GRIMSHAW, THOMAS WALTER.

GEOLOGY OF THE WIMBERLY AREA, HAYS AND COMAL COUNTIES, TEXAS.

GEOLOGY OF THE WIMBERLEY AREA,

HAYS AND COMAL COUNTIES, TEXAS

APPROVED:

GEOLOGY OF THE WIMBERLEY AREA,
HAYS AND COMAL COUNTIES, TEXAS

by

THOMAS WALTER GRIMSHAW, B.S.

THESIS

Presented to the Faculty of the Graduate School of
The University of Texas at Austin
in Partial Fulfillment
of the Requirements
for the Degree of
MASTER OF ARTS

THE UNIVERSITY OF TEXAS AT AUSTIN
January 1970

FRONTISPIECE

JACOB'S WELL

GEOLOGY OF THE WIMBERLEY AREA, HAYS
AND COMAL COUNTIES, TEXAS

Thomas Walter Grimshaw, B. S.

ABSTRACT

Cretaceous limestone, marl, and dolomite of Late Aptian to Middle Albian age crop out in the Wimberley area, a 5-minute by 10-minute quadrangle in central Texas situated in the dissected eastern margin of the Edwards Plateau. Formations exposed are the upper part of the Glen Rose, the Walnut, and the lower part of the Edwards. The Glen Rose, which crops out over 90% of the area, is subdivided into 7 informal members defined on mappability on aerial photographs. Six major step faults of the Balcones fault zone transect the area, displacing the strata downward to the southeast about 700 feet. The outstanding geomorphic features are the high relief hills and ridges south of the Blanco River, which are caused by dissection along the Edwards Plateau margin, and the deflections of Cypress Creek and Blanco River where they cross faults.

CONTENTS

TEXT

Page

Introduction 1
Location of area 1
Accessibility 1
Methods of investigation 3
Previous investigations 3
Acknowledgements 5

Geography 6
Regional geography 6
Local physiography 6
Drainage 6
Landmarks 6
Elevations 7
Climate 7
Vegetation 7
Local history 8
Economy 8

Regional geology 9
Texas Craton and Ouachita Structural Belt 9
Balcones Fault Zone 11
Comanche Shelf, Gulf Coast Reef Trend, and San Marcos Platform 12

Stratigraphy 13
Cretaceous System 13
Trinity Group 15
Subsurface formations 15
Glen Rose Formation 16
Member A 18
Member B 20
Member C 22
Member D 29
Member E 23
Member F 25
Member G 26
Fredericksburg Group 28
Walnut Formation 29
Bull Creek Member 30
Bee Cave Member 30

Edwards Formation 30
Quaternary System 32
Álluvium 33
Colluvium 33
Upland deposits 33

Structural geology 33
Faults 33
Major faults 34
Lone Man fault 34
Jacob's Well fault 35
Tom Creek fault 37
Wimberley fault 37
Devil's Backbone fault 38
Hidden Valley fault 38
Minor faults 38
Poppy Ranch fault 38
Eagle Rock Ranch fault 38
Unnamed faults 39
Joints 39
Regional and fault block dip 39

Geomorphology 40
Edwards Plateau 40
Drainage characteristics 40
Drainage patterns 40
Fault deflections 40
Minor geomorphis features 41
Terraced topography 41
Caves 41
Surficial solution features 41
Corrasion grooves 41

References cited 43

Appendix 48
Introduction 49
Measured Section 1 54
Measured Section 2 58
Measured Section 3 62
Measured Section 4 68
Measured Section 5 73
Measured Section 6 77
Measured Section 7a 80
Measured Section 7b 86
Measured Section 8 95

Measured Section 9 96
Measured Section 10 98
Measured Section 11 101

Vita 105

ILLUSTRATIONS

Figure | Page

Frontispiece. Jacob's Well iii

1. Location of the Wimberley area 2
2. Regional geologic elements 10
3. Columnar section of the Cretaceous System in the Wimberley area 14
4. Contact between Members A and B 19
5. Contact between Members B and C 21
6. Contact between Members D and E 24
7. Contact between Members F and G 27
8. Bee Cave marl 31
9. Outcrops of Jacob's Well fault 36
10. Terraced topography 42
11. Tinajita 42

Plate | Page

1. Geologic map and cross sections of the Wimberley area ..... (in pocket)
2. Measured sections ..... (in pocket)

INTRODUCTION

The Wimberley area is a quadrangle situated in the Balcones fault zone and in the central Texas outcrop belt of the Cretaceous Comanche Series. This study describes the surface geology of that area. Emphasis is placed on stratigraphy and faulting; other aspects of the geology of the area are briefly discussed. The area is presented in the context of its geographic, climatic, and regional geologic setting. This thesis is one of a continuing series of studies of the Cretaceous System in central Texas being conducted at the University of Texas Department of Geological Sciences under the supervision of Dr. Keith Young.

Location of area: Most of the Wimberley area is in Hays County, Texas, about forty miles southwest of Austin and ten miles northwest of San Marcos (Figure 1). The extreme southwest corner of the area is in adjoining Comal County. The area is defined on the east and west by the meridians 98°05′ and 98°10′ west longitude and on the south and north by the parallels 29°55′ and 30°05′ north latitude. The north-south dimension is about 11.5 miles and the east-west length is 5.0 miles.

The area is centered on the common corner of four U.S. Geological Survey 7½-minute quadrangles, taking in two-ninths of the area of each sheet. These are the Rough Hollow, Driftwood, Wimberley, and Devil's Backbone quadrangles (Plate 1).

The name for the thesis area is taken from the community of Wimberley, the best-known geographic feature of the area. Since it is defined by lines of latitude and longitude, the area is, in a geometric sense, a quadrangle. However, because the name "Wimberley quadrangle" is preempted by the U.S. Geological Survey, 7½-minute quadrangle that takes in the southeast quarter of the area, the thesis quadrangle is referred to as the Wimberley "area."

Accessibility: Access to the Wimberley area is excellent. The quadrangle is easily reached from Austin via U.S. Highway 290 to Dripping Springs and then southward on Texas F.M. 12 toward Wimberley. An alternative approach is through San Marcos on Texas F.M. 12.

Within the area, the most important public roads are F.M. 12, F.M. 32, Purgatory

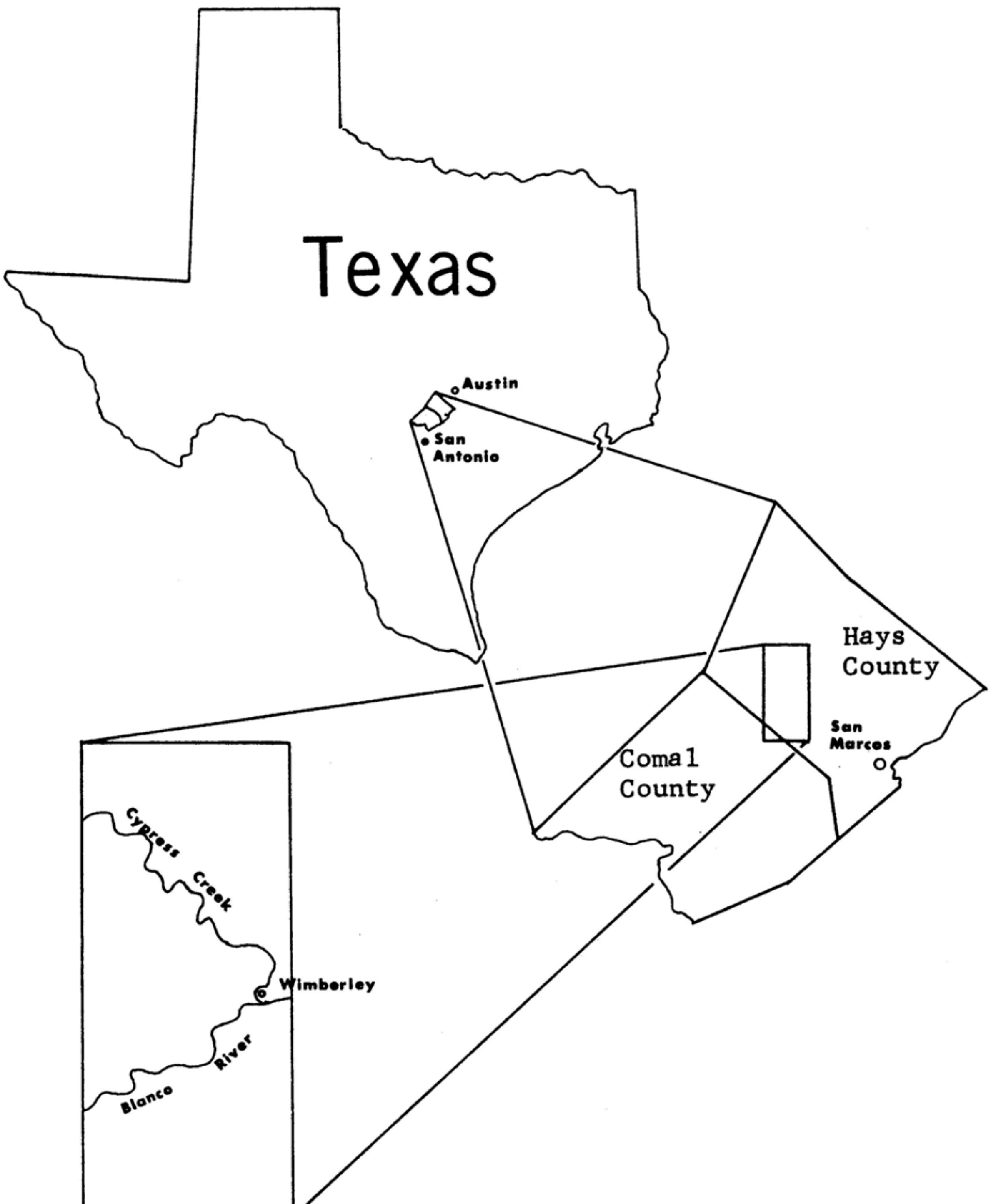


Figure 1.
Location of the Wimberley Area

Road, Cloptin Road, Deer Lake Road, Jacob's Well Road, and Mount Sharp Road. Numerous private roads and trails lead to most points not reachable by public road.

Methods of investigation: After an initial reconnaisance of the thesis area was made, several stratigraphic sections were measured and described. These sections were pieced together and correlated to include all but the uppermost forty-six feet of the stratigraphic interval exposed in the area. Bed thicknesses were measured with a Jacob's staff and Brunton compass clinometer to the nearest one-tenth foot. Rock descriptions were made using a 10X hand lens. Samples were collected from as many beds as possible and were taken to the laboratory, sawed into slabs, etched with dilute hydrochloric acid, and described with the aid of a binocular microscope having up to 60X magnification. Folk's (1962) classification of carbonate rocks was used in all rock descriptions. The synthesized field and lab descriptions appear in the Appendix, and the weathering profiles, lithologies, fossil content, and correlations of the measured sections are shown on Plate 2. The measured section numbers and bed numbers in the Appendix correspond to those of Plate 2.

After the sections were measured and described, the thesis area was mapped on aerial photograph stereo pairs that were flown in 1938. Extensive field checks were made to verify the information mapped on the air photographs. Data from the photographs was transferred with a Saltzmann projector to U.S. Geological Survey 7½-minute topographic quadrangle base maps.

The sections were measured and described in the summer of 1968 and spring of 1969, and the mapping was done during the spring and early summer of 1969. This thesis was written in the late summer of 1969.

Previous investigations: The first significant contributions to the study of Texas geology were made by Ferdinand Römer of the Berlin Academy of Sciences who came to Texas in 1845 and remained for 18 months to determine the suitability of the area for German settlement. During his visit, he made several trips up the canyon of the Guadalupe River, a few miles south of the Wimberley area, to describe the strata and collect fossils. After returning to Germany, he published a series of reports describing the geology and geography of central Texas (1846, 1848, 1849, 1852).

Hill and Vaughan (1898b) described the geology and ground water resources of the Edwards Plateau and Rio Grande Plain. This study included Hays and Comal Counties and they referred to a "canyon well" in the valley of the Blanco River at Wimberley (1898b, p. 271).

Dr. F. L. Whitney supervised several surface studies in Hays and Comal Counties from 1925 to 1935. No reports were written for these studies, but Whitney compiled them into a map which has been edited and published by Dr. Keith Young as a series of 15-minute quadrangles. These maps are available for purchase at the University of Texas Bureau of Economic Geology. The northern half of the Wimberley area is included in the Southeast Blanco sheet and the southern half is on the Hunter sheet.

Marion Whitney (1937) described and named many Glen Rose fossils from the region in and around Comal County and published excerpts from her study (1952a, 1952b).

George (1952) and DeCook (1963) described the geology and ground water resources of Comal and Hays Counties respectively. In these reports, they named some of the faults in the Wimberley area and gave the discharge of Jacob's Well and of the Blanco River at Wimberley.

Stead (1951) studied the Foraminifera of the Glen Rose Formation in Travis, Hays, and Comal Counties. Two of the sections he measured and collected are situated within the Wimberley area.

Lozo and Stricklin (1956) presented stratigraphic notes on some of the classic basal Cretaceous outcrops in central Texas and introduced a tripartite subdivision of the Trinity using the sedimentary cycle concepts of R. T. Hill.

Behrens (1965) closely examined approximately 50 feet of Glen Rose section, 25 feet above and 25 feet below the "*Corbula* bed," in several counties west and southwest of Hays County. His objective was to interpret the depositional environments of the strata.

The U.S. Army Corps of Engineers (1964) made a detailed study of Glen Rose lithology and faulting in the vicinity of the proposed Cloptin Crossing Dam site about two miles upstream from Wimberley on the Blanco River. Included in the report were a measured and described section of the strata above the bed of the Blanco at the dam site and the lithologic descriptions of 11 cores taken along the proposed dam axis.

Moore has recently studied the stratigraphy of the Walnut Formation (1961) and the Fredericksburg Division (1964) in several central Texas Counties including Hays and Comal Counties. One of the sections for these studies was measured along Purgatory Road about 100 yards south of the southern boundary of the Wimberley area.

Barnes (1952-1967) has mapped several 7½-minute quadrangles northwest of the Wimberley area. The closest of these to the thesis quadrangle is the Yeager Creek quadrangle, which joins the Rough Hollow quadrangle on the northwest.

Dr. Keith Young of the University of Texas Department of Geological Sciences has supervised several masters theses which describe the geology of quadrangles in Hays, Comal, and adjoining counties (Abbott, 1966; Bills, 1957; Cooper, 1964; Davis, 1962; DeCook, 1956; King, 1957; Noyes, 1957). Noyes' thesis area, most of which is immediately southeast of the area described here, includes a small rectangle in its northwest corner that is common to the southeast corner of the Wimberley area. Davis' quadrangle is at the same latitude as the southern half of the Wimberley area but is located 5 miles to the east. The northeast corner of Abbott's map approaches the southwest corner of the Wimberley area.

Acknowledgments: I wish to express my sincere thanks to Mr. Lyman Dawe not only for familiarizing me with Glen Rose lithology and stratigraphy and for acquainting me with effective field methods, but also for providing essential encouragement in the early stages of the field work for this study.

My thanks are also given to the numerous landowners in the thesis area who permitted me to enter their property and to the residents of Wimberley who gave much "logistic" support. Two persons in particular, Mr. P. C. Wenger and Mr. C. B. Smith, deserve thanks for granting me unlimited access to their ranches.

I wish to acknowledge the University of Texas Department of Geological Sciences for purchasing necessary aerial photographs and the Texas Water Development Board for providing the essential topographic maps.

To Dr. P. U. Rodda and Dr. L. S. Land I extend my thanks for serving on my supervising committee.

Finally, I wish to express my sincere gratitude to Dr. Keith Young, the supervising professor for this study, for suggesting the problem, for providing invaluable guidance and suggestions, and for editing the manuscript.

GEOGRAPHY

Regional Geography

The Wimberley area is located on the dissected eastern margin of the Edwards Plateau. The boundary between the plateau and the Gulf Coastal Plain passes about seven miles southeast of the area.

Local Physiography

Drainage: The thesis area contains parts of the drainage basins of four major central Texas rivers; the Blanco, Colorado, Guadalupe, and San Marcos Rivers.

The Blanco River is the most important of the four, draining about 85% of the thesis area. It rises in Kendall County and flows east across Blanco County and then southeast and east across Hays County into the San Marcos River a few miles southeast of San Marcos. Within the bounds of the Wimberley area, the river flows predominantly in an anomolous northeast direction because of fault deflections. Cypress Creek, a perennial stream fed by the spring, Jacob's Well, flows southeast across the area and empties into the Blanco near Wimberley. The gradient of Blanco River is about 8 feet per mile, and the gradient of Cypress Creek is about 24 feet per mile.

The remainder of the thesis area is drained by tributaries to the other three rivers. Sink Creek and Purgatory Creek, both of which are major tributaries to San Marcos River, head in the Wimberley area and drain the southeastern part of the area. The southwestern corner is drained by a small tributary of the Guadalupe River and the northeastern corner is drained by a tributary to Onion Creek, which flows into the Colorado River southeast of Austin.

Landmarks: Several landmarks of the Texas hill country are located in the Wimberley area. The most prominent are Lone Man Mountain, which is situated in the northeast corner of the area, the Devil's Backbone, the sharp, high-relief drainage divide between Blanco and Guadalupe Rivers, and Jacob's Well, one of the largest springs in

Hays County. Other salient features are Lone Woman Mountain, Little Twin Sisters Peaks, and Joe Wimberley Mountain.

Elevations:The highest elevation in the Wimberley area is 1421 feet above sea level at the top of Lone Man Mountain and the lowest is about 805 feet where the Blanco River flows out the eastern margin of the area. A distance of about six miles separates these elevation extremes.

Climate

The climate of the central Texas region, including the Wimberley area, is humid temperate to humid subtropical. The Köppen climate classification symbol for the area is Cfa, which signifies the following: 1. The climate is warm, temperate, and rainy; 2. The average temperature of the coldest month is below 64.4°F (18°C); 3. The average temperature of the hottest month is above 71.6°F (22°C); and 4. There is no distinct dry season (Trewartha, 1954). The average annual rainfall of the Wimberley area, according to an isohyetal map of central Texas published by the U.S. Army Corps of Engineers (1964), is about 34 inches.

Vegetation

The Wimberley area is largely covered with a growth of trees, shrubs, and grasses. Cuyler (1931) has noted the usefulness of vegetation as an indicator of geologic formations of the Texas Cretaceous System. Within the Wimberley area, both the type and the abundance of vegetation are useful in the field and on aerial photographs as an aid to mapping. The most important indicators are the trees and other woody plants. The tree populations on each of the map units will be discussed in the section on stratigraphy.

The taxonomic names of the trees discussed below are taken from Vines (1960). Two species, the live oaks (*Quercus virginiana*) and the junipers (*Juniperus virginiana*), dominate the tree population of the thesis area. The live oaks are most abundant on the more resistant limestone strata, probably because the limestones are fractured and act as water-carrying horizons. The junipers thrive on marl slopes. Live oaks and junipers flourish together in areas of low relief where a soil mantle is developed, but the junipers are commonly removed by ranchers to promote the growth of grass for stock.

Mesquite (*Prosopis juliflora*) prospers on very clayey soils and is usually found on the alluvial terraces of Blanco River and Cypress Creek. Cypress (*Taxodium distichum*) and sycamore (*Platanus occidentalis*) trees flourish along the banks of Cypress Creek and Blanco River where a plentiful supply of water is available.

Local History

The Tonkawa Indians inhabited the Wimberley area at the time of arrival of the first whites. The Tonkawa were organized into a number of politically and economically independent tribes that were united by a common language and culture. They were semi-nomadic, living primarily on game animals and practicing little agriculture (Suhm, 1960, p. 64). Their numbers dwindled rapidly in the 19th century because of diseases introduced by white settlers and because of attrition by their traditional enemies, the Comanches. The single tribe into which they had coalesced by the late 1800's was removed to an Oklahoma reservation (Suhm, 1960, p. 65) and, aside from a few artifacts, no trace of their presence remains today.

Settlement of the Wimberley area began after 1840. Nearby San Marcos was permanently settled in 1845 (Dobie, 1932). Wimberley traces its beginnings to the fall of 1848, when William Carvin Winters constructed a saw mill at the present site of the community (Dobie, 1932). The village was initially called Glendale, but the name was changed to Wimberley Mills for Pleasant Wimberley, the third owner of the mill. The name was later shortened by the U.S. Post Office Department to its present name of Wimberley (Shawe, 1963).

Economy

The economy of the Wimberley area has been primarily agricultural since the area was settled. With the exception of small parts of upland areas and narrow strips on the alluvial terraces along Cypress Creek and Blanco River, the land is not suitable for farming because of high relief and thin or nonexistent soil. Ranching is, therefore, the predominant source of income, and cattle and goats are the most important livestock. Many ranchers supplement their incomes by leasing their ranches for deer hunting during the season from November to January.

In the vicinity of Wimberley and along Blanco River and Cypress Creek, the economy is changing because of the growing popularity of the area for resorts and summer homes. This change is manifested in the rising prices of real estate, the breaking up of large ranches into smaller acreages, and the influx of capital from sources outside the area. A dam to be built about two miles upstream from Wimberley on Blanco River has been proposed by the U.S. Army Corps of Engineers (1964). If, or when, it is constructed, the economy of the area will no doubt be enhanced by increased use of the area for recreation.

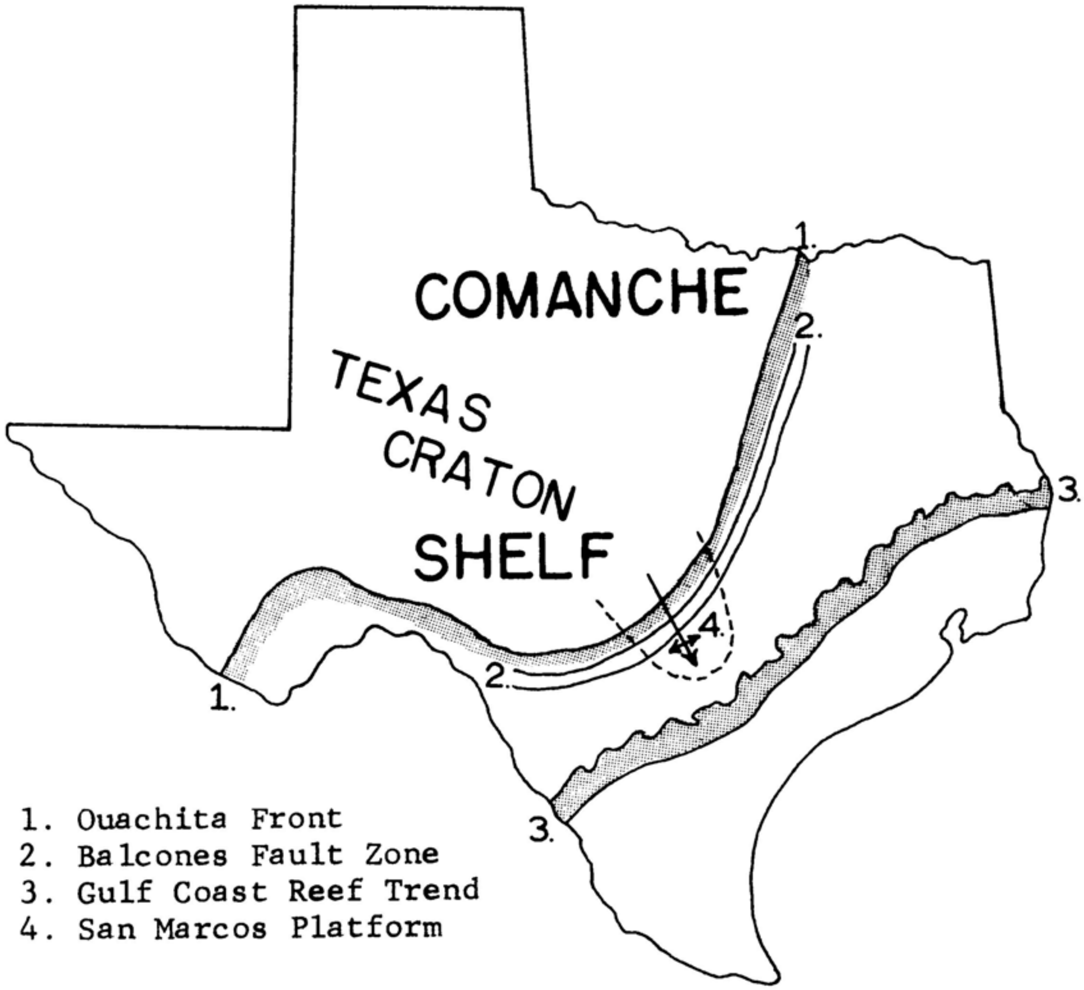
Two petroleum companies hold most of the oil leases on the property in the area and one of them is engaged in active seismic exploration at the time of this writing.

REGIONAL GEOLOGY

The geology of the Wimberley area is most clearly described and understood if it is viewed in the context of its regional setting. The major regional elements of central Texas will therefore be reviewed here briefly. These elements are the Texas craton, the Ouachita structural belt, the Comanche shelf, the Gulf Coast reef trend, the San Marcos platform, and the Balcones fault zone (Figure 2).

Texas Craton and Ouachita Structural Belt: Two basement features, the Texas craton and the Ouachita structural belt, have been important in the geologic development of the Wimberley area. The Texas craton, the most fundamental element in the basement of Texas, is "a great northwesterly elongated, mostly subsurface, mass of essentially granitic Precambrian plutonic rocks which extends from central Texas into southeastern New Mexico." (Flawn, 1956, p. 25) Rocks taken from the Llano uplift, where the southeast nose of the craton is exposed, have been found by radiochemical dating to be about 1 billion years old (Flawn, 1956).

The southeast margin of the Texas craton is delimited by the Ouachita structural belt, a linear band of faulted and folded Paleozoic rocks which extends at least 1300 miles from east-central Mississippi across Louisiana and Texas and into Mexico for an unknown distance. The belt is named for the Ouachita Mountains where it is well exposed. It was formed late in the Paleozoic Era when orogenic forces compressed the Paleozoic sedimentary rocks of the Ouachita geosyncline against the Texas craton, which acted as a buttressing foreland, and deformed them into complex folds and faults. Flawn



1. Ouachita Front
2. Balcones Fault Zone
3. Gulf Coast Reef Trend
4. San Marcos Platform

Figure 2.
Regional Geologic Elements

et al. (1961) recognize two tectonic zones in the foldbelt that are defined on degree and type of deformation and degree of metamorphism. The outer or frontal zone is marginal to the Texas craton and is characterized by strong folding and faulting and by unmetamorphosed to very weakly metamorphosed sedimentary rocks. The inner or interior zone is composed of weak to low grade metasedimentary rocks that have undergone deformation with a high shear component. Flawn *et al.* (1961) have also defined and mapped four lithologic units: 1. Cambrian (?) through Devonian (possibly including Lower Mississippian) rocks; 2. Mississippian-Pennsylvanian rocks; 3. dark, fine-grained to coarse grained, clastic rocks of unknown age; and 4. phyllite, slate, metaquartzite, marble, and schist of unknown age.

The Texas craton and Ouachita structural belt are important to the geology of the Wimberley area because they served as the basement upon which the Cretaceous rocks of the area were deposited and because the boundary between them is a zone of structural weakness along which the Balcones fault zone has developed. The thesis area is situated over the frontal zone of the Ouachita belt and the basement rocks under the area have been mapped by Flawn *et al.* (1961) as Mississippian-Pennsylvanian.

Balcones Fault Zone: The Balcones fault zone is a band of fractures extending from north-Texas south, southwest, and west in a broad arc through the central part of the state (Fig. 2). It passes through Austin and San Antonio and continues westward. The zone was named for the Balcones Escarpment, the present-day topographic expression of the zone. This fault-line scarp is most conspicuous between Austin and San Antonio. The Balcones fault zone is composed of many *en echelon,* normal, synthetic, down-to-the-coast strike faults, which together form the northwest side of a northeast trending faulted graben. The southeast side of the graben is formed by the up-to-the-coast faults of the Luling fault zone (Weeks, 1945).

Balcones faulting resulted from tensional stresses caused by uplift of the Edwards Plateau relative to the Gulf Coastal Plain. Estimates of the age of the faulting range from the Cretaceous Period to the Pleistocene Epoch. Considerable movement must have occurred during the Miocene because the Oakville, a Gulf Coastal Plain formation of that age, contains calclithite and reworked Cretaceous fossils that indicate uplift and erosion of the Cretaceous strata to the west (Folk, 1955).

The location of the Balcones zone, as previously stated, is controlled by the zone of structural weakness at the boundary between the Texas craton and the Ouachita structural belt. George (1952) cites a cumulative displacement on the zone of about 1500 feet across Comal County and DeCook (1963) gives a figure of 1700 feet for Hays County.

Comanche Shelf, Gulf Coast Reef Trend, and San Marcos Platform: The term Comanche shelf was used by Rose (1968) for the vast, flat, generally submerged plain which, during Comanchean time, included most of Texas except the present southeast margin of the Gulf Coastal Plain. It was on this surface that the sediments of the Cretaceous Comanche Series accumulated. The shelf was separated from the deeper waters of the the ancestral Gulf of Mexico basin to the southeast by the Gulf Coast reef trend. This belt is composed of a series of long, narrow, slightly sinuous, stacked reefs that trend generally parallel to, but several miles inland from, the present Texas coast line. These reefs grew intermittantly throughout most of Comanchean time and profoundly affected depositional conditions in the shelf area behind it. The reef trend was originally named the Stuart City Reef by Winter (1962), but that name is now restricted to the reef that grew during deposition of the Edwards Formation and other names have been applied to the older reefs (Hendricks and Wilson, 1967).

Two large depressions, the Maverick Basin on the southwest and the North Texas-Tyler Basin on the northeast, were superimposed on the Comanche Shelf. These basins were separated by the Central Texas Platform (Rose, 1968; =Comanche Platform, Cartwright, 1932), a broad, elongate swell bearing southeasterly from the vicinity of San Angelo, Texas, across the Llano uplift to the Gulf Coast reef trend. The southeast end of the Central Texas Platform is called the San Marcos Platform (Rose, 1968). The San Marcos Platform was originally called the San Marcos Arch by W. S. Adkins (1933), who thought that the San Marcos River flows approximately down the arch axis. Winter (1962) changed the name to San Marcos Platform because it has no present topographic expression and its existence is inferred from the thinning of Cretaceous units over its crest. The axis of the platform trended southeastward between San Marcos and New

Braunfels and probably shifted back and forth in that vicinity during Comanchean time (Keith Young, personal communication).

The Wimberley area is situated on the northeast flank of the San Marcos Platform many miles inland from the Gulf Coast reef trend.

STRATIGRAPHY

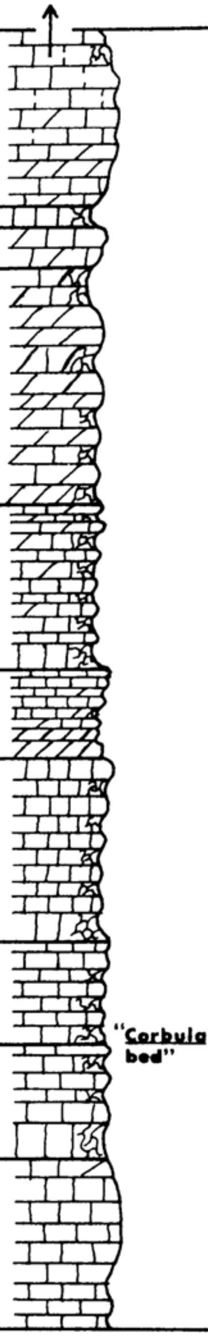
Rocks of two systems, the Cretaceous and the Quaternary, crop out in the Wimberley area. The age of the basement rocks, as previously stated, is Mississippian and Pennsylvanian. Triassic and Jurassic rocks are present below the surface of the Gulf Coastal Plain, but they pinch out several miles southeast of the thesis area. Several Cretaceous formations are present below the surface of the area and three formations, the Glen Rose, the Walnut, and the Edwards, are exposed at the surface. Quaternary alluvium, colluvium, and upland deposits cover the older strata in several places.

CRETACEOUS SYSTEM

Cretaceous rocks ranging in age from Late Aptian to Middle Albian (Young, 1966, 1967b) are exposed at the surface in the Wimberley area (Figure 3). The stratigraphy of the Cretaceous System in Texas was largely established by R. T. Hill in the late 19th and early 20th centuries. Hill divided the system, using the concept of sedimentary cycles, into two series, the Comanche below and the Gulf above. A series, as Hill conceived it, was deposited during a major cycle of sedimentation and represented a "complete Ternary succession of strata, to-wit: 1. A lower stage of sandstones, shales, and other sedimentary deposits, representing prevalence of land with downward movement. 2. A middle stage, chiefly of limestone, representing prevalence of sea, and general quiescence and elaboration of calcareous organic formations. 3. An upper stage, and more of mechanical sediments, indicative of proximity to land." (Hill, 1889, p. xv)

Hill divided the Comanche Series into three "divisions" which are, in ascending order, the Trinity, the Fredericksburg, and the Washita. Each division was deposited as a smaller sedimentary cycle superimposed on the larger Comanche cycle. Although it is not recognized in the Code of Stratigraphic Nomenclature (American Commission on Stratigraphic Nomenclature, 1961), the division is a formal stratigraphic unit which,

System	Substage (Young. 1967)	Group	Formation	Member	Thickness (feet)	Generalized Lithology +42 feet covered
CRETACEOUS	Middle Albian	Fredericksburg	Edwards		93.0	
			Walnut	Bee Cave	10.5	
				Bull Creek	23.8	
	Lower Albian	Trinity	Glen Rose	G	120.9	
				F	87.7	
				E	44.4	
				D	98.5	
				C	52.6	
				B	60.4	
	Lower Albian / Upper Aptian			A	88.0	



scale: 1"=100'

Figure 3.

Columnar Section of the Cretaceous System in the Wimberley Area because it is bounded by isochronous surfaces, is equivalent to the time-stratigraphic unit defined in the Code (Young, 1967a). Adkins (1933) used Hill's divisions in a rock-stratigraphic sense by referring to them as groups. At the present, the Trinity, Fredericksburg, and Washita may be regarded either as divisions or as groups. The choice of which is used depends on the size of the area being studied and the point of view that is presented. The division is most useful for regional work and for interpretations of origins of rock units. The group is more useful for mapping in small areas (Young, 1967a). The Trinity, Fredericksburg, and Washita are regarded here as groups because the thesis area includes a relatively small portion of the Texas Comanche rock body, both in areal extent and in the total stratigraphic section represented, and because the units mapped are rock stratigraphic; that is, they are formations and members. Parts of two groups, the Trinity and the Fredericksburg, crop out in the Wimberley area.

Trinity Group

Hill (1889, p. xv) named his Trinity Division for excellent exposures along West Fork and Clear Fork of the Trinity River northwest of Fort Worth. After he made several changes in the formations that compose the Trinity (Young, 1967a, p. 13, table 2), Hill finally (1937) decided to include in it the Glen Rose and underlying formations. Several formations of the Trinity Group are present below the surface of the Wimberley area, but the group is represented only by the upper part of the Glen Rose at the surface.

Subsurface formations

Four formations of the Trinity Group are present below the surface of the Wimberley area. They are, in ascending order, the Hosston and Sligo (Sycamore), the Pearsall (Hammett and Cow Creek), and the Hensel Formations. Because this study is a surface mapping project, these units were not studied and will be discussed only briefly here. The data given are taken from other authors, chiefly Young (1967a).

The Hosston Formation, a transgressive, dominantly terrigenous unit, is a shoreward shale and sand facies of the overlying marine Sligo Formation and is the subsurface rock-stratigraphic equivalent of the outcropping Sycamore Formation. The Sligo Formation, which is primarily a marine limestone, does not crop out in the central Texas region. The Pearsall Formation is the subsurface equivalent of the combined

Hammett and Cow Creek Formations (Forgotson, 1957), which are exposed north and northwest of the Wimberley area. The Hensel Sand, which is a shoreward sand facies of the Glen Rose Formation, thins to the south and southeast as a result of replacement by Glen Rose strata.

Glen Rose Formation

The Glen Rose is the most extensive formation in the Wimberley quadrangle, cropping out over about 90% of its area. The formation was originally named the *Caprotina* Limestone by Shumard (1860, p. 588). Hill initially (1889, p. xvii) called it the "basal or alternating beds" but later formally named it the Glen Rose Limestone (1891) and designated the type section along the Paluxy River near the town of Glen Rose, Somervell County. This type section is in the thinned, updip, nearshore extension of the formation.

The Glen Rose is primarily a carbonate deposit with varying amounts of clay. It was laid down on the Comanche Shelf in the vast lagoon behind the Gulf Coast reef trend. This back reef area possessed several types of depositional environments in which the Glen Rose sediment accumulated. Young classed the environments into four broad categories: "(1) nearly normal saline environments as indicated by the micrites with diverse mollusc assemblages; (2) tidal flats that are represented by the flats on which dinosaurs left their tracks; (3) biogenic growths now represented by tabular and biohermal rudistid and coral reefs; and (4) hypersaline environments represented by evaporite beds, celestite bearing beds, and fine-grained dolomites" (Young, 1967a, p. 18). Recent reports on selected portions of the Glen Rose by paleoecology classes at the University of Texas at Austin (Scott, *ed.*, 1967, 1968) show that a variety of environments at or very close to sea level existed during Glen Rose deposition. Three basic environments - subtidal, intertidal, and supratidal - are recognized and are shown to be related to each other vertically in a logical facies sequence that is a reflection of cyclic deposition: "The repetitious nature of Glen Rose rocks suggests a cyclic onlap-offlap sequence. The actual cycles may be thought to begin by a rapid transgression followed by a longer period of regression or depositional progradation. Onlap sequences are seldom well represented in Glen Rose sediments. The offlap phase is probably due to progradation as a result of subsidence. The record in an ideal offlap sequence would then be subtidal, intertidal, ending in a beach and/or marsh. This ideal is seldom, if ever, realized." (Bishop, 1968, p. 3)

The upper 553 feet of the Glen Rose Formation is exposed in the Wimberley area. The total thickness of the formation is given below. The lower contact does not crop out within the confines of the area but is exposed less than five miles to the west. The upper contact in Hays and Comal County area has been described by Moore (1964, p. 6): "The Bull Creek Limestone unconformably onlaps the Glen Rose to the northwest and west; this unconformity seems to die out to the south and the Bull Creek and Glen Rose intercalate." No evidence for an unconformity was observed in the thesis area.

The Glen Rose, at its outcrop belt in the central Texas region, has been arbitrarily divided into two members, the Upper and the Lower, at a key bed known as the "*Corbula* bed." This key bed was first recognized and utilized by F. L. Whitney, who noted its persistent association with the subjacent "*Salenia texana* marl" and its constant relation to the top of the Glen Rose (Lozo and Stricklin, 1956). The "*Corbula* bed" will be described more completely in a later section. Tucker (1962, p. 188, fig. 6) has constructed an isopachous map of the Lower Glen Rose indicating that the member ranges in thickness from 300 feet in the northern part to about 400 feet in the southern part of the area. Measured sections for this study show that the Upper Glen Rose is approximately 400 feet thick. Thus the thickness of the entire Glen Rose Formation in the area ranges from 700 to 800 feet.

The Glen Rose Formation in the Wimberley area is divided here into seven cartographic units designated in ascending order by the letters A through G. The purpose of defining these units is to classify stratigraphic information of the Glen Rose, to allow more detailed mapping of the thesis area (Plate 1), and to provide control horizons for locating faults and determining their displacements. The units are considered to be informal members because they do not fit the definition of formal members (Code of Stratigraphic Nomenclature, American Commission on Stratigraphic Nomenclature, 1961) in the following respects: 1. They are defined chiefly on mappability; 2. There is as much lithologic variation within some of the members as there is between different members; and 3. The members are not given geographic names. The establishment of formal members of the Glen Rose Formation must await study of the formation over a larger area than the Wimberley area. The members defined here may or may not be valid or useful outside the thesis area.

A condensed discussion of the lithology and fossil content of each of the members is given below; a more detailed bed by bed description appears in the Appendix and Plate 2. The vegetation growing on each of the members is also discussed below and, because the members are defined primarily on air photograph mappability, their air photograph characteristics will also be described. The data given for each of the members are taken from areas where their full thicknesses are exposed and their outcrops are good.

Member A: Member A is composed of the oldest exposed strata in the Wimberley area. The outcrop area of the member is confined to the part of the drainage basin of Cypress Creek that lies northwest of Jacob's Well fault. The description of the member given below applies only to its upper 88 feet, the portion that is exposed in the Wimberley area.

The upper 54 feet of Member A consists of very thick bedded, massive, resistant, gray-weathering limestones that range in composition from fossiliferous micrite to packed biomicrite. The 34 feet of strata below these limestones is composed of thin to medium bedded limestones and marls. A single 9 foot thick bed of massive limestone occurs about 68 feet below the top of the member.

The base of Member A is defined as the base of the Glen Rose Formation. Approximately the upper 88 feet of Member A crops out at the surface and a sample taken from inside Jacob's Well about 54 feet below the base of the surface outcrop had Glen Rose and not Hensel lithology, indicating a minimum thickness of 142 feet for the member.

The top of the member (Figure 4) is usually marked by a sharp break in slope and by a well defined change in tone on air photographs. The break in slope is caused by change in lithology from the thick, resistant limestones of the upper part of Member A to the less resistant marls of Member B and the tonal change results from a change in the density of vegetation from very dense on A to moderately sparse on B.

Figure 4.

Contact between Members A and B

Northwest view showing the massive, thick bedded limestones at the top of Member A and the thinner bedded marls and limestones at the base of Member B. The break in slope at the contact is also visible, but the normal greater abundance of vegetation on Member A than on Member B is not displayed. The photo was taken near Mt. Sharp Road about 0.5 miles northwest of the intersection with Jacob's Well Road.

The appearance of Member A on air photographs is generally different from the rest of the Glen Rose because it lacks the distinctive well-bedded, contoured appearance of the rest of the formation, appearing instead relatively massive, unbedded and homogeneous. The member supports a dense growth of mixed live oaks and junipers, and thickets of shin oaks (*Quercus harvardii*?) also grow profusely in some areas.

Member B: Member B is 60 feet thick. With the exception of a narrow, mostly covered outcrop band along the Blanco River upstream from Wimberley fault, outcrops of the member are present only on either side of the Cypress Creek drainage basin northwest of Jacob's Well fault and on both sides of Cypress Creek in the fault block between Jacob's Well and Tom Creek faults. The member is composed of three thick, non-resistant, recessive marls that are separated by thin to medium bedded limestones and marly limestones.

Miliolids, orbitolines, and serpulids are common in the member and *Monopleura* sp. were observed in at least two beds. The seven to eight foot thick "*Salenia texana* marl" near the top of the member is one of the most fossiliferous beds of the Glen Rose Formation. The regular echinoid *Salenia texana* Credner, the namesake of the bed, rarely occurs in any other Glen Rose strata. Other fossils present in the *Salenia* zone are several species of regular and irregular echinoids, extremely abundant orbitolines, several species of pelecypods in the form of "heart clam" steinkerns, serpulids, *Nerinea* sp., *Porocystis globularis* Giebel, and fragmented oysters.

The lower boundary of Member B was described in the summary of Member A. The upper boundary is defined as the top of the "*Corbula* bed," the key bed which divides the Glen Rose Formation into its formal Lower and Upper Members. This distinctive stratum is easily recognized in the field because it is heavily iron stained and it contains a profusion of the small clam *Corbula harveyi* (=*Corbula martinae* Whitney, 1952a; =*Leda harveyi* Hill, 1893) which superficially resembles large wheat grains. The bed is also usually ripple-marked with low amplitude symmetrical ripples (Figure 5). This key bed is an excellent mapping horizon not only because it is readily recognized in outcrops, but also because it is easily traced on air photographs, appearing as a thin, continuous black line separating lighter-toned areas on either side. This line is caused by an abundance of trees in a generally sparsely vegetated interval.

Figure 5.

Contact between Members B and C

Two views of the "*Corbula* bed", the contact between Members B and C. The upper print shows the characteristic ripple-marked upper surface of the bed. The lower print is an eastward view showing the subjacent "*Salenia texana* marl" capped by the "*Corbula* bed". Several moderately resistant marly limestones separate the "*Corbula* bed" from the lower, marly part of the "*Salenia* marl."

Member B possesses the characteristic well-bedded, contoured appearance of the Glen Rose on air photographs. The sparse tree population on the member is made up of mixed live oaks and junipers.

Member C: The 53 foot thick Member C crops out on both sides of the Cypress Creek drainage area northwest of Jacob's Well and Lone Man faults and in the west central half of the area between Wimberley fault and Jacob's Well fault. It is composed of interbedded recessive marls and more resistant limestones. The limestone beds are usually slightly dolomitic. In the lower part of the member, the limestone beds are thinner than the marls but in the upper part of the member the limestones are thicker than the marls. A distinctive 4.5 foot thick bed in the lower part of the member, which is composed of a network of textureless sparry calcite veins, was probably originally deposited as an evaporite.

Fossils are not abundant in Member C. Miliolids are the most frequent, occurring in several beds in the lower and upper parts of the member. Three thin flags of *Corbula*-bearing limestone occur near the base, but they are easily distinguished from the stratum used to separate Members B and C because they are much thinner and are not ripple-marked.

The lower boundary of Member C was described in the discussion of Member B. The upper contacts of Members C, D, and E are similar (Figure 6) in that they are defined at changes in lithology that are expressed on air photographs as sharp breaks in slope and tone. The upper boundary of Member C marks a change from medium bedded, resistant limestones at the top of the member to much less resistant, thick marls in the lower part of Member D. The contact is usually marked on air photographs by a sharp break in slope and by a sudden tonal change. The change in slope is usually marked by a decrease in slope upward from the resistant limestones of the upper part of C to the nonresistant marls at the base of D. The change of tone is from dark near the top of C, where live oaks and junipers are abundant, to very light on the almost barren marls near the base of D.

The air photograph characteristics of Member C are similar to those of Member B; that is, the member appears well bedded and trees are moderately sparse. Near the top of the member, however, the trees become much more abundant. The trees are mixed live oaks and junipers.

Member D: Member D, which is about 99 feet thick, is one of the most widespread units in the Wimberley area. It is composed of interbedded limestones, marls, and marly limestones. The poorly resistant marls are generally thicker than the resistant limestones, and they form the greater portion of the lower part of the member. The limestones, however, gradually constitute a greater part of the section upward, until near the top of the member they predominate.

Member D is moderately fossiliferous. The most abundant fauna are orbitolines and miliolids. The first occurrence of orbitolines above the *Salenia texana* marl of Member B is from 6 to 12 feet above the base of Member D. Miliolids are scattered through many beds within the member. The algal fruiting body *Porocystis globularis* Giebel was observed in 2 beds in the member, one near the base and the other near the top. Pelecypod steinkerns are common in several beds near the middle of the member. Rudists, including both *Monopleura* sp. and *Toucasia* sp., were observed about 12 feet above the base of the member.

The lower boundary of Member D was described in the summary of Member C. The upper contact (Figure 6) is defined at a sharp break in slope associated with the change in lithology from the hard, resistant limestones at the top of the member to the less resistant dolomites at the base of Member E. In areas of moderate relief, the contact is also marked by a change of tone from the dark tone of the densely vegetated limestones at the top of Member D to the light tone of the more sparsely vegetated dolomites near the base of Member E.

On air photographs, Member D exhibits the characteristic well bedded appearance of the Glen Rose. The tone of the member grades from very light on the sparsely vegetated marls near the base to dark on the more densely vegetated limestones near the top. Member D supports a tree population of mixed live oaks and junipers. The junipers are dominant, although sparse, near the base and the oaks predominate near the top of the member.

Member E: Member E, which is about 44 feet thick, occurs in three parts of the Wimberley area. It circumscribes Lone Man and Lone Woman Mountains in the northeastern part of the area, it crops out in the central part of the area on the fault

Figure 6.

Contact between Members D and E.

Southeast view showing the break in slope at the contact of the hard, resistant limestones at the top of Member D and the softer, less resistant dolomite beds at the base of Member E. The contacts between Members C and D and between Members E and F show a similar break in slope associated with a change from resistant limestones below the contact to less resistant beds above.

block between Tom Creek and Wimberley faults, and a narrow outcrop band is present immediately south of the Blanco River and east of Wimberley fault.

The lower 16 feet of Member E comprises several sacchoroidal, porous dolomite beds that have little or no trace of their original limestone textures. The next 6 feet is a distinctive dolomitic marl, and the remainder of the member is composed of a sequence of dolomites, dolomitic limestones, and hard, resistant limestones. The resistant limestones compose a greater part of the section upward, until near the top of the member, they form the entirety of the section.

Aside from miliolids, which occur sporadically through the entire member, fossils are not abundant. Several specimens of *Porocystis globularis* Giebel are present in the dolomitic marl above the basal dolomite beds and abundant *Monopleura* sp. were noted near the top of the member.

The lower boundary of Member E was described in the discussion of Member D. As in Members C and D, (Figure 6) the upper boundary of Member E is defined at a sharp break in slope. The slope break at the contact between Members E and F is caused by a change in lithology from the hard, resistant limestones at the top of Member E to much less resistant marls at the base of Member F. In areas of moderate relief, the contract is also marked by a change of air photograph tone from dark on the rather densely vegetated limestones at the top of Member E to light on the sparsely vegetated marls of Member F.

The tone of Member E gradually changes from light on the dolomitic and marly lower part to dark on the resistant limestones of the upper part of the member. The tree population of Member E is composed of mixed live oaks and junipers.

Member F: The most extensive outcrops of the 88 foot thick Member F are along the high relief area south of the Blanco River across the entire width of the thesis area. Other less extensive occurrences are in the northern and northeastern part of the area in the vicinity of Lone Man and Lone Woman Mountains, in the central part of the area around Little Twin Sisters Peaks and Joe Wimberley Mountain, and along the eastern margin of the area south of Lone Man fault. The member is composed of thick marls separated by thin interbeds of resistant limestones. The member is dolomitic in its upper part, with the dolomite content increasing upward.

Member F is moderately fossiliferous. Miliolids are abundant through the entire section. Two beds in the upper part of the member contain an abundance of the regular echinoid *Loriola* sp. and are the most fossiliferous in the member. These beds contain, in addition to *Loriola* sp., abundant oyster fragments, gastropods, serpulid fragments, clam steinkerns, and occasional specimens of *Neithea* sp.

The lower contact of Member F was described in the section on Member E. The upper contact (Figure 7) is defined as the base of the lowest dolomite bed of Member G. This bed is the lowest stratum above the dolomites of Member E which, when weathered, is a massive, saccharoidal, porous dolomite bed. The measured section including this contact was on a relatively fresh roadcut, and the lowest bed of Member G was not a dolomite, but was instead a dolomitic limestone, indicating that the calcareous content of this stratum is removed by solution when the bed is weathered. On air photographs the contact is marked by a subtle change in slope (Figure 7) and by a well defined change in weathering character from the rounded appearance of Member G to a more angular and "fluted" appearance of the upper part of Member F. The contact is also marked by a change of tone from light on the sparsely vegetated Member F to very light on the very sparsely vegetated Member G. Member F appears almost homogeneous on air photographs, displaying little of the characteristic contoured appearance of the Glen Rose. The sparse growth on Member F is composed almost exclusively of junipers.

Member G: Member G, which has a thickness of 121 feet, is the thickest member of the Glen Rose. It crops out most extensively in the high relief area south of the Blanco River in a wide band that, like Member F, crosses the entire width of the thesis area. It is also exposed on high relief hills along the eastern margin of the area south of Lone Man fault and at the tops of other high hills, including Lone Man and Lone Woman Mountains, the Little Twin Sisters Peaks, and Joe Wimberley Mountain.

The member is composed of interbedded limestone, dolomitic marl and limestone, and dolomite. The dolomite beds are saccharoidal, fine to medium crystalline, and medium to thick bedded. Although relict features are common in these beds, dolomitization has effaced most of the original limestone textures and structures. Most of the intervening limestones and marls between the dolomite beds are dolomitic.

Figure 7.

Contact between Members F and G

Westward view of the westernmost mountain of the Little Twin Sisters Peaks showing the break in slope and the change in abundance of vegetation at the contact between Members F and G.

Approximately the upper 21 feet of the member comprises a sequence of interbedded dolomite and pulverulite (chalky, porous calcium carbonate) beds that are laced with textureless sparry calcite veins "Distorted bedding" and collapse breccia were also seen. These beds are interpreted to be evaporitic deposits from which the evaporite minerals have been removed by solution.

Member G contains few fossils, partly because the depositional environment may not have been suited for a prolific fauna and partly because much of the fossil content may have been effaced by dolomitization Abundant burrows, however, indicate considerable biogenic activity.

The lower boundary of Member G was described in the discussion of Member F. The upper boundary is the contact of the Glen Rose Formation and the Bull Creek Member of the Walnut Formation which has been discussed. This horizon is difficult to map because it is marked by neither a break in slope nor a change in tone on air photographs. It must normally be traced by assuming a constant thickness of the Bull Creek Limestone and placing the contact a distance equal to that thickness below the more easily mappable Bull Creek—Bee Cave contact above On air photographs Member G exhibits the characteristic well-bedded, contoured appearance of the Glen Rose Formation. It is very light toned in its lower part because it supports only a very sparse population of trees that are almost exclusively junipers. The tone becomes darker upward owing to an increasing density of vegetation until near the top of the member the tone is dark The tree population in the upper part of the member is composed primarily of junipers with occasional live oaks

Fredericksburg Group

The Fredericksburg was first named by Römer (1846) for the town of Fredericksburg in Gillespie County. Römer was unaware of the Balcones fault zone and thought the Fredericksburg strata overlay younger Cretaceous strata of the Gulf Coastal Plain. Hill recognized the correct stratigraphic position of the Fredericksburg and used the name for the intermediate division of his Comanche Series (1887b, p. 301). Moore, who has recently done a regional study of the Fredericksburg in nine counties of central Texas including Hays and Comal Counties, recognizes three formations in the

Fredericksburg which are, in ascending order, the Walnut, Comanche Peak, and Edwards Formations. Moore's stratigraphic classification, because it is the most recent and comprehensive in the area, is used here. The Edwards Formation, according to Moore, thickens southward from the Williamson County area and replaces the Comanche Peak Formation and the upper members of the Walnut Formation by facies change.

The Fredericksburg Group in the Wimberley area is most extensive on the upland in the southern part of the area. Smaller outcrops are present along the eastern margin in the northern half of the area on the downthrown side of Lone Man Fault.

Walnut Formation

The Walnut Formation was named by R. T. Hill (1891, p. 512) for exposures near the town of Walnut (now Walnut Springs), Bosque County.

Moore (1964) divided the Walnut into five members in his regional study of the formation in central Texas. In ascending order, they are the Bull Creek, Bee Cave, Cedar Park, Keys Valley, and "upper marl" members. The upper three Members, as well as the overlying Comanche Peak Formation, are replaced by the Edwards in the Wimberley area, and only the Bull Creek and Bee Cave Members are present. The Bee Cave also pinches out south of the thesis area because of facies replacement by the Edwards. Before Moore's classification of the Walnut, the strata that comprise the Bull Creek Member were included in the Glen Rose Formation and the Bee Cave alone was considered to represent the Walnut in Hays County.

The thickness of the Walnut Formation in the Wimberley area is about 34.5 feet. The Bull Creek and Bee Cave Members are mapped as separate units in areas of low to moderate relief where they can be distinguished on air photographs, but they are grouped together and mapped as undifferentiated Walnut Formation in areas of steep relief where the contact between the two members cannot be recognized on air photographs and where the upper and lower contact lines of the Walnut are too close together on the map to allow room for the Bull Creek–Bee Cave contact line.

Bull Creek Member: Moore (1961, p. 22) named the Bull Creek Member for exposures in the drainage of Bull Creek west of Austin, Travis County. The member is about 24 feet thick in the Wimberley area and is composed of hard, resistant, medium bedded limestones and dolomitic limestones that are mostly biomicrites and intraclastic biomicrites. A single bored surface was noted about 7.5 feet below the top of the member.

Although gastropods are common, other macrofauna is sparse in the Bull Creek. Miliolids occur through most of the thickness of the section. Moore (1964, p. 27), in his facies analysis of the Fredericksburg, classed the Bull Creek in his "intraclast facies" and identified the depositional environment as relatively high energy shallow marine. He believed the member to be "a submarine bar-type deposit parallel to the shore, possibly analogous to the present Mustang Island along the Gulf Coast of Texas." (1964, p. 27)

The lower boundary of the Bull Creek was discussed in the section on the Glen Rose Formation. The upper contact is pitted, corroded, and iron-stained, suggesting that the Bull Creek may have been emergent for a time before the onset of Bee Cave deposition. This distinctive horizon, according to Moore (1961, p. 25), is traceable throughout central Texas. The Bull Creek supports a dense growth of mixed live oaks and junipers and consequently has a dark tone on air photographs.

Bee Cave Member: The Bee Cave Member was named by Moore (1961, p. 26) and the type section was designated just west of Austin, Travis County. The member is 10.5 feet thick in the Wimberley area and is composed of a single fossiliferous nodular marl bed (Figure 8). The overwhelmingly dominant fossil is the oyster *Exogyra texana* Römer, but several species of echinoids, gastropods, and clams are also present.

Because the Bee Cave is a relatively thin and poorly resistant marl sandwiched between the resistant limestones of the Bull Creek and Edwards, it is, in areas of low to moderate relief, the most easily mappable unit in the Wimberley area. Both the upper and lower contacts are marked by sharp breaks in slope and by changes in tone. The light toned Bee Cave appears as a white band between the darker toned underlying Bull Creek and overlying Edwards limestones.

The Bee Cave supports a population of mixed live oaks and junipers. The growth is sparse in areas of low to moderate relief and dense where relief is high.

Edwards Formation

The Edwards Formation was first named the *Caprina* Limestone by Shumard (1860, p 584). Hill initially called it the "Barton Creek Limestone" to replace the

Figure 8.

The Bee Cave Marl

Westward view of the Bee Cave Member of the Walnut Formation showing characteristic nodular appearance. The motorcycle rests on the Bull Creek-Bee Cave contact. The Bee Cave-Edwards contact (indicated by arrow) is at the base of the lowest resistant limestone above the marl.

paleontologic name used by Shumard, but Hill and Vaughan (1898a, p. 2; 1898b, p. 227-235) renamed it the Edwards Formation for the Edwards Plateau. Although Hill probably considered Barton Creek near Austin the type section, he failed to designate it formally and the task was fulfilled by Adkins (1933, p 339).

Rose (in press) has studied the Edwards in central Texas and is raising it to group status using two sets of formational nomenclature, one for surface exposures on the Edwards Plateau and the other for the subsurface between the Balcones Fault Zone and the Gulf Coast Reef Trend. He recommends usage of his subsurface formations, the Kainer below and the Person above, for the Edwards outcrops within the Balcones Fault Zone. The Edwards in the Wimberley area is considered here to be a formation because only the lower part of the Kainer is present and because Rose's study has not yet been published.

The maximum thickness of the Edwards in the Wimberley area is about 130 feet on one of the upland hills in the southern part of the area. The lower 93 feet was measured and described in a very poorly exposed section; the remainder of the section is too badly covered with soil and vegetation for description. The portion described is composed mostly of dolomitized or recrystallized limestones. Bluish gray chert nodules with white patina were observed about 85 feet above the base of the formation.

With the exception of a few recognizable miliolids in scattered beds and occasional rudists, the Edwards, at least in the section measured, is largely unfossiliferous.

The Edwards supports a dense growth of mixed live oaks and junipers. Prickly pear cactus and Texas (black) persimmon (*Diospyros texana*) are also abundant. The vegetation displays well developed bedding control that is exhibited as alternating bands of dense and sparse vegetation.

QUATERNARY SYSTEM

Quaternary deposits of three different types are present in the Wimberley area. Alluvial deposits were laid down by perennial and intermittent streams, colluvium was deposited directly by the action of gravity, and upland deposits remain at or near the place of their release from bedrock. Only the alluvial deposits are extensive enough to map.

Alluvium: Alluvial deposits of clay through gravel size occur along the Blanco River and Cypress Creek and along the courses of small intermittent streams. These deposits are composed mostly of limestone gravel with clay matrix. Their thicknesses are variable, approaching 40 feet in some of the terraces of the Blanco River.

Colluvium: Colluvial blocks up to 50 feet in length have dropped from cut banks of Cypress Creek in the portion of the creek that flows in Member A. These blocks have fallen as the result of undercutting by the creek.

Upland deposits: The upland areas having Glen Rose bedrock, where relief is relatively low, are covered with a veneer of limestone gravel and dark brown to black soil. The Edwards Formation on the upland area in the southern part of the thesis area is mantled with a regolith of reddish brown terra rosa type soil and a residuum of chert and limestone gravel. These deposits are at or near the point of their release from bedrock. No stream-worn or percussion marked chert gravel characteristic of "Uvalde-type" gravel was observed.

STRUCTURAL GEOLOGY

Three major kinds of structural features occur in the Wimberley area. Several faults of the Balcones system transect the area, numerous joints are present in the harder, more resistant limestone beds, and the strata throughout the area dip gently to the southeast.

Faults

Six major Balcones faults pass through the Wimberley area, and several minor faults cross some parts of the area. Like most faults of the Balcones system, these faults are normal, northeast trending, southeast dipping strike faults. The dips of the fault surfaces cannot be measured accurately because, although occasional fault outcrops do occur (Figure 9), they are not well enough exposed to permit measurement of dip angle. The traces of the faults are not appreciably affected by topography, indicating that the faults are nearly vertical. Displacement on the faults may be confined to a single surface or it may be distributed over a zone of varying width.

The faults in the Wimberley area seldom have appreciable topographic expression.

They are either intraformational or they displace different formations having about equal resistance to erosion into contact with each other so that erosion has proceeded at an equal rate on both sides of the faults and no fault-line scarps have formed. The most useful method of locating the faults is to find displaced stratigraphic horizons. One of the primary reasons for subdividing the Glen Rose Formation, as previously stated, was to provide such control horizons for locating faults and determining their displacements. Another good indicator of faulting in an area is the presence of dipping beds; that is, of beds with sufficient dip to be easily seen in the field. Such high angle dips are usually caused by solution collapse or drag along a fault and are confined to the immediate vicinity of the fault.

If a fault is suspected in an area, it can usually be mapped accurately by examining aerial photographs for lineations. Although lineations can frequently be seen by using the photographs as stereo pairs, they are more conspicuous if the photographs are used singly and are viewed obliquely down the trace of the suspected fault. When viewed in this way, the linear features "line up" and the faults can be mapped easily and accurately.

The major faults and some of the minor faults in the area are described below. The general trends of the fault traces are given, but, because the traces are slightly irregular or serrate, the bearing of a trace at a particular point may differ considerably from the general trend. The stratigraphic separation (Badgley, 1965), referred to below simply as displacement, has been determined at several places along each of the faults by comparing elevations of stratigraphic horizons on both sides of the faults. These elevations, which were taken from the topographic base map, are normally accurate to about 15 feet, so that in most cases the accuracy of the displacement is about ±30 feet. The accuracy is greater for small-displacement faults and less where strata of fault blocks on either or both sides of the fault dip relatively steeply or where different stratigraphic horizons on either side of the fault must be used.

Major Faults

Lone Man Fault: The name Lone Man is applied here to a major displacement fault situated near the eastern boundary of the thesis area about 1½ miles south of Lone

Man Mountain. At its southwest end, near the intersection of Texas F.M. 12 and Jacob's Well Road, the fault splits into two smaller faults – Jacob's Well fault and Tom Creek fault. The portion of the fault located in the Wimberley area has a bearing of approximately N58°E, and its displacement is about 275 feet downward to the southeast. A short distance east of the area the Edwards formation has been faulted down into contact with Member D of the Glen Rose formation.

Jacob's Well Fault: The northern branch from Lone Man fault is named here for Jacob's Well, a large perennial spring in the bed of Cypress Creek about 300 yards upstream from the fault (Frontispiece). The trace of Jacob's Well fault is slightly irregular to serrate, but its average trend is N55°E. The contact between Members B and C is displaced downward to the southeast approximately 150 feet along Jacob's Well Road and about 100 feet in the vicinity of the intersection of Jacob's Well Road and Texas F.M. 2325. The fault begins in the northeast where it branches from Lone Man fault near the intersection of Jacob's Well Road and Texas F.M. 12. It progresses along the northeast portion of Jacob's Well Road to the intersection with Mt. Sharp Road and continues southwestward from there. The fault crosses the western boundary of the thesis area about ½ mile south of Fischer Store Road.

Jacob's Well Fault is the best exposed fault in the Wimberley area (Figure 9). It is also well expressed as a lineation on aerial photographs, especially on the unnamed hill ½ mile southwest of the intersection of Jacob's Well Road and Texas F.M. 12, where a sharp tonal change occurs at the lineation.

The spring Jacob's Well, which is caused by the fault, flowed about 1100 gallons per minute when its discharge was measured in 1955 (DeCook, 1963, p. 57). Increased rainfall in recent years has probably increased this flow somewhat. The conduit from which the spring issues is approximately 110 feet deep, but its actual length is greater than that because it extends horizontally about as far as it is deep and it is somewhat sinuous. The width of the well at the surface is about 10 feet and the conduit remains wide enough downward to permit entry of scuba divers all the way to the bottom. Photographs of fretted walls inside the well indicate that solution is still active. The source of the water issuing from the spring is ground water which flows down-dip through

Figure 9.

Outcrops of Jacob's Well Fault

The upper print is a southwest view showing Member D faulted against Member B. The photo was taken on an unnamed hill about 0.5 miles southwest of the intersection of Jacob's Well Road and Texas FM 12.

The lower print is a northeast view of Jacob's Well fault showing slight fault drag on the upthrown side of the fault and several blocks that were detached from the upthrown side of the fault and dragged downward slightly. Most of the displacement occurred on a surface just to the right of the "dragged blocks." The photo was taken across Cypress Creek where the creek crosses the fault.

the cavernous limestones of Member A. This water meets an impermeable barrier at Jacob's Well fault, where the marls and thin limestones of Member B are faulted down into contact with Member A. The water does not flow to the surface along the fault plane but rises instead about 300 yards updip from it, possibly because fractures associated with the fault provided a channel early in the history of the spring.

Tom Creek Fault: Tom Creek fault was named by W. O. George (1952, p.52) for Tom Creek, a tributary to the Guadalupe River in Comal County. Tom Creek fault in the Wimberley area begins where it branches from Lone Man fault and progresses southwestward, passing just northwest of Little Twin Sisters Peaks and leaving the thesis area on the west along Cloptin Road.

The trace of Tom Creek fault, like that of Jacob's Well fault, is slightly irregular and serrate but its general trend is about N35°E. Displacement is downward to the southeast and ranges from about 130 feet on the unnamed hill southwest of the Jacob's Well Road–Texas F.M. 12 intersection to about 100 feet southwest of Little Twin Sisters Peaks. Well exposed outcrops of Tom Creek fault are rare.

Wimberley Fault: The Wimberley fault was named by DeCook (1963, p. 46) for the community of Wimberley. The fault is composed of two segments, a short eastern segment having a bearing of N40°E and a much longer western segment that has a bearing of about N53°E in the northeast and approximately N43°E in the southwest. The eastern segment crosses the eastern boundary of the area approximately one mile northeast of Wimberley and continues southwest about ½ mile and then "splays out" into three segments and becomes covered by alluvium of Cypress Creek. Although the fault is not mapped beyond Wimberley, a small displacement extension of it may continue for as much as another mile to the southwest, as indicated by the anomolous northeast course of the Blanco River and by slightly dipping strata that were observed in the bed of the river about ¾ mile southwest of the community.

The longer, western segment of the fault begins a short distance north of the eastern segment and trends southwestward, passing near Pioneer Town and leaving the area about ½ mile north of the Devil's Backbone. Displacement on the fault is downward to the southeast and amounts to about 100 feet in the vicinity of Cloptin Road and approximately 120 feet near the western margin of the area. The fault crops out near the mouth of Smith Hollow Creek, where its apparent dip is about 80° southeast.

Devil's Backbone Fault: The Devil's Backbone fault is named here for the Devil's Backbone, a high relief ridge forming the sharp divide between the drainage basins of the Blanco and Guadalupe Rivers on the western margin of the thesis area. The fault trends generally N80°E across the entire width of the area in the vicinity of Texas F.M. 32. The fault trace is, however, very irregular and serrate and its trend ranges from N58°E to N80°W. The Bee Cave-Edwards contact is displaced downward to the south about 60 feet. The fault appears to be a cross-fault between Hidden Valley fault and Wimberley fault.

Hidden Valley Fault: Hidden Valley fault was named by George (1952, p. 31). Only a short segment of this fault is present in the Wimberley area, transecting the southeast corner of the area at a bearing of about N50°E. Lack of stratigraphic control prevented determination of the displacement of the fault, but it was estimated by George (1952) to be about 200 feet. No outcrops of the fault were observed in the Wimberley area.

Minor Faults

Poppy Ranch Fault: The Poppy Ranch fault is named for the ranch in the thesis area on which most of its length is located. The fault enters the area from the northeast approximately ½ mile south of Lone Man fault and dies out about ¾ mile to the southwest. The trend of the fault is about N55°E and its displacement is downward to the southeast, ranging from zero at its southwest end where it dies out to a minimum of 35 feet at the eastern margin of the area. This fault is closely related to the much larger displacement Lone Man fault and probably branches from it east of the thesis area.

Eagle Rock Ranch Fault: Eagle Rock Ranch fault, like the Poppy Ranch fault, is named for the ranch on which most of its length is located. The fault branches from Lone Man fault and is about 2¾ miles long. It is connected to Tom Creek fault by a short cross fault a short distance west of Texas F.M. 12. The segment of the fault northeast of the short cross-fault differs from other faults in the area in being downthrown to the northwest. The fault block between Lone Man fault and this northeast segment of Eagle Rock Ranch fault is a small graben. Southwest of the cross-fault, displacement on the fault is normal; that is, downward to the southeast.

Displacement on the fault is variable and could not be determined because fault block dip on the southeast side of the fault is too great to provide stratigraphic control. A good outcrop of the fault occurs at the top of a small hill a short distance northeast of the point where the fault is crossed by Texas F.M. 12.

Unnamed faults: Two short, unnamed, small-displacement faults are located northwest of Jacob's Well fault near the western margin of the thesis area. The average trend of the northern fault is about N75°E and the southern fault bears about N52°E. The two faults converge at their northeast ends. Displacement on each of the faults is about 20 feet downward to the southeast.

Joints

Several sets of vertical joints were observed in the Wimberley area, but a rigorous statistical analysis of them is beyond the scope of this study. Consequently no attempt was made to collect systematic joint data or to relate the joints to faulting in the area. Davis (1962) collected joint data in a quadrangle 5 miles east of the Wimberley area and found two pairs of joint sets. One pair trended northeast and northwest and were interpreted to be tension joints related to Balcones faulting. The other pair trended north-south and east-west and were interpreted to have formed before Balcones faulting.

The few joint data collected in the Wimberley area are shown in Plate 1. Almost all of the joints trend either northeast or northwest and, like those in Davis' area, are probably related to the Balcones faults in the area.

Regional and Fault Block Dip

The regional dip northwest of Jacob's Well fault, as determined by the three point method, is 19 feet per mile in a S70°E direction. The two fault blocks between Jacob's Well and Tom Creek faults and between Tom Creek and Wimberley faults are also tilted to the southeast, but apparently at a slightly greater angle then the regional dip angle. The strata between Wimberley fault and Hidden Valley fault appear to dip southeast at about the angle of regional dip. The dip southeast of Hidden Valley fault is not known.

GEOMORPHOLOGY

Edwards Plateau

The Wimberley area, as previously stated, is situated on the dissected eastern margin of the Edwards Plateau. The boundary between the plateau and the Gulf Coastal Plain lies at the main Balcones fault line scarp about seven miles southeast of the thesis area. The Edwards Plateau is a stripped structural surface from which strata overlying the resistant Edwards formation were removed before the plateau was uplifted to its present height (Fenneman, 1936). The eastern margin of the plateau is presently being actively eroded and dissected, as indicated by its high relief and rugged topography. Evidence of this dissection can be seen in the Wimberley area in the high relief hills and ridges along the southern drainage basin of the Blanco River and in the high rounded hills such as Lone Man and Lone Woman Mountains and Little Twin Sisters Peaks, which are erosional remnants of the plateau surface.

Drainage Characteristics

The drainage in some parts of the Wimberley area displays pronounced structural control. This control is manifested in two ways: (1) by the drainage pattern of streams in some sections of the area, which is probably controlled by jointing, and (2) by deflections of individual streams, which are caused by faults.

Drainage patterns: The streams north of Cypress Creek have a strong preferred north-south alignment that is probably controlled by jointing. The Blanco River and its tributaries in the southern part of its drainage basin exhibit a dominant northeast orientation which is no doubt related to joints and very small displacement faults associated with Wimberley fault. The streams between Cypress Creek and the Blanco River and those in the area south of the southern drainage divide of the Blanco do not appear to display any preferred orientations.

Fault deflections: Cypress Creek is deflected sharply to the southwest from its general southeast course in two places where it crosses major faults. The first deflection occurs approximately one mile north of Little Twin Sisters Peaks where the creek crosses Tom Creek fault and the second is a short distance north of Wimberley, where the creek crosses Wimberley fault. The second deflection causes the creek to make a peculiar hook-like bend shortly before it flows into the Blanco River. The Blanco, where it enters the Wimberley area from the west, changes from its normal southerly and easterly course and flows generally northeast across the area because of control by Wimberley fault and associated small-displacement faults.

Minor Geomorphic Features

Terraced topography: Members B through G of the Glen Rose Formation, where relief is moderate to steep, weather to a distinctive terraced topography that is characteristic of the Glen Rose Formation and is used extensively in the central Texas region for identifying the formation in the field (Figure 10). The terraces are caused by differential weathering of the nearly horizontal, thin to thick bedded strata of the formation.

Caves: Several caves, some of which are shown on Plate 1, are present in the Wimberley area. The caves are almost exclusively confined to two stratigraphic units, the Edwards Formation and Member A of the Glen Rose Formation, possibly because the clay content of the other units in the thesis area is too high to permit solution and cave development. No sinkholes were observed in the area.

Surficial solution features: Abundant surficial solution features were observed in the Wimberley area in the form of *lapiés* or *karren* which occur mostly on the Edwards Formation in the upland areas, and tinajitas (Udden, 1925), which were seen only in the vicinity of the Blanco River (Figure 11).

Corrasion grooves: Corrasion grooves (King, 1927) are abundant in the Blanco River and they also occur above the present bed of the river on strata that the river formerly flowed on. These emergent grooves are presently being converted into tinajitas.

Figure 10.

Terraced Topography

Northeast view showing characteristic "terraced" topography of the Glen Rose Formation. Three terraces can be seen. The photo is of Member D and was taken in the northern part of the thesis area.

Figure 11.

Tinajita

View showing the characteristic flat bottom and overhanging sides of a tinajita. The photo was taken near the bed of Blanco River at about the north-south median of the thesis area.

REFERENCES CITED

Abbott, P. L., 1966, The Glen Rose section in the Canyon Reservoir area, Comal County, Texas: Univ. Texas M. A. thesis (unpublished), 146 pp., 4 figs., 6 pls.

Adkins, W. S., 1933, The Mesozoic Systems in Texas, *in* Sellards, Plummer, and Adkins, The Geology of Texas, Part 2, Stratigraphy: Univ. Texas Bull. 3232, v. 2, pp. 239-517, 15 figs.

American Commission on Stratigraphic Nomenclature, 1961, Code of stratigraphic nomenclature: Am. Assoc. Petroleum Geologists Bull., v. 45, no. 5, pp. 645-660.

Badgley, P. C., 1965, Structural and tectonic principles: New York, Harper and Row, 521 pp.

Barnes, V. E., 1952-1967, Geologic maps of 7½-minute quadrangles in Gillespie and adjoining counties, Texas: Univ. Texas Bureau of Econ. Geology Geol. Quad. Maps Nos. 1-20, 25, 27, 29, 32-34.

Behrens, E. W., 1965, Environment reconstruction for a part of the Glen Rose Limestone, central Texas: Sedimentology, v. 4, pp. 65-111, 11 figs., 10 pls., 8 tables.

Bills, T. V., 1957, Geology of Waco Springs quadrangle, Comal County, Texas: Univ. Texas M. A. thesis (unpublished), 108 pp., 5 figs., 16 pls., 4 tables.

Bishop, G. A., 1968, Interpretation of depositional environments, Glen Rose Formation (Lower Cretaceous), Mt. Bonnell, Travis County, Texas, *in* Early Cretaceous depositional environments: Unpublished Term Reports, Geology 383K, Department of Geological Sciences, The University of Texas at Austin, pp. 1-19, 9 figs., 2 pls.

Cartwright, L. D., 1932, Regional structure of Cretaceous on Edwards Plateau of southwest Texas: Am. Assoc. Petroleum Geologists Bull., v. 16, no. 7, pp. 691-700, 3 figs.

Cooper, J. D., 1964, Geology of Spring Branch area, Comal and Kendall Counties, Texas: Univ. Texas M. A. thesis (unpublished), 183 pp., 16 figs., 6 pls.

Cuyler, R. H., 1931, Vegetation as an indicator of geologic formations: Am. Assoc. Petroleum Geologists Bull., v. 15, pp. 67-78, 12 figs., 1 table.

Davis, W. E., 1962, Geology of Lime Kiln quadrangle, Hays County, Texas: Univ. Texas M. A. thesis (unpublished), 90 pp., 11 figs., 1 pl.

DeCook, K. J., 1956, Geology of San Marcos Spring quadrangle Hays County, Texas: Univ. Texas M. A. thesis (unpublished), 86 pp., 17 figs., 1 pl.

DeCook, K. J., 1963, Geology and ground-water resources of Hays County, Texas: U. S. Geol. Survey Water-Supply Paper 1612, 72 pp., 12 figs., 5 pls., 4 tables.

Dobie, D. R., 1932, The history of Hays County, Texas: Univ. Texas M. A. thesis (unpublished), 134 pp., 21 figs.

Fenneman, N. M., 1936, Cyclic and non-cyclic aspects of erosion: Geol. Soc. America Bull., v. 47, no. 2, pp. 173-186.

Flawn, P. T., 1956, Basement rocks of Texas and southeast New Mexico: Univ. Texas Bull. 5605, 261 pp. 9 figs., 3 pls., 12 tables.

Flawn, P. T., Goldstein, A., King, P. B., and Weaver, C. E., 1961, The Ouachita system: Univ. Texas Bull. 6120, 401 pp. 13 figs., 15 pls., 7 tables.

Folk, R. L., 1955, Petrographic stratigraphy of the Texas Gulf Coast Tertiary: Tertiary Field Trip, Univ. Texas Geol. Society, Oct., 1955, pp. 15-18, 4 figs., 1 pl.

Folk, R. L., 1962, Spectral subdivision of limestone types, *in* Classification of Carbonate Rocks-a Symposium: Am. Assoc. Petroleum Geologists, Memoir 1, pp. 62-84., 7 figs., 1 pl., 2 tables.

Forgotson, J. M., Jr., 1957, Stratigraphy of the Comanchean Cretaceous Trinity Group: Am. Assoc. Petroleum Geologists Bull., v. 41, no. 10, pp. 2328-2363, 9 figs.

George, W. O., 1952, Geology and ground-water resources of Comal County, Texas: U. S. Geol. Survey Water-Supply Paper 1138, 126 pp., 7 figs., 6 pls., 21 tables.

Hendricks, L., and Wilson, W. F., 1967, Introduction, *in* Comanchean (Lower Cretaeeous) Stratigraphy and Paleontology of Texas: Publication 67-8, Permian Basin Section, Soc. Econ. Paleontologists and Mineralogists, pp. 1-6, 3 figs.

Hill, R. T., 1887, The topography and geology of the Cross Timbers and surrounding regions in northern Texas: Am. Jour. Sci., Series 3, v. 33, pp. 291-303, 1 fig., 2 pls.

———, 1889, A preliminary annotated check list of the Cretaceous invertebrate fossils of Texas, accompanied by a short description of the lithology and stratigraphy of the System: Texas Geol. Survey Bull. 4, xxxi plus 57 pp., 23 tables.

———, 1891, The Comanche Series of the Texas-Arkansas region (with discussion by C. A. White and others): Geol. Soc. America Bull., v. 2, pp. 503-528.

———, 1893, Paleontology of the Cretaceous formations of Texas; The invertebrate paleontology of the Trinity division: Biol. Soc. of Washington, Proc., v. 8, pp. 9-40.

———, 1901, Geography and geology of the Black and Grand Praries, Texas: U.S. Geol. Survey 21st Annual Report, pt. 7, 666 pp., 80 figs., 71 pls.

———, 1937, "Paluxy sands," with further notes on the Comanche Series (abs.): Geol. Soc. America Proc. for 1936, pp. 79-80.

Hill, R. T., and Vaughan, T. W., 1898a, Description of the Nueces quadrangle: U.S. Geol. Survey Geol. Atlas, Nueces Folio (no. 42), 4 pp., 10 figs., 2 pls., 1 table.

———, 1898b, Geology of the Edwards Plateau and Rio Grande Plain adjacent to Austin and San Antonio, Texas, with reference to the occurrence of underground waters: U.S. Geol. Survey 18th Annual Report, pt. 2, pp. 193-321, 24 figs., 69 pls.

King, P. B., 1927, Corrosion and corrasion on Barton Creek, Austin, Texas: Jour. Geology, v. 35, no. 7, pp. 631-638, 7 figs.

King, V. L., 1957, Geology of the Mission Valley quadrangle, Comal Couty, Texas: Univ. Texas M. A. thesis (unpublished), 86 pp., 4 figs., 1 pl.

Lozo, F. E., and Stricklin, F. L., Jr., 1956, Stratigraphic notes on the outcrop basal Cretaceous, central Texas: Gulf Coast Assoc. Geol. Soc., Transactions, v. 6, pp. 67-78, 8 figs.

Moore, C. H., 1961, Stratigraphy of the Walnut Formation, south-central Texas: Texas Jour. Sci., v. 13, no. 1, pp. 17-40, 10 figs.

Moore, C. H., 1964, Stratigraphy of the Fredericksburg Division, south-central Texas: Univ. Texas Bureau of Econ. Geology Rept. Invest., no. 52, 48 pp., 12 figs., 19 pls., 3 tables.

Noyes, A. P., 1957, Geology of the Purgatory Creek area, Hays and Comal Counties, Texas: Univ. Texas M. A. thesis (unpublished), 94 pp., 16 figs., 1 pl.

Römer, F., 1846, A sketch of the geology of Texas: Am. Jour. Sci., Series 2, v. 2, pp. 358-365.

———, 1848, Contributions to the geology of Texas: Am. Jour. Sci., Series 2, v. 6, pp. 21-28.

———, 1849, Texas: Bonn, Adolphus Marcus, 464 pp.

———, 1852, Die Kreidebildungen von Texas und ihre organischen Einschlüsse: Bonn, Adolphus Marcus, 100 pp.

Rose, P. R., 1968, Edwards formation, surface and subsurface, central Texas: Univ. Texas Ph. D. dissertation (unpublished), 302 pp., 55 figs., 6 pls., 3 tables.

———, (in press), Edwards formation, surface and subsurface, central Texas: Univ. Texas Bureau Econ. Geology Rept. Invest.

Scott, A. J., *ed.*, 1967, Carbonate depositional environments, central Texas: Unpublished Term Reports, Geology 383K, Department of Geological Sciences, The University of Texas at Austin, 153 pp.

———, *ed.*, 1968, Early Cretaceous depositional environments, central Texas: Unpublished Term Reports, Geology 383K, Department of Geological Sciences, The University of Texas at Austin, 125 pp.

Shawe, W., *ed.*, 1963, Wimberley's legacy: San Antonio, Texas, The Naylor Company, 260 pp.

Shumard, B. F., 1860, Observations upon the Cretaceous strata of Texas: St. Louis Acad. Sci., Transactions, v. 1, pp. 582-590, 1 table.

Stead, F. L., 1951, Foraminifera of the Glen Rose Formation (Lower Cretaceous) of central Texas: Texas Jour. Sci., v. 3, no. 4, pp. 577-605, 7 figs., 3 pls.

Suhm, D. A., 1960, A review of central Texas archeology, part 1: Bulletin of the Texas Archeological Society, v. 29, pp. 63-107, 4 figs.

Trewartha, G. T., 1954, An introduction to climate: New York, McGraw Hill Book Company, 395 pp.

Tucker, D. R., 1962, Subsurface Lower Cretaceous stratigraphy, central Texas, *in* Contributions to the geology of south Texas: South Texas Geological Society, pp. 177-216, 20 figs.

Udden, J. A., 1925, Etched potholes: Univ. Texas Bull. 2509, 9 pp. 2 figs., 6 pls.

U. S. Army Corps of Engineers, 1964, Survey report on Edwards underground reservoir, Guadalupe, San Antonio, and Nueces rivers and tributaries, Texas: U. S. Army Corps of Engineers, Fort Worth District, 3 vols., 198 pp.

Vines, R. A., 1960, Trees, shrubs, and woody vines of the Southwest: Austin, Texas, Univ. Texas Press, 1104 pp.

Weeks, A. W., 1945, Balcones, Luling, and Mexia fault zones in Texas: Am. Assoc. Petroleum Geologists Bull., v. 29, no. 12, pp. 1733-1737, 1 fig.

Whitney, M. I., 1937, Fauna of the Glen Rose Formation: Univ. Texas Ph. D. dissertation (unpublished), 274 pp., 59 pls., 5 tables.

———, 1952a, Some zone marker fossils of the Glen Rose Formation of central Texas: Jour. Paleo., v. 26, no. 1, pp. 65-73, 4 pls.

———, 1952b, Some new Pelecypoda from the Glen Rose Formation of Texas: Jour. Paleo., v. 26, no. 5, pp. 697-707, 4 pls.

Winter, J. A., 1962, Fredericksburg and Washita strata (subsurface Lower Cretaceous), southwest Texas, *in* Contributions to the geology of south Texas: South Texas Geological Society, pp. 81-115, 21 figs.

Young, K. P., 1966, Texas Mojsisovicziinae (Ammonoidea) and the zonation of the Fredericksburg: Geol. Soc. America Memoir 100, 225 pp., 21 figs., 38 pls., 5 tables.

———, 1967a, Comanche Series (Cretaceous) south central Texas, *in* Comanchean (Lower Cretaceous) Stratigraphy and Paleontology of Texas: Publication 67-8, Permian Basin Section, Soc. Econ. Paleontologists and Mineralogists, pp. 9-29, 7 tables.

———, 1967b, Ammonite zonations, Texas Comanchean (Lower Cretaceous), *in* Comanchean (Lower Cretaceous) Stratigraphy and Paleontology of Texas: Publication 67-8, Permian Basin Section, Soc. Econ. Paleontologists and Mineralogists, pp. 65-70, 8 tables.