slope of the Point Peak shale member were used as guides in determining the boundary. Often the boundary of the member, as shown on Plate I, differs from that shown by Woolsey (1958, Plate I). The slight differences are attributed to field identification of the member.

The basal portion of the Point Peak member is composed of alternating grayish-green siltstone, limestone, and intraformational conglomerate beds with poorly developed bedding planes. The intraformational conglomerate beds are composed of sub-rounded, nearly flat, limestone pebbles enclosed in a matrix of gray, silty limestone. The limestone pebbles are oriented with their greatest length parallel, or nearly parallel, to the bedding planes.

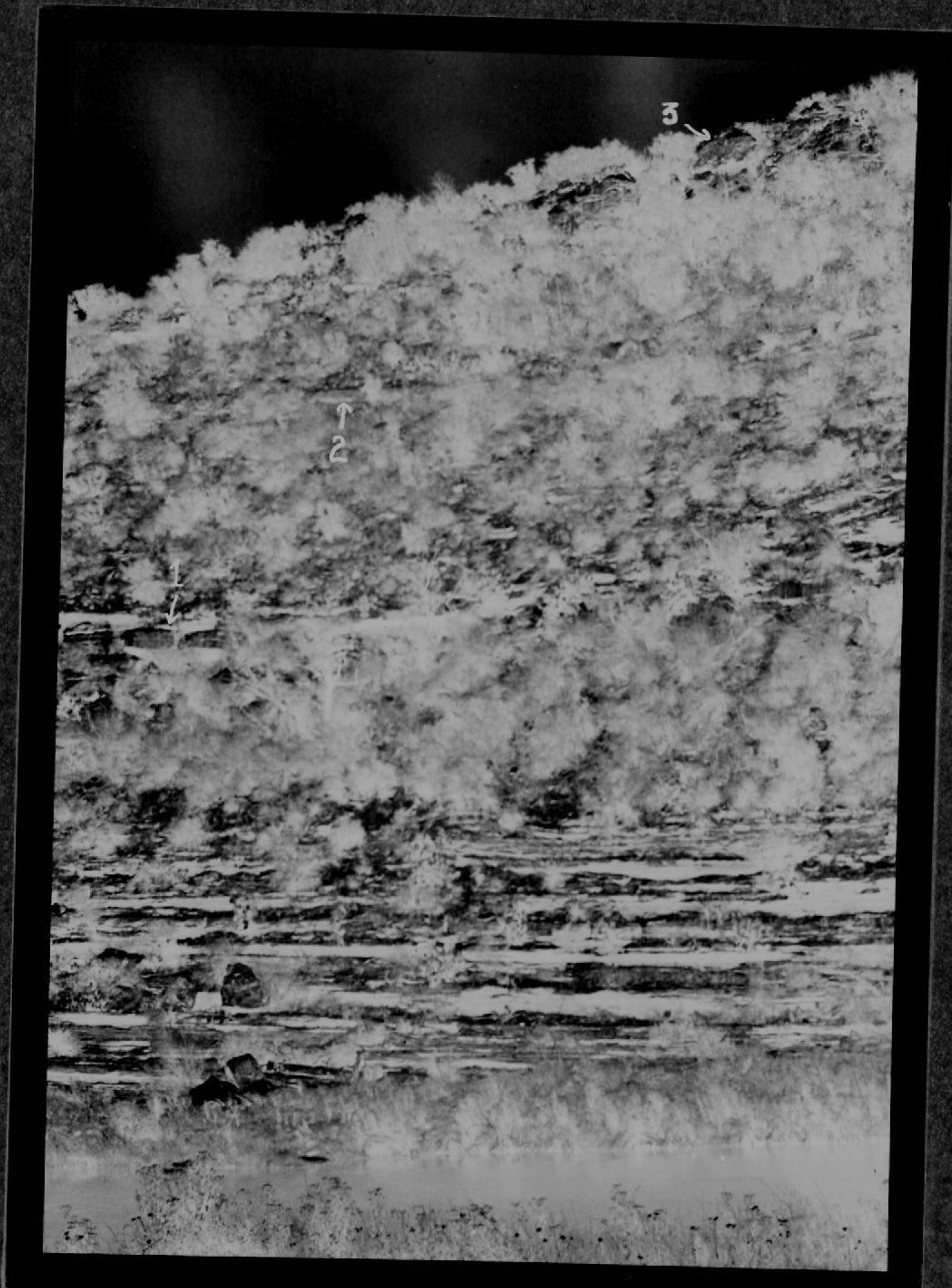
At 38.5 feet above the base of the Point Peak member, a biohermal reef zone occurs. This bioherm unit is believed to retain the same stratigraphic position throughout the thesis area and has been mapped as a unit within the Point Peak member. For purposes of identification, this unit is designated as the lower bioherm zone (Cwpl) on Plate I. The lower bioherm zone consists of gray-to-slightly purple, massive, sub-lithographic limestone.

Above the lower bioherm zone, the member persists as an alternating sequence of siltstone, limestone, and intraformational conglomerate beds. This sequence of calcareous beds, approximately 75 feet thick, is lithologically similar to those below the lower bioherm zone with the exception of several massive, brown, non-glauconitic, sub-lithographic limestone beds. These beds are traceable throughout the Loyal Valley-West area where the Point Peak shale member is exposed. Although not identified by fossils, these brown, massive, limestone beds are believed to correspond to the Plectotrophia beds mapped by Barnes (1952) in the Squaw Creek Quadrangle. The relative position of these beds to the upper and lower bioherm zones of the Point Peak member is shown on Plate XI.

Within the Loyal Valley-West area the uppermost portion of the Point Peak member is characterized by a second bioherm zone. This reef zone, about 25 feet thick, is designated as the upper bioherm zone (Cwpu) Plate I. Lithologically, the upper bioherm zone differs slightly from the lower bioherm zone. In contrast to the smooth surface expression present on the weathered blocks of the lower bioherm zone, a very irregular, rough surface expression is present on the weathered, yellow-brown, reef material of the upper bioherm zone. Some of the yellow reef material in the upper bioherm zone is dolomite. According to Peterson (1959, p. 43), the upper bioherm zone is replaced by bedded limestone about 1/4 mile west of the measured section shown on Plate I, and is not found farther west in the Beaver Creek area. East of the locality of the measured section on Beaver Creek, this reef zone is known to extend eastward.

PLATE XI

Point Peak Shale Member



Three distinct, ledge forming units in complete section of the Point Peak shale member. Notation 1: lower bioherm zone, 2: probable *Plectotrophia* beds, and 3: upper bioherm zone. See Location 10, along Beaver Creek, Plate I, western part of thesis area

Topography and vegetation:

The Point Peak shale member forms a gentle slope marked by sharp irregularities. Where the argillaceous and silt content of the member is high, the surface expression is a gentle slope. The sharp topographic irregularities present in the topographic expression of this member are due to both the upper and lower bioherm zones and the massively bedded limestone horizons. The lower bioherm zone forms a sharply defined topographic expression which consists of large boulders of reef material as shown on Plate XII. The topographic expression of the upper bioherm zone is not as sharply defined as that of the lower bioherm zone.

The vegetation on the Point Peak shale member consists of scrub oak, Mexican persimmon, mesquite, and various forms of cacti and grasses. Mexican persimmon and scrub oak are the dominant plants. Vegetation alignments are observable on aerial photographs below both the upper and lower bioherm zones within the Point Peak member. The vegetational alignment below the lower zone is more pronounced than that of the upper zone.

PLATE XII

Lower Bioherm Material of the Point Peak Member

Unusual weathering pattern present on large boulders of lower bioherm zone material of the Point Peak shale member. See Location 11, near Beaver Creek, Plate I

San Saba Limestone Member

Definition and thickness:

Comstock (1890, p. 301) initially used the term San Saba as a series classification in his description of limestone outcrops near Camp San Saba, McCullough County, Texas. Bridge (1937, p. 237) reduced the San Saba to member status. According to Bridge, Barnes, and Cloud (1947, p. 117), the San Saba limestone member is defined as including all of the Cambrian strata above the Point Peak shale member of the Wilberns formation, and below the Tanyard formation of the Ellenburger group. The type locality for this member of the Wilberns formation is at the intersection of the San Saba River and the Mason-Brady highway, north of old Camp San Saba, McCullough County, Texas.

According to Bridge, Barnes, and Cloud (1947, p. 117), the thickness of the member is 280 feet at the type locality. The average thickness of the member is 270 feet. Approximately seven miles southwest of the thesis area in Squaw Creek and Threadgill Creek, thicknesses of 281 and 259 feet have been measured. The member was not measured in the Loyal Valley-West area because of poor exposures. The estimated thickness of the member in the Loyal Valley-West area is 270 feet.

Lithology and stratigraphic relationship:

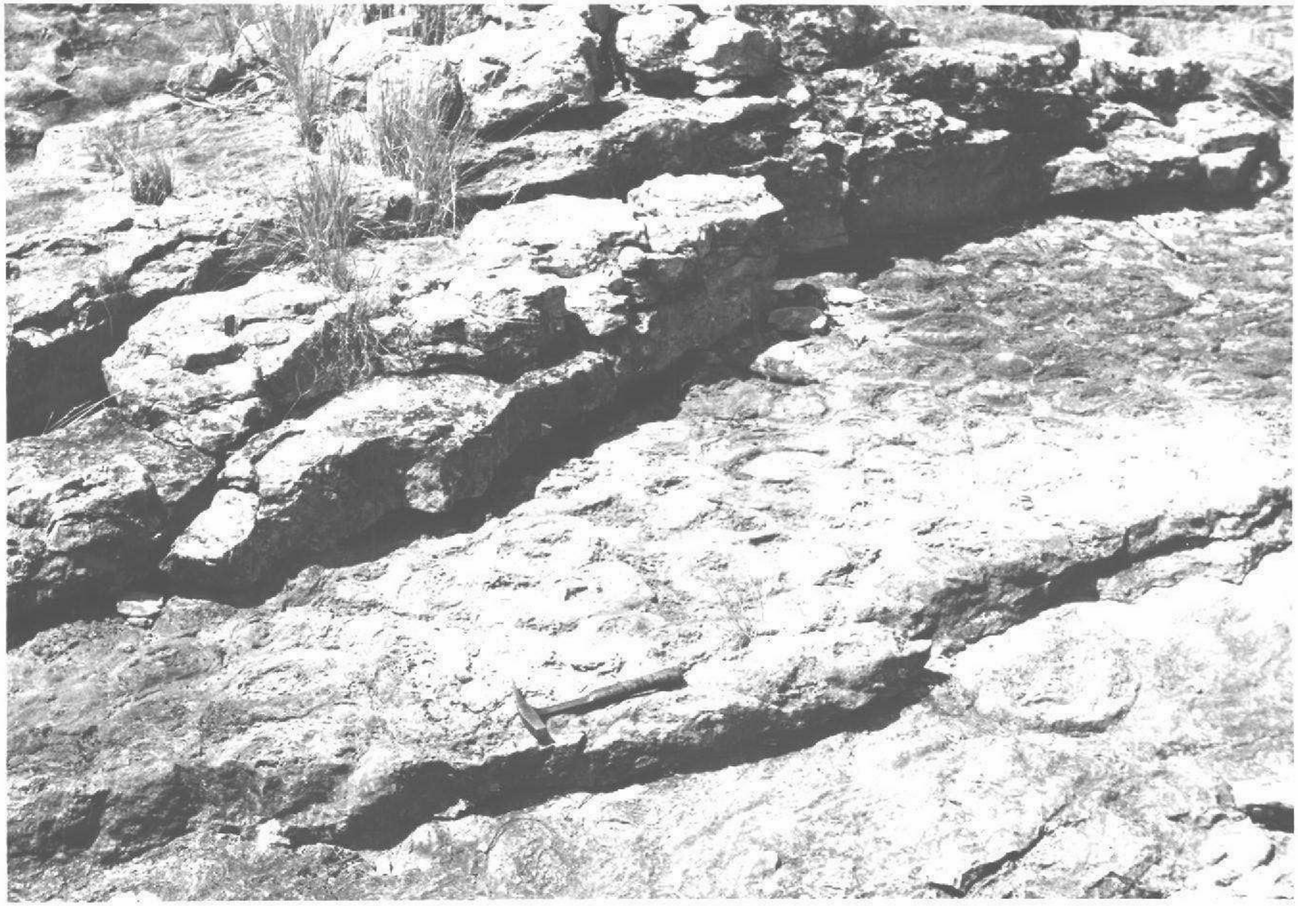
In areas where the upper bioherm zone of the Point Peak shale member is recognized, the contact between the Point Peak shale member and the San Saba limestone member is placed immediately above this bioherm zone. In areas where the upper bioherm zone of the Point Peak shale member is absent or non-discernible, the contact was placed where the last significant greenish-gray siltstone beds of the Point Peak shale member are overlain by gray to yellowish-brown limestone beds of the San Saba member.

The lower portion of the San Saba limestone member is composed of gray to yellowish-brown, argillaceous, flaggy to massively bedded, glauconitic, fossiliferous limestones. Bioherms are not found in the lower 60 to 70 feet of the member. The sparsely glauconitic limestones of this 60 to 70 foot section have an abundance of marks that may be fossil trails and borings. The fossil Girvanella is abundant in this sequence of strata. These marble-sized masses of probable algal origin are reported by Bridge, Barnes, and Cloud (1947, p. 120) as also present in the Cap Mountain and Point Peak members.

Above this 60 to 70 foot sequence of bedded limestones, a biohermal reef zone is present. This reef zone is believed to be continuous throughout the thesis area and was mapped separately as the San Saba bioherm zone (CWss). The thickness of this tan to yellowish-brown sub-lithographic reef mass is not constant, varying from 10 to 35 feet in thickness. The vertical surface expression of the bioherm zone on weathered surfaces is noticeably less cliff-like than that of either of the two bioherm zones mapped in the Point Peak member. A "cabbage-head" expression, as shown on Plate XIII, is generally present on the reef material of the San Saba bioherm zone in the Loyal Valley-West area. Patches of the reef material are

PLATE XIII

Small Bioherms as Developed in the San Saba Limestone Member



"Cabbage-head" development of small bioherms that constitute an integral part of the bioherm zone present in the San Saba limestone member. See Location 12 in southwest portion of Plate I dolomitized. The dolomitized patches of the reef material are generally characterized by a yellow color in contrast to the overall tan to brown color of the unit.

The upper part of the San Saba member is predominantly bedded limestone interspersed with bioherms that are very limited in their lateral development. The coarsely crystalline limestone beds vary in thickness from 4 inches to a maximum of 2 feet. The upper part of this member is also marked by very glauconitic bedded limestones. These greenish-gray beds are limited to a short vertical range above the bioherm zone. Above the glauconitic beds, the limestones are gray to tan, slightly glauconitic to non-glauconitic, and the beds vary in thickness from 2 inches to 8 inches. Some of these beds are dolomitized and are yellow. The lateral extent of the dolomitization of individual beds was not determined although it appears to be discontinuous. Several buff to pink calcareous sandstone beds occur within this sequence of slightly glauconitic to non-glauconitic limestone beds. The coiled gastropod, Ophileta, is found within the thinly bedded limestones of the uppermost part of this member. An unnamed, small, tightly coiled gastropod is also present in the upper part of the member.

Topography and vegetation:

No particular topographic pattern is expressed by this member within the thesis area. The relative elevation of this member is as high as any of the other Paleozoic limestone units found within the thesis area. The bioherm zone within the member does not form a distinctive topographic feature as that which is developed on the bioherm zones of the Point Peak shale member.

With the exception of the dense vegetation near the outcrops of the reef structure, sparse vegetational covering is generally representative of the member. Plants include Mexican persimmon, Spanish dagger, prickly pear, scrub oak, and mesquite.

ORDOVICIAN SYSTEM

The Ordovician system is represented in the Loyal Valley-West area by rocks of the Ellenburger group of Early Ordovician age.

Ellenburger Group

Definition and thickness:

The term "Ellenburger limestone" was first used by Paige (1911, p. 24) in his description of the limestone outcrops that form the Ellenburger Hills in southeastern San Saba County, Texas. Cloud, Barnes, and Bridge (1945, p. 139) revised the nomenclature, elevated the Ellenburger formation to group status, and divided the group into formations. In ascending order, these divisions are the Tanyard, Gorman, and Honeycutt formations. The Ellenburger group is treated here as the lowest unit of Ordovician age, although Barnes and Bell (1954, p. 25), indicate the possibility that the Cambrian-Ordovician boundary may be located lower than the base of the Ellenburger group and within the San Saba member of the Wilberns formation. According to Barnes and Bell (1954, p. 35), the average thickness of the Ellenburger group in the Llano region is 1694 feet.

The Ellenburger group is not differentiated into formations in the Loyal Valley-West area. It is very probable that the Ellenburger exposures found in the thesis area represent the lowest portion of the group, the Tanyard formation, as the contact with the underlying San Saba limestone member appears conformable. If the contact is conformable in the Loyal Valley-West area, the exposures in the area belong to the Threadgill member of the Tanyard formation. Southwest of the area, in the Squaw Creek quadrangle of Gillespie County, the Threadgill member is 280 feet thick and lies conformably on the San Saba limestone member of the Wilberns formation. The exact thickness of the Ellenburger group exposed in the thesis area was not determined due to poor exposure and faulting. However, it is not believed to be in excess of 200 feet.

Lithology and stratigraphic relationship:

The contact of the Ellenburger group with the underlying San Saba limestone member was placed at the base of the bed containing first specimens of the gastropod, *Lytospira gyrocera*. This open form gastropod is believed to occur initially in the most basal Ellenburger group and is not found in older sediments. The lack or scarcity of glauconite is also used as a criteria in locating the contact between the glauconitic San Saba member and the non-glauconitic Ellenburger group.

The exact location of the contact between these two units is difficult to determine in the thesis area due to poor exposures and the presence of numerous small faults. The existing differences between the contact placed by the author (Plate I) and that placed by Woolsey

(1958, Plate I) in the overlap area are essentially differences of opinion and individual interpretation of the available field data.

The lower part of the Ellenburger group is composed of gray to white sub-lithographic limestone beds that generally vary in thickness from 2 inches to 18 inches. These non-glauconitic beds are characterized by the abundance of the gastropod fossils, Ophileta and Lytospira gyrocera.

Above this lower portion, the limestones are medium-to-thick bedded, with the beds varying in thickness from 6 to 36 inches. These micro-granular limestone beds are noticeably darker in color than the gray-to-white sublithographic beds in the lower portion. The weathered surfaces of some of the individual, thicker beds, are very similar to the weathered surfaces of the bioherm deposits found in the Cambrian deposits in the area. The etched and very irregular markings on the large weathered blocks are suggestive of "worm-trails" or "borings" but are probably only manifestations of differential weathering.

Topography and vegetation:

The outcrop of the Ellenburger group is characterized by a hilly and rolling topography with only moderate relief. Large, irregular blocks of the micro-granular limestone deposits are scattered over the outcrop areas of the Ellenburger group as shown on Plate XIV.

Vegetation is meager in relation to that found on the outcrops of the other stratigraphic units in the area of investigation. Prickly pear is found in abundance with lesser amounts of scrub oak, Spanish persimmon, and turkey pear also present on the outcrop.

PLATE XIV

Surface Expression of the Ellenburger Limestone Group

Typical, very irregular surface expression of the Ellenburger limestone group. See Location 13 in the south central portion of Plate I

MESOZOIC ERA

CRETACEOUS SYSTEM

Deposits of Lower Cretaceous age (Comanchean Series) surround the Llano region with the exception of the northern flank of the uplift area. These Cretaceous deposits rest unconformably on the older rock units of the region and dip gently to the southeast.

The Cretaceous units relevant to the thesis area are classified by Barnes (1948, p. 5) as follows:

Lower Cretaceous

- Shingle Hills formation (new)
  - Glen Rose limestone member
  - Hensell sand member
- Travis Peak formation (restricted)
  - Cow Creek limestone member
  - Sycamore sand member

This order of classification was deemed necessary by Barnes (1948, p. 8) who stated that the Hensell sand was a clastic shoreward facies of the Glen Rose limestone in the general area of northern Gillespie County. Barnes (1948, p. 8) thus proposed that the Hensell sand be removed from the Travis Peak formation and placed in a new formation, the Shingle Hills formation, composed of the Hensell sand and Glen Rose limestone members.

In the Loyal Valley-West area, the Cretaceous deposits are represented by only a thin veneer of conglomeratic sandstone which varies in thickness from a feather edge to an estimated five feet.

Included in this unindurated sandstone unit are pebble and cobble-sized particles of quartz and arkose conglomerate. This unindurated to loosely indurated deposit is mapped as the Cretaceous sandstone unit.

Cretaceous Sandstone Unit

Definition and thickness:

The Cretaceous sandstone unit, varying in thickness from a feather edge to approximately five feet, is probably equivalent to the Hensell sand member. This correlation is gained from the reported presence by Cloud and Barnes (1948, p. 189), of the Hensell sand member in the Lange's Mill vicinity which is about 7 miles southwest of the thesis area. Cloud and Barnes (1948, p. 189) further stated that the Hensell sand member is the oldest Cretaceous unit present in the Lange's Mill vicinity. The basal conglomerate beds of the Hensell sand member, the Lange's Mill conglomerate, are not present in the Loyal Valley-West area as they are in the Lange's Mill vicinity.

Unindurated to loosely indurated Lower Cretaceous deposits similar to those in this area have been reported in nearby areas. Coughran (1959, p. 52) reported a sequence of unindurated to loosely indurated Lower Cretaceous sandstone resting on Paleozoic outcrops. He also stated that soil derived from this sandstone unit rests upon the Lange's Mill conglomerate of Early Cretaceous age. Harwood (1959, p. 42) reported an alluvium plain of rust-red sand at the base of the Cretaceous plateau in the Salt Creek area, Mason County, Texas.

Woolsey (1958, Plate I) recognized arkosic conglomerate particles in a loosely indurated deposit completely surrounding the Cretaceous deposits in the Squaw Creek-Marshall Creek Area, Mason County, Texas. Woolsey classified this unindurated to loosely indurated deposit as Recent alluvium that was derived from the adjacent Cretaceous units.

The possibility exists that the deposit mapped as the Cretaceous sandstone unit is a soil or Recent alluvium derived from Cretaceous deposits. Due to poor exposures, this possibility could not be determined.

Lithology and stratigraphic relationship:

The Cretaceous sandstone unit rests unconformably upon Paleozoic rocks. The outcrop pattern, about one-quarter mile in diameter, is limited to the top of a hill composed of Morgan Creek limestone and San Saba limestone. This hill, although considerably higher than nearby valleys, is not the highest area in the Loyal Valley-West area.

The Cretaceous sandstone unit is an unindurated to loosely indurated dark red to rust conglomeratic sandstone. Pebble and cobble-sized particles of quartz and arkose conglomerate are randomly scattered throughout the unit with no bedding plan apparent, as shown on Plate XV.

The arkose conglomerate particles are lithologically the same as those described by Rogers (1955), Woolsey (1958), and Mangum (1960). Sand and pebble-sized, sub-rounded, milky-to-clear quartz particles, varying in size from one to four millimeters, are less

PLATE XV

Cretaceous Sandstone Unit

Arkosic conglomerate and quartz particles in unindurated and weathered Cretaceous sandstone unit. Pencil and pen point to arkosic conglomerate particles. See Location 15 in central portion of Plate I abundant than the feldspar particles. The cementation of the conglomerate appears to be a combination of silica and ferruginous material. The glossy, black appearance of the conglomerate is attributed to the ferruginous cement.

Topography and vegetation:

The thin veneer of Cretaceous sediments cap a hill of Morgan Creek limestone and San Saba limestone. This hill has only moderate relief.

The vegetation on the thin veneer of Cretaceous sediments is similar to that present on outcrops of the Morgan Creek limestone and San Saba limestone members. Scrub oak and Mexican persimmon are the dominant trees. Native grasses are generally common on the outcrop except in isolated areas, as shown on Plate XVI, where accumulations of quartz particles cover the soil development of the member.

PLATE XVI

Weathered Surface of Cretaceous Sandstone Unit

Weathered surface of Cretaceous sandstone unit typified by abundance of quartz particles and general absence of arkosic conglomerate particles. See Location 14 in central portion of Plate I

CENOZOIC ERA

TERTIARY AND QUATERNARY SYSTEMS

The Cenozoic era is represented in the Loyal Valley-West area by deposits of alluvium, conglomerates, and caliche.

The alluvial deposits occur only in the small stream beds. With the exception of the alluvium found in Beaver Creek, the areal extent of these deposits does not warrant a demarcation and representation on Plate I. The alluvium is composed of abraded material from the stratigraphic units exposed in the individual stream courses and drainage areas. The color of the alluvium varies from a light buff to dark gray. Sand sized particles predominate with lesser amounts of silt and pebble-sized particles.

The coarse conglomeratic deposits occur both in the stream beds and nearby adjacent areas. The conglomerate is composed of sand-to-boulder-sized particles derived from the Paleozoic and older beds that are exposed in the stream's drainage area. The cementation of the conglomerate deposits is by a caliche-like to calcareous tufa-like material.

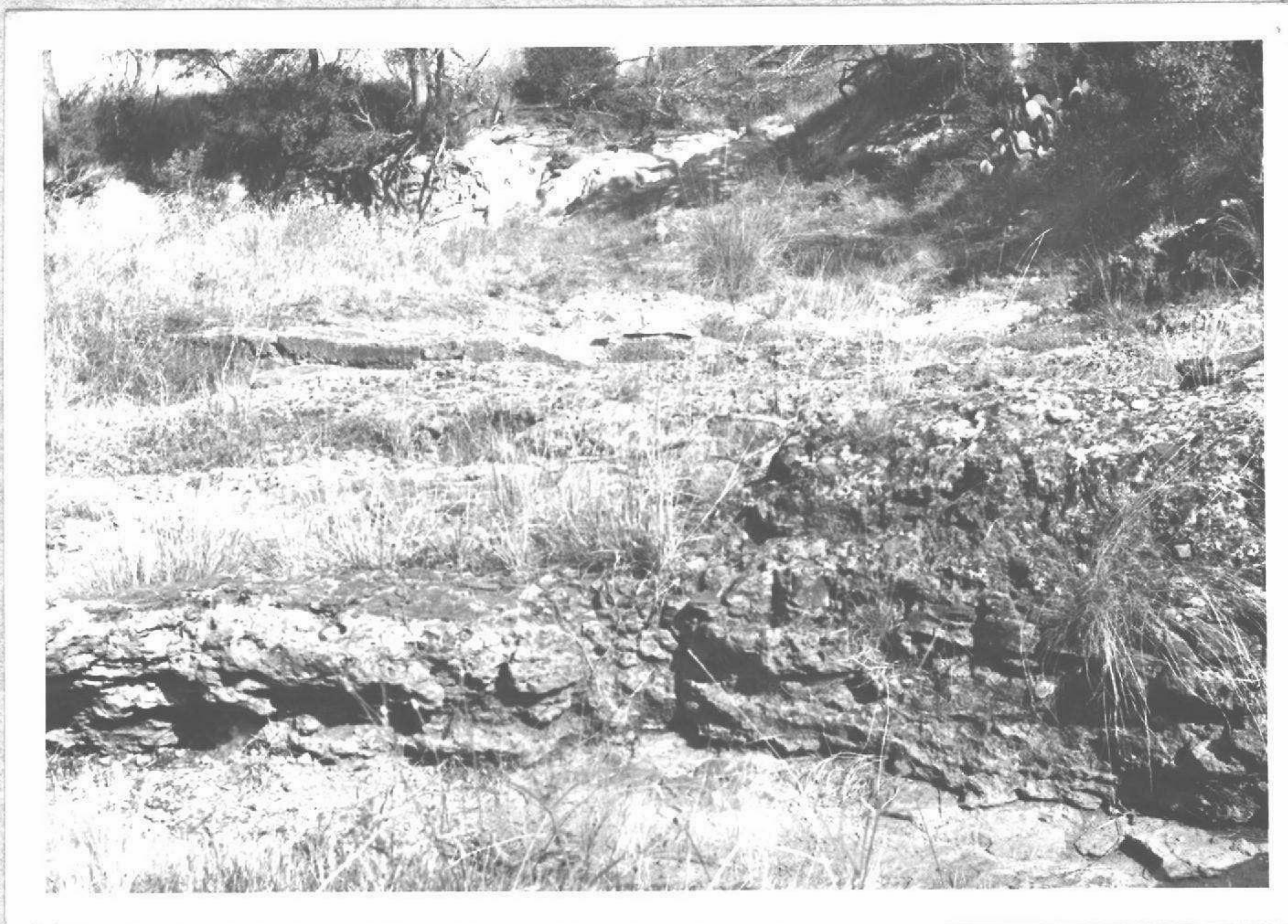
At location 16, Plate I, conglomeratic deposits are found at a level 5 to 10 feet higher than the present stream bed. These deposits are 50 to 500 feet north of the stream bed and indicate that the stream formerly existed at the old location and level, or that the stream formerly had a flood plain that extended to this position and level.

An indication of the age of the stream conglomerate deposits may be gained from the conglomerate deposit found at location 17, Plate I. This conglomerate deposit is found within the stream bed proper and apparently was deposited against and around a man-made concrete structure as shown on Plate XVII. The age of this structure has been estimated at less than 50 years old by residents of the area. This indicates that gravel and boulders may be indurated to conglomerates by calcareous cementation in a short time. Evidence was not found that would give an indication of the age of the deposits found away from the stream beds. However, it is assumed that they are Recent in age.

Caliche deposits of two types are found within the thesis area. At location 18, Plate I, caliche deposits, probably formed by capillary action of the ground water in the exposed Cap Mountain limestone member and the underlying Hickory sandstone member, are in excess of 5 feet thick. This area is marked by a series of small faults and it is believed that the faults aided the circulation and availability of the ground water and enhanced the capillary action in this area. At location 8, Plate I, caliche deposits are found that represent weathering of the Morgan Creek limestone member. The topographic and drainage conditions present at this location allow for the calcareous material to weather and remain in place. This weathered material is very similar to the other material classified as caliche in the thesis area and similar conditions for its formation are assumed.

PLATE XVII

Recent Conglomerate



Recent conglomerate embracing concrete structure. Concrete structure indicated by hat. See Location 17, ~~east~~ west of U. S. Highway 87, Plate I

STRUCTURAL GEOLOGY

GENERAL STATEMENT

The Loyal Valley-West area is located on the south flank of the structurally domed area now commonly referred to as the Llano uplift. The rocks of the Llano uplift area have undergone two major deformations. Distinctive features of the first deformation that affected only the Precambrian rocks include intense metamorphism, folding, faulting, and igneous intrusions. The second deformation of the area occurred during Pennsylvanian time. The major characteristic of this deformation was normal faulting. Evidence of both disturbances are present in the Loyal Valley-West area where outcrops of Precambrian, Paleozoic, Mesozoic, and Cenozoic rocks are present.

Although only limited areas of Precambrian outcrops are present in the Loyal Valley-West area, effects of the Precambrian deformation are evident. The association of the metamorphic rocks with the granitic igneous intrusions indicates that the exposed rocks were probably deeply buried when this deformation occurred.

The Paleozoic strata exposed in the Loyal Valley-West area have a general southeasterly dip of about 5 degrees. Numerous normal faults cut the Paleozoic and older deposits. A small synclinal structure is present in the Loyal Valley-West area and its importance and significance are discussed in the section on folding.

FOLDING

Description of Folding

A small syncline is present in the northeast portion of the Loyal Valley-West area. More specifically, this structure is located on the J. Keyser property (Plate I). The syncline is partially bounded on its south, east, and western borders by normal faults. The dips taken from readings on the immediate flanks of this small structure vary from one to eight degrees with the largest dip readings west of the intersection of the Squaw Creek and Loyal Valley faults.

Origin of Folding

Although folding, independent of faulting, has been reported present in the Llano region, it is possible that the small synclinal structure in the thesis area owes its existence to drag originating from the normal faults that surround it on three sides.

Evidence that the folding is due to drag movement of normal faults is supported by dip readings obtained near the most eastern edge of the synclinal structure which is just west of the northerly trending Loyal Valley fault. Here the Cap Mountain member, present on the downthrown side of the Loyal Valley fault, strikes almost north-south and dips in a westerly direction. Near the fault trace, dip readings of approximately 8 degrees are obtained from the Cap Mountain limestone member. Approximately 300 feet west of the fault trace, dip readings of approximately 4 degrees west are obtained in the same member. Such a condition of decreasing dip away from the fault trace would be expected if the attitude of the strata was influenced by drag due to fault movement.

The dips of the strata on the southwestern edge of the synclinal structure are in the opposite direction of the regional dip. This anomalous condition is attributed to the Squaw Creek fault as the reversal in dip is not present west of the small, north-easterly aligned fault that branches off of the Squaw Creek fault.

Further evidence that the syncline is due to folding caused by fault movement are the strike and dip readings of the Cap Mountain member about 1000 feet north-east of the synclinal area. This area is east of the Loyal Valley fault and the westerly dipping outcrops of the Cap Mountain member previously described. In this area the strike of the Cap Mountain member is northeast and the dip is to the southeast and conforms to the regional dip and strike of Paleozoic strata in the Llano region. Such a deviation from a regional southeasterly dip to a westerly dip in a short distance could possibly be best explained by attributing the westerly dip to drag caused by the Loyal Valley fault.

FAULTING

Detection of Faulting

The detection and tracing of the fault patterns within the Loyal Valley-West area were accomplished by study of aerial photographs and field observations.

Some of the fault traces are indicated on aerial photographs by vegetational lineations and changes of vegetational patterns. Abrupt topographic changes, observable on the aerial photographs with the aid of a stereoscope, also served as an aid in the determination of the presence of faults.

Field inspections confirmed or discredited the observations gained from studies of the aerial photographs. Sandstone dikes, anomalous strike and dip of strata, brecciated zones, and repetition, omission, offset, and termination of mappable units were all used as guides in the field identification of the faults.

Inferred faults, where fault traces are not observable on the surface but outcrop conditions indicate or require the presence of a fault, are shown on Plate I by a dashed line. Where the direction of movement of known faults was not determinable by field inspection, the faults are recorded on Plate I but the relative vertical movement of the fault is omitted.

Description of Faulting

Numerous faults are present in the Loyal Valley-West area. The faults are divided into major and minor faults for purposes of discussion with the division being based on the magnitude of displacement. The faults are grouped within loosely defined zones which are generally composed of a major fault and a series of minor faults closely associated in character with the major fault. The downthrown sides of the faults are commonly to the northwest, although there are some faults in the western portion of the study area having the downthrown side to the southeast. The strike of the faults vary in their alignment from 30 degrees west of north to 60 degrees east of north.

The most prominent fault in the area is the Loyal Valley fault, named by Woolsey (1958) in his discussion of the area immediately south of the Loyal Valley-West area. The maximum throw of the Loyal Valley fault, south of the Loyal Valley-West area (Woolsey, 1958), is about 1200 feet where Ellenburger strata have been displaced against the strata of the Hickory sandstone member. The downthrown side of this fault is on the west side. The largest displacement of this fault in the Loyal Valley-West area is about 350 feet where the Cap Mountain limestone member has been displaced against Precambrian rocks. The Loyal Valley fault strikes in a northerly direction for about 2 miles along the eastern edge of the area. The strike of the fault shifts from a northerly direction to approximately 30 degrees west of north after its intersection with the Squaw Creek fault. The throw of the fault decreases north of its intersection with the Squaw Creek fault. At the most northern limits of the Loyal Valley-West area, the fault is contained within the Hickory sandstone member.

The second major fault in the thesis area is the Squaw Creek fault which crosses the southeastern portion of the study area. This fault was also named by Woolsey (1958). Southwest of the thesis area, this fault has been mapped for a distance of approximately 10 miles through the Squaw Creek-Marshall Creek area by Woolsey (1958), the Beaver Creek area by Peterson (1959), and the Doss North area by Coughran (1959). East of the thesis area, this fault is believed to be the one mapped by Paige (1912) which extends northeasterly for approximately five miles in Llano County before its surface trace disappears in the Precambrian complex. The greatest displacement of this fault in the thesis area is in the southern portion where the throw is estimated to be somewhat greater than 500 feet. Immediately west of the intersection of the Squaw Creek and Loyal Valley fault, the Squaw Creek fault is contained within the Cap Mountain limestone member and the vertical displacement is probably less than 300 feet. East of the intersection of the Squaw Creek and Loyal Valley faults and at the most eastern border of the thesis area, the throw is possibly greater than 300 feet as the basal portion of the Cap Mountain limestone member has been displaced against Precambrian rocks.

Many minor faults are found within a wide band in the western portion of the thesis area. Their strike and location indicate that they are possible fault splinters of the Squaw Creek and Law Creek faults. The Law Creek fault, named by Peterson (1959), is located west of the thesis area. The throw of these minor faults is estimated to be less than 50 feet and with four exceptions, all of the minor faults are downthrown to the northwest.

The presence of small faults within the Cap Mountain limestone member has been indicated on Plate I. Whereas the possibility does exist that these fractures observable within this stratigraphic unit are joints rather than faults, anomalous dips at or near the surface of these fractures suggest that these fractures are normal faults. Due to the absence of key beds within the Cap Mountain limestone member in which these fractures occur, the relative movements and magnitude of vertical displacements were not determinable for these fractures.

Age of Faulting

In the Loyal Valley-West area, the Ellenburger group is the youngest Paleozoic unit exposed. Unfaulted Cretaceous deposits rest on the eroded surface of the faulted Paleozoic rocks. Therefore, information gained from the thesis area alone would indicate that the faulting was post-Ellenburger and pre-Cretaceous in time. Data gained from regional studies of the Llano uplift area by Cloud and Barnes (1948, p. 121) indicate that the faulting occurred during Strawn or post-Strawn time and prior to Canyon time.

Origin of Faulting

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

Paige (1912, p. 74) stated that the existence of the faults in the Llano region could be attributed to the subsidence of the southerly existing floor in the region of the Gulf of Mexico whereby the subsequent compressive stresses produced vertical movement. This linkage with the southerly existing geosynclinal area is similarly treated by Cloud and Barnes (1948, p. 118) in their explanation that the faulting was due to tectonic activity south and east of the Llano area.

The possibility that the deformation of the Llano area is associated with the Concho arch has been cited by Cheney and Goss (1952, p. 105) who stated:

> "the Llano uplift is the uptilted southeast part of a very extensive structural axis, the Concho arch. This arch extended northwest to the present Texas Panhandle region but it has lost prominence as a result of the subsidence beneath the Permian basin."

Ammer (1959) stated that the stress patterns which produced the structural deformation of the Llano area could possibly be determined from the orientation and dip angles of the normal faults. He observed that the structural deformation of the Llano region, in relation to the Mohr-Coulomb theory of fracture (Fig. II, p. 75) was not compatible for a vertically oriented major principal stress as the general dips of many of the faults are too high.

It is the author's opinion that the structure present in the Llano region can be related to the forces that produced the late Paleozoic folding and thrust faulting of the Llanoria geosyncline. An argument supporting this contention is presented by the use of a hypothetical geosynclinal area that subsequently undergoes isostatic adjustment after deposition (Fig. III, p. 76).

The Mohr-Coulomb theory of fracture, as outlined by Terzaghi (1943), and by Anderson (1951), is used to interpret the stress conditions that produced the shear patterns of the Llano region and Llanoria geosyncline. These stress conditions are then compared with those postulated for the hypothetical geosynclinal area.

An assumption is made that the hypothetical geosynclinal area and the adjoining part of the craton were isostatically compensated prior to deposition. For purposes of simplicity, the area occupied by the geosynclinal and adjoining part of the craton is considered as an elongate body and the total area is treated as a system in itself. For purposes of discussion, it is assumed that the forces acting per unit area can be resolved into three stresses with an orientation such that one horizontally directed stress is parallel to the axis of the geosyncline (P_x in Fig. IIIa), one horizontally directed stress is perpendicular to the axis of the geosyncline (P_y in Fig. IIIa), and one stress is directed vertically to the area (P_z in Fig. IIIa).

New gravimetric values different from those present during the state of gravitational equilibrium will be created with deposition in the geosynclinal area. This results from an excess of mass now present in the geosynclinal area. It follows that the magnitude of the differences in stress conditions from those existing prior to deposition are now related to the shape of the previously defined elongate depositional area. At any point in the area under consideration, the selected horizontally directed stress (P_x in Fig. IIIb) parallel to the axis of the geosyncline would exhibit the least difference from the stress having the same orientation prior to deposition (P_x in Fig. IIIa). Also, the previously selected horizontally directed stress (P_y in Fig. IIIb), perpendicular to the axis of the geosyncline and the vertically directed stress (P_z in Fig. IIIb), would exhibit greater stress differences from the stresses having the same orientation prior to deposition (P_z and P_y in Fig. IIIa). These conditions are postulated due to the elongate shape of the mass under consideration.

If the area under discussion is to adjust to its original state of equilibrium, a transference of mass out of the geosynclinal area and a transference of mass into the now mass-deficient continental area must occur. This transference of mass is limited to the continental and geosynclinal area if the state of equilibrium of adjacent areas are to be maintained.

A net transference of mass to reduce the anomalous stress conditions present in both the continental and geosynclinal area may be accomplished by either faulting with a horizontal component of movement or "flowage" of the material. The properties of the material at the place of transference necessarily prescribe the type of movement. Benioff (1950, p. 1839) plotted focal points of earthquakes to depths of 700 kilometers and it is probable that faulting does occur at this depth. Also indicative that faulting possibly predominates over flowage at depth is gained from the observation of Bullen (1953, p. 245) on the fracture strength of material who stated:

> "------- the strength of the material of the earth at a depth of 600 to 700 kilometers is, in certain regions at least, not significantly less than the maximum strength existing in the crustal layers."

For purposes of discussion and a comparison with the tectonic characteristics most commonly available to investigators, it is assumed that faulting with possible preceding plastic flow is the dominant mechanism of mass transference.

If both normal and thrust faulting are mechanisms of mass transference, and if each serves to reduce anomalous stress conditions (as postulated for the hypothetical geosynclinal area), the faults should parallel the length of the depositional area. This relationship, interpreted by the Mohr-Coulomb theory of fracture

(Fig. II), would be due to the minimum change in the horizontally directed stress parallel to the axis of the geosyncline (P_x in Fig. IIIb). The orientation of the fracture planes of the faults, free to vary from horizontal to the vertical, would be dependent on the horizontally directed stress perpendicular to the axis of the geosyncline (P_y in Fig. IIIb), and the vertically directed stress of the area (P_z in Fig. IIIb) as these stresses, i.e., P_y and P_z in Fig. IIIb, exhibit maximum differences from those existing prior to deposition.

In an attempt to explain the causative forces that produced the deformation of the Llanoria geosyncline and the Llano region, an analogy is made between the stress conditions of the deformed areas and the stress conditions postulated for the hypothetical geosynclinal area. This analogy shows that the stress conditions, as interpreted from the orientation and dip angles of the fracture patterns of the deformed areas, are compatible with those postulated for an area with an excess of mass such as the hypothetical geosynclinal area.

According to Flawn (1959, p. 22), the strikes of the thrust faults in the Llanoria geosyncline parallel the length of the elongate depositional area. For a development of this shear pattern, the major stress was approximately horizontal and directed perpendicular to the elongate area; the intermediate stress was horizontal and directed parallel to the elongate area, and the minor stress was approximately vertical (Fig. IIa).

In the Llano region, the strikes of the normal faults are commonly aligned in the northeast and southwest quadrants. The dip angles of the faults most commonly reported are generally within 30 degrees of the vertical. The faults most commonly have downthrown sides to the northwest. For a development of this shear pattern, the intermediate stress was essentially horizontal and parallel to the strike of the faults, the minor stress was essentially horizontal and perpendicular to the faults, and the major stress was within 30 degrees or so of the vertical (Fig. IIb).

The above listed stress conditions of the Llano area and the Llanoria geosynclinal area would be expected if the stress conditions that caused the fracture patterns were due to an excess of mass in the geosynclinal area. The relief of these stresses by transference of mass out of the geosynclinal area should necessarily prescribe that all faults exhibit a horizontal component of movement. This horizontal component of movement is best exhibited by the thrust faults of the Llanoria geosyncline.

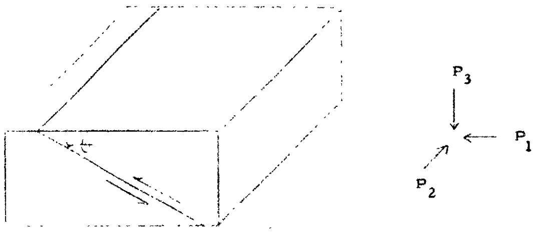
The apparent transference of mass away from the geosynclinal area by the normal faults of the Llano region is not indicated by data available to investigators. However, if the faults of the Llano region have a southeast dip at some depth, rather than a vertical or northwest dip, the faults would be capable of transferring mass out of the geosynclinal area. This type of curving fault plane, in some places a curvature to the vertical and then past the vertical, is probable if the faults of the Llano area relieved stresses caused by an excess of mass in the geosynclinal area. No data are available that indicate that the normal faults of the Llano area have this type of curving fault plane.

The doming of the Llano area may possibly be explained if it is assumed that the direction of the intermediate stresses, as expressed by the strikes of the normal faults. are dependent on the elongate shape of the geosynclinal area. Normal faulting, with the fault strikes parallel to and existing in a band away from the geosynclinal area, would produce only uplift. However, an intersection of normal faults, such as in the Llano region where the strike of the faults often varies 45 degrees from the most common northeast strike, would produce greater uplift in the area of intersection and a doming effect.

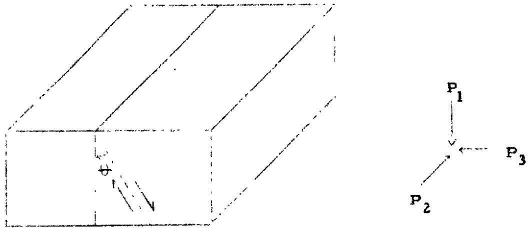
Lending credence to the above possible explanation of the doming of the Llano area is the northerly trending Llanoria geosynclinal area east of the Llano region and the easterly directed continuation of the Llanoria geosynclinal area south of the Llano region.

The hypothesis that the tectonics of the Llano area are due to the excess of mass in the Llanoria geosynclinal area is perhaps justified if the assumption is correct that an excess of mass in an isostatically compensated area causes anomalous stresses. Necessarily. the orientation and magnitude of these stresses are related to the shape and magnitude of the excess mass. If faulting is a method of relieving such stresses it is the author's opinion that the tectonics of the Llano area reflect the compensation necessitated by the excess mass in the Llanoria geosynclinal area.

Figure II



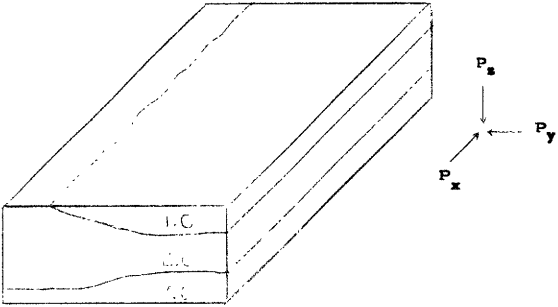
a. Thrust Fault



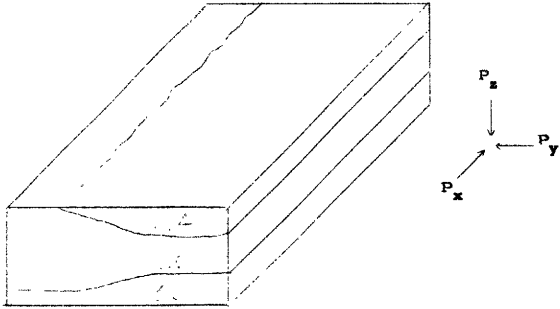
b. Normal Fault

Principal stresses relative to deformation where P_1 greater than P_2 and P_2 greater than P_3. According to Mohr-Coulomb theory of fracture, angle θ represents deviation from direction of P_1 and due to internal friction of material.

Figure III



a. Geosynclinal Area Prior To Deposition



b. Geosynclinal Area After Deposition

Geometry of geosynclinal area under consideration. General densities of material given and P_x, P_y, and P_z represent effective stresses of the geosynclinal area.

SUMMARY OF GEOLOGIC HISTORY OF THE LLANO REGION

PRECAMBRIAN ERA

As in other areas of the Llano region, the Precambrian outcrops present in the Loyal Valley-West area represent a varied and complex history as evidenced by their nature and stratigraphic relationships. Both metamorphic and igneous Precambrian rocks are exposed in the area. According to Sellards (1932, p. 32), the metamorphic rocks are alteration products of both sedimentary and igneous units and the granite and associated igneous rocks are intrusive in nature.

The coarse grain size of the granite indicates that the solidification of the igneous rocks occurred at depth. The sharp contacts, where the igneous rocks cut the metamorphic rocks, indicate that the igneous rocks are intrusive.

Gradational contacts between igneous and metamorphic rocks are also present in the Loyal Valley-West area. The gradational relationship between igneous and metamorphic is generally explained as a result of injection of magma, magmatic soaking or differential fusion. Any of the above conditions could conceivably cause the gradational contacts between the igneous and metamorphic units.

PALEOZOIC ERA

CAMBRIAN SYSTEM

An erosional surface of considerable local relief was developed on the Precambrian complex of the Llano region prior to the deposition of the first known Cambrian sediments. According to Bridge, Barnes, and Cloud (1947, p. 113), topographic highs of several hundred feet elevation are known to have existed on the erosional surface invaded by the first Paleozoic sea. This irregular erosional surface is evidenced by isolated occurrences of the Cap Mountain limestone member resting unconformably on eroded Precambrian rocks. A normal thickness of the Hickory sandstone member is present in the Loyal Valley-West area which indicates that the erosion surface is relatively smooth.

The Hickory sandstone member is the oldest Cambrian deposit in the Llano region. In the northwest part of the Loyal Valley-West area, a relatively well exposed contact between the Precambrian erosion surface and the Hickory sandstone member is present (location 2, Plate I). The lower-most beds of this sandstone member are conglomeratic, containing pebbles of quartz varying in diameter from 1/4 to $1^1/2$ inches. These pebbles (Plate III, p. 22), incorporated in a matrix of predominantly sand-sized quartz particles, are sub-rounded to sub-angular in shape. The surfaces of the pebbles appear to be frosted and pitted, suggesting a possible eolian origin for the pebbles with subsequent marine deposition.

The Hickory sandstone member exposed in the Loyal Valley-West area is similar to the regional description of the member reported by Goolsby (1957). The initial sediments within the member indicate a transgressive sea and a source area that is relatively close, or topographically high, in relation to the depositional site. The presence of shaley beds, intraformational conglomerate, and ripple marks in the upper part of the member indicates a shallowing of a depositional sea and a lower source area for the detrital material. The dark red color of the cement in the upper part of the member indicates that iron oxide in the form of hematite is present as a minor constituent of the member. The manner of deposition of ferruginous material is not known, either by direct removal from the sea of deposition or by colloidal gel accumulations of ferruginous material derived from the source area. Nodules of hematitic material formed by weathering, are also present in this portion of the member. The nodules, particularly abundant on the erosional surface of the upper portion of the member in the southwest portion of the thesis area (location 19, Plate I), are noticeably lighter in weight and smaller than those present on outcrops of the Lion Mountain sandstone member. These nodules may have formed under similar conditions outlined by Pettijohn (1954, p. 460) whereby ferruginous material selectively collected around a quartz particle or other nucleus.

The presence of calcareous material in the Cap Mountain limestone member signifies that the depositional environment is quite different from that of the upper portion of the Hickory sandstone member. Megascopically, the amount and character of detrital material at the boundary of the two depositional units appear to be approximately the same. The presence of limonite stains on limestone beds in the middle portion of the Cap Mountain member indicates that some ferruginous material was deposited.

The absence of large amounts of detrital material in the Cap Mountain member, with the exception of the massive arenaceous limestone beds (Plate VII, p. 30) in the middle portion of the member, suggests a stable source area far removed from the site of deposition. The transition from the limestone deposits of the Cap Mountain member signifies a change in the environmental conditions of deposition between these two members.

The abundant broken fossil remains, the sand-sized quartz particles, the cross-bedding and the inclined lenses in the Lion Mountain sandstone member suggest a well aerated, littoral-like sea of deposition with a source area providing an abundant supply of detrital material. The calcareous content of the member indicates that the salinity, temperature, and carbon dioxide content of the sea of deposition did favor the deposition of calcareous material. The existence of a possible greater than usual amount of ferruginous material in the sea of deposition, is indicated by the high iron content of the member in the form of hematite and glauconite. The unusually large glauconite content of the member necessarily required certain environmental conditions. These conditions, favorable for the formation of glauconite, according to Galligher (1936), Tahahashi (1938), Grim (1953), and Cloud

(1955), are summarized as follows: (1) concentrations of available ferric, magnesium, and potassium ions and more soluble SiO_2 than Al_2O_3, (2) certain oxidation-reduction potentials, favoring a slightly reducing condition with normal salinity of the marine waters, (3) cool temperature, (4) bottom conditions favorable to sediment ingesting organisms with low oxygen requirements, (5) presence of decaying organic matter, (6) no definite requirements for turbulence but formation probably favored where there is a lack of turbulence, and (7) a source area of micaceous materials or bottom muds of high iron content.

If one assumes that the detrital material, consisting of broken shell remains, sand, silt, and clay-sized particles, were intermixed and deposited with chemically precipitated carbonaceous material under turbulent conditions, the effect of the abundant organic material from the known animal life must be considered. The organic material, once in solution, must have accumulated on the bottom of the sea either as a direct precipitate, or as a gel, or was collected and transported to the bottom by the sorption characteristics of the smaller detrital particles. The presence of organic material, intermixed with other sediments, could create zones of reducing conditions. With zones of reducing conditions and other conditions favorable for the formation of glauconite, it is conceivable that a diagenetic modification of the clay mineral complex into glauconite could occur at the site of deposition.

According to Cloud and Barnes (1948, p. 343), the contact between the Lion Mountain and Welge sandstone member is disconformable. Palmer (1954, p. 714) indicates that this disconformity becomes less significant in a southeasterly direction. Daughterty (1960) states that the roundness and sphericity determinations of the clastic particles of the members show that the Welge member represents a more mature sand than the Lion Mountain sandstone member. The higher degree of maturity of the particles of the Welge sandstone member suggests a possible secondary derivation from a pre-existing source, namely, a reworked portion of the Lion Mountain sandstone member.

The environment of deposition for the Welge sandstone member is markedly different from that existing during the deposition of the Lion Mountain sandstone member and is characterised by stable conditions and a high degree of sorting of the sediments. According to Daughterty (1960), data, derived from a study of the heavy minerals and particle size study of the two members, indicate that the sediments of both the Lion Mountain and Welge member came from the same area north of the Llano region. The lack of calcareous material in the Welge member indicates a marked change in the sea of deposition that formerly favored the deposition of calcareous material.

The recomposed faces on the quartz particles of the Welge member suggest that there existed, either during deposition or post-deposition, an imbalance of soluble SiO_2 that was later deposited over the original quartz particles. The time that the over-growth occurred on the quartz particles is not known and possibly occurred after deposition and burial of the sediments. Daughterty (1960), in a study of the Welge member, notes that some of the over-growth crystals show pitting and frosting which suggest transportation after the authigenic growth. Etching by chemical action, after deposition and consolidation of the Welge member, should also be considered as a cause for the pitted surface present on the over-growth quartz particles.

The environmental conditions which characterize the non-calcareous Welge sandstone member changes gradually to an environment favoring the calcareous deposits of the Morgan Creek limestone member. The source area for the smaller clay and silt sized detrital particles is noticeably farther removed from the depositional site or lower than that present during deposition of the Welge sandstone member. The intraformational conglomerate and the algae-type bioherms present in the member indicate a shallow sea.

A shallow protected sea, as a lagoonal area, could possibly be the type of depositional area of the Point Peak member where shaley detrital material was deposited contemporaneously with calcareous material in the form of bioherms and bedded limestone. The lower bioherm zone is continuous in the adjoining areas of southern Mason County and the lateral persistence of this unit suggests that the Llano area was very stable during this interval of time. The upper bioherm zone, as mapping of the zone indicates, is not as persistent in both vertical and lateral development over southern Mason County as is the lower bioherm zone.

The thick, shaley and silty limestone beds of the lower portion of the San Saba member are very similar in nature to those in the Point Peak shale member and similar environmental conditions of deposition are believed to have existed. The non-persistent bioherm development in the upper portion of the member, even within the Loyal Valley-West area and adjoining Middle Beaver Creek area (Peterson, 1959), suggests that the environmental conditions necessary for their development fluctuated over short distances. Reducing conditions, considered necessary for the formation of glauconite, were present during the deposition or consolidation of the highly glauconitic beds in the upper portion of the member above the bioherm zone.

ORDOVICIAN SYSTEM

Apparently there is no time break between the deposition of the San Saba limestone member and the Ellenburger limestone group in the Loyal Valley-West area. The non-glauconitic nature of the Ellenburger limestone group indicates that reducing conditions are non-existent. An environment that would encourage the formation of fine-grained limestone and dolomitic deposits with fossil remains and a negligible amount of detrital material, would be an alkaline, open sea where the carbonate material is chemically precipitated.

SILURIAN SYSTEM

Following the deposition of the Lower Ordovician limestone sequence in the Llano region, regional uplift occured and a long period of erosion resulted. According to Cloud and Barnes (1948, p. 113), this is indicated by the unevenly truncated Ellenburger limestone and the complete lack of Late Ordovician and Silurian deposits in the Llano region.

DEVONIAN SYSTEM

According to Cloud and Barnes (1948, p. 113), isolated Devonian deposits are found in solution pits and cavities on the eroded surface of the Ellenburger limestone group on the eastern and western flanks of the Llano uplift. No Devonian deposits have been found in the Loyal Valley-West area.

MISSISSIPPIAN SYSTEM

Marine conditions existed in the Llano region during the Mississippian time as evidenced by the Chappel and Barnett formations. Uplift contemporaneous with the deposition of the Barnett formation is confirmed by the thinning of this formation over the Llano region. After deposition of the Mississippian strata, pre-Pennsylvanian uplift occurred over the Llano region. This uplift is substantiated by the presence of the truncated Barnett and Chappel formations. No Mississippian deposits are found in the Loyal Valley-West area.

PENNSYLVANIAN SYSTEM

According to Cloud and Barnes (1948, p. 113), it is known that marine invasions also occurred during Pennsylvanian time. A period of unrest and deformation, consisting primarily of normal faults, affected the Pennsylvanian and underlying sediments. This is evidenced by the faults present in the Strawn group and their absence in the younger Pennsylvanian deposits, the Canyon group.

PERMIAN SYSTEM

Deposits of Permian age are not found in the Llano region.

MESOZOIC ERA

TRIASSIC AND JURASSIC SYSTEMS

Deposits of Triassic and Jurassic age are not found in the Llano region. This is indicative of a long period of non-deposition or a period of emergence prior to Early Cretaceous time.

CRETACEOUS SYSTEM

Although Cretaceous deposits are now removed from a large portion of the Llano region, it is assumed that the Cretaceous seas deposited a complete blanket of sediments over the Llano region. Pre-Cretaceous peneplanation in the Llano region is evidenced by low-relief erosion surfaces. The Cretaceous age sands, conglomerates, siltstones and limestones were deposited on this erosion surface by progressive overlap. Widespread uplift followed deposition and subsequent erosion has stripped the

Cretaceous deposits from the center of the Llano region to form a large topographic basin.

CENOZOIC ERA

RECENT

There is no record of marine deposits in the Llano region younger than Cretaceous. Cenozoic deposits of caliche-like conglomerates, caliche deposits, and stream deposits are found in the Llano region and the Loyal Valley-West area.

ECONOMIC GEOLOGY

Grazing land is the most important natural resource of the Loyal Valley-West area around which the ranching economy of the area has been developed. Small cultivated fields within the area produce cattle feeds and truck products. These cultivated fields are essentially limited to the soil development from the outcrops of the Hickory sandstone member.

Stock and domestic water are most often obtained from the Hickory sandstone member. Other aquifers of the area include the Precambrian rocks and Paleozoic limestones. The wells that produce from the Paleozoic limestone units are located on or near fault planes.

Caliche deposits, weathered outcrops of the Lion Mountain sandstone member, and weathered outcrops of the Precambrian rocks are often used for road metal.

No ore or petroleum deposits are found in the area.

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APPENDIX

SECTION I

The Section of Upper Cambrian strata, with complete sections of the Welge sandstone member, the Morgan Creek limestone member, and the Point Peak shale member of the Wilberns formation, was measured along Beaver Creek. The section description and measurement were collectively compiled by the author and Don H. Peterson under the guidance and assistance of Dr. M. C. Schroeder (A. and M. College of Texas) in August, 1958. Stratigraphically, the section starts in the Lion Mountain sandstone member of the Riley formation and extends to the San Saba limestone member of the Wilberns formation. Geographically, the route followed in the measurement of the section begins 0.5 miles north of the hunting cabin on the S. Keyser land along Beaver Creek and extends in an eastward direction along Beaver Creek for a distance of about 0.7 miles and terminates on the summit of the westerly facing bluffs of Beaver Creek. The route followed in the measurement of the section is indicated on Plate I.

	Thickness in feet
Wilberns formation	
San Saba limestone member	
22. Limestone, light buff with yellowish blotches, thin bedded, weathering to flags, finely crystalline and containing Girvanella - - - - - - - - - - - - -	2.0
Total San Saba member measured - - -	2.0
Point Peak shale member	
21. Bioherm zone, light grayish-green, thick, discontinuous, sublithographic, stromatolitic limestone reef which grades laterally into limestone and shale. Bioherms weather dark gray on side surface and light gray showing typical "Cabbage head" structure on top surface. Width of weathered bioherm boulders may be as much as 12 to 14 feet across - - - - - -	24.5
20. Siltstone and limestone-alternation of olive green to brownish, laminated, calcareous siltstone and gray, very fine-grained, non-glauconitic limestone beds 0.4 to 0.6 inches thick - - - - - - - - -	13.0
19. Bioherm, light greenish gray and purplish hue, coalescing, sublitho-	

		Thickness in feet
	graphic, stromatolitic limestone about 2 feet in diameter with compaction and arching of siltstone enclosing the unit - - - - - - - - - - - -	2.5
18.	Siltstone, limestone, and intraformational conglomerate and same as unit 16 except siltstone is olive green to tan -	21.5
17.	Limestone, dark gray, rust mottled, hard, thick-bedded, fine-grained, non-glauconitic with bottom and top beds 1 and 2 feet thick respectively - - - - - -	3.5
16.	Siltstone, limestone, and intraformational conglomerate, - gray to tannish, laminated to thin bedded, calcareous siltstone interbedded with gray, very fine grained, non-glauconitic, limonitic ledges of regularly bedded limestone and intraformational conglomerate of fine grained matrix of dark green limestone 2 to 4 inches thick with various colored pebbles orientated with their long axes up to 1.5 inches almost paralleling the bedding planes - - - - - - - - - - - - - - - - - - -	37.5

Thickness in feet

15. Bioherm zone, dark gray and splotched with light green, massive, coalescing, sub-lithographic stromatolitic reef material. Very resistant due to extreme hardness and fine texture. Each algae bioherm may weather out separately forming an 8 to 10 foot high rock doughnut with a diameter about 10 to 15 feet. The zone is fairly continuous laterally although its thickness is variable - - - - 20.0

14. Siltstone, shale and intraformational conglomerate, - alternating beds of dark gray to olive green, calcareous siltstone and shale; intraformational conglomerate of varied colored pebbles in beds 2 to 4 inches thick of dark green, fine-grained limestone. The pebbles are orientated with their long axes roughly parallel to the bedding planes. The shale beds range in thickness from 1 to 3 inches while the siltstone layers are much thinner - - - - - - - - - 17.0

13. Siltstone, limestone, intraformational conglomerate, and two stromatolitic limestones. The siltstone is dark gray to

Thickness
in feet

brown and is irregularly interspersed with gray to tan, 0.5 to 0.6 foot thick, finely crystalline limestone beds, and 0.2 to 0.5 foot thick beds of intraformational conglomerate. The conglomerate beds contain pebbles 1.0 to 1.5 inches long and the matrix is a dark gray, finely crystalline limestone. Layers of greenish-blue, sub-lithographic, coalescing, stromatolitic reef beds occur at 13.5 and 15.5 feet in the member - - - 21.5

Total Point Peak shale member -- - - - 160.0

Morgan Creek limestone member

12. Siltstone, shale, limestone and bioherms-purplish gray, sub-lithographic, coalescing, stromatolitic, "baby" bioherm reefs occur in about one foot zones at 86.0, 95.5, 97.5, 105.5 and 110.5 feet up in the Morgan Creek limestone. The top zone is arbitrarily picked as the contact with the overlying Point Peak shale member. Limestones in this sequence often grade upward into reef material whereas calcareous siltstone usually laps over them. In the interval between bio-

	Thickness in feet
herm reefs, there are alternating beds from 3.0 to 6.0 inches of light greenish-gray, hard, fossiliferous, finely crystalline limestone; green medium-grained glauconitic limestone; green siltstone and shale. The limestone beds are splitched with limonitic stains -	36.0
11. Limestone, dark gray with yellowish stains, 2.0 to 3.0 feet thick, coarsely crystalline to hashy limestone with abundant cystoid stems and plates with large grains of glauconite - - - - - - - - -	6.5
10. Siltstone and limestone beds - green, irregular thin beds of slightly glauconitic siltstone and greenish to purplish-gray, limonitic stained, finely crystalline to coarsely hashy, glauconitic, fossiliferous, flaggy to slabby limestone - - - - - - - - -	21.0

At this point a shift, across a small fault of unknown displacement, was made from the bluff bordering Beaver Creek to the middle of the creek about 100 yards upstream. The top of the marker zone Eoorthis texanna was picked for making this shift because of its consistent nature throughout the uplift region as reported by Bridge, Barnes, and Cloud (1947, p. 111). Correlation was mainly based on this zone and a comparison of the gross lithology supported this correlation between the two parts of the composite sections.

	Thickness in feet
9. Coquina-like limestone, composed of abundant ribbed brachiopods <u>Eoorthis texanna</u> and Billingsella, plus trilobite remains occur in beds 42.5 to 43.5 and 47.0 to 49.0 from the bottom of the Morgan Creek limestone, referred to as the <u>Eoorthis</u> zone. These fossils occur in a greenish-gray to gray, medium grained, glauconitic coquinite intercalated with 0.2 to 0.5 foot beds of slightly glauconitic, silty limestone - - -	6.5
8. Limestone, alternating layers of sandy to silty limestone and fine, hard crystalline limestone. Reddish and purplish tones predominate for the lower 25 feet and then grade upward into greenish-gray hues. The arenaceous and argillaceous limestones are usually thinly bedded, partly glauconitic, with layers 13 to 15 feet up in the section containing coarse, limonitic	

Thickness
in feet

stained quartz grains. The silty strata contain cystoid stems but are generally less fossiliferous than the crystalline limestones. Laterally these beds correspond to greenish-gray to olive-green calcareous shales and siltstones having poor fissility. The siltstone bedding planes are usually irregular and have a somewhat lumpy appearance. Strata of crystalline limestone are usually about 0.4 to 0.8 foot thick and are of hard, fossiliferous, glauconitic and sometimes cross-bedded limestone. The fossils consist of cystoid stems, calcareous brachiopod and trilobite fragments. Within this sequence at 27.5 to 28.0 and 31.5 to 32.1 feet up in the member are gray, trilobite "hash" beds - - - - - - - - - - - - 36.0

7. Sandstone, tan and white turning to purplish, medium grained with a varied carbonate content - - - - - - - - - - - - - 6.5

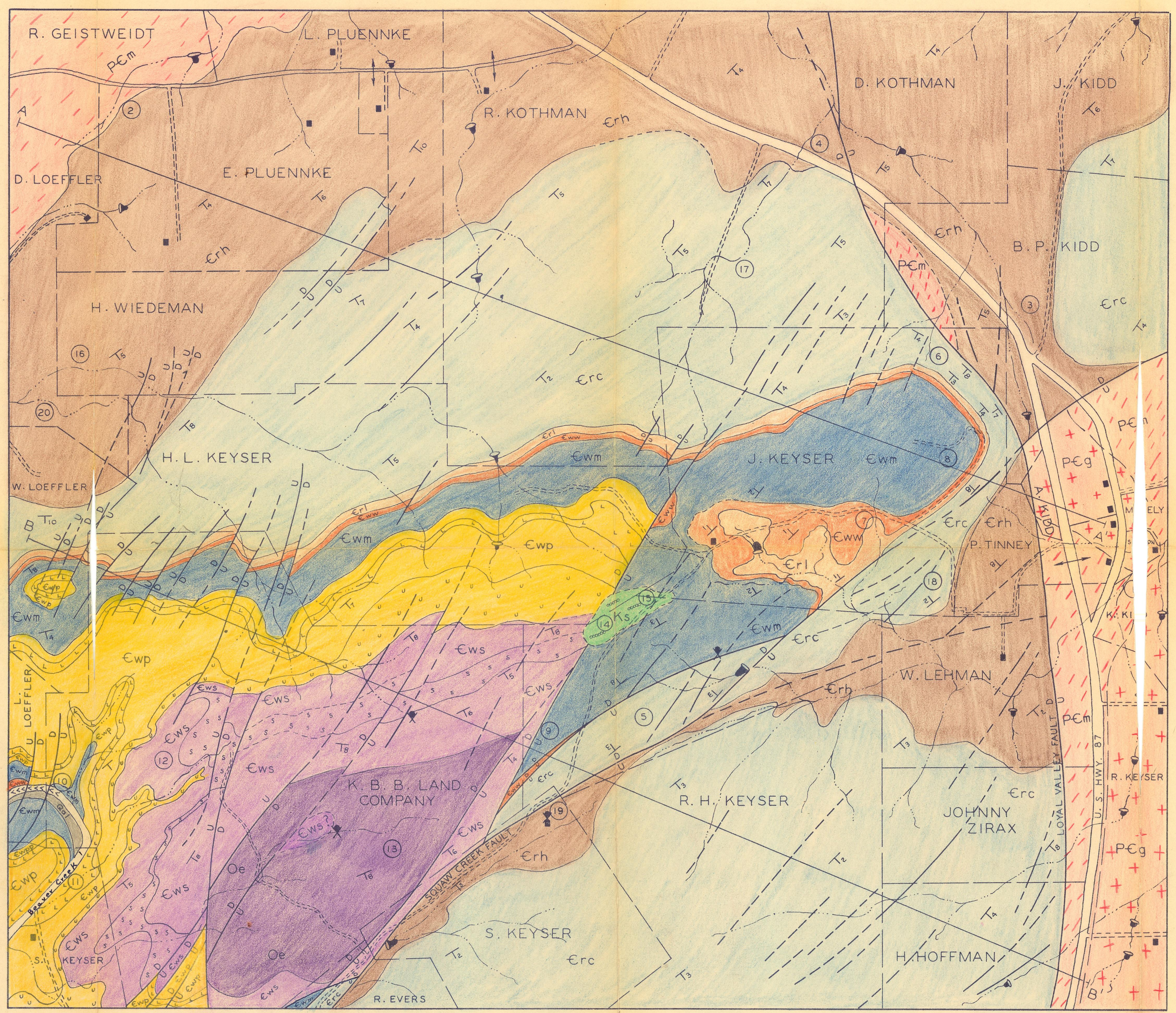
Total Morgan Creek limestone member - 112.5

Welge sandstone member

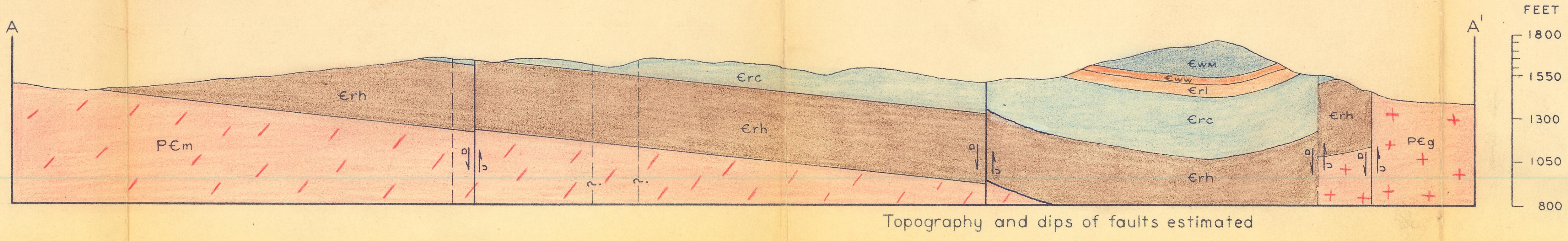
6. Sandstone, tan to white, quartz particles,

	Thickness in feet
non-calcareous, non-glauconitic and generally medium grained. Fewer recrystallised quartz faces and not as well indurated as the lower portion of the member - - - - - - - - - - - - - - -	3.0
5. Sandstone, tan, thick bedded, hard, indurated quartz sandstone with prevalent cross bedding and recrystallised quartz grain faces. Beds average 1.0 to 2.0 feet in thickness - - - - - - - - - - - - -	12.4
4. Sandstone, tan, quartz particles, non-glauconitic, non-calcareous, medium grained - - - - - - - - - - - - - - - - - - -	1.0
Total Welge sandstone member - - - - -	16.4
Riley formation	
Lion Mountain sandstone member	
3. Siltstone and sandstone - green, glauconitic, sandy siltstone with very poor fissility and dark green, tan to rust colored, thin bedded, fine-to-coarse grained, well rounded, non-calcareous, quartz and glauconitic sandstone -	3.5
2. Covered by weathered material - - - - -	1.9
1. Sandstone, dark green, cross bedded,	

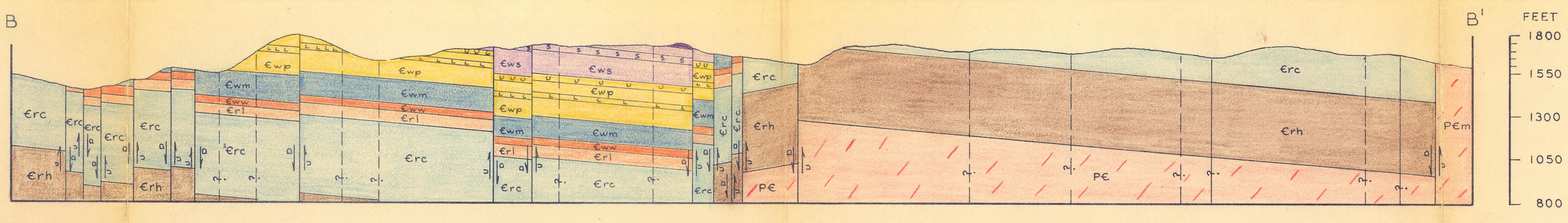
	Thickness in feet
glauconite and quartz particles predominate constituent with some lenses of light gray, "hashy" limestone. The "hashy" nature is due to abundant trilobite remains. Black hematite nodules found on surface - - - - - - - - - - - - - -	6.2
Total Lion Mountain sandstone member measured - - - - - - - - - - - - - - - - -	11.6
Cumulative thickness measured - - - - -	302.5



Geology by J. Kmiecik, 1961



Topography and dips of faults estimated



EXPLANATION

GEOLOGIC COLUMN

RECENT

Qal — Alluvium

UNCONFORMITY

CRETACEOUS

Ks — Cretaceous sandstone unit

UNCONFORMITY

ORDOVICIAN — ELLENBURGER GROUP

Oe — Ellenburger limestone group

CAMBRIAN

WILBERNS FORMATION

€ws — San Saba limestone member with bioherm zone

€wp — Point Peak shale member with lower (L) and upper (u) bioherm zone

€wm — Morgan Creek limestone member

€ww — Welge sandstone member

RILEY FORMATION

€rl — Lion Mountain sandstone member

€rc — Cap Mountain limestone member

€rh — Hickory sandstone member

UNCONFORMITY

PRECAMBRIAN

P€g — Precambrian granite

P€m — Precambrian gneiss and schist

SYMBOLS

Normal fault
U, upthrown side
D, downthrown side

Inferred normal fault

Observed and inferred contacts

Strike and dip of strata

Flowing stream

Intermittent stream

A —— A' Structure section line

Property line fence

Line of described section

Windmill

Paved road

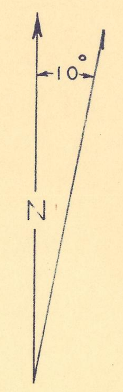
County road

Ranch road

Stock tank

Ranch building

⑨ Location described in text



Approximate mean declination

HORIZONTAL SCALE: 1:20,000

0 1/2 1 2 miles

VERTICAL SCALE: 3.3 X HORIZONTAL SCALE
DATUM = APPROXIMATE SEA LEVEL

Base from U. S. Department of Agriculture, Soil Conservation Service, Aerial Photographs, 1955-1956.

GEOLOGIC MAP AND SECTION OF THE LOYAL VALLEY - WEST AREA, MASON COUNTY, TEXAS