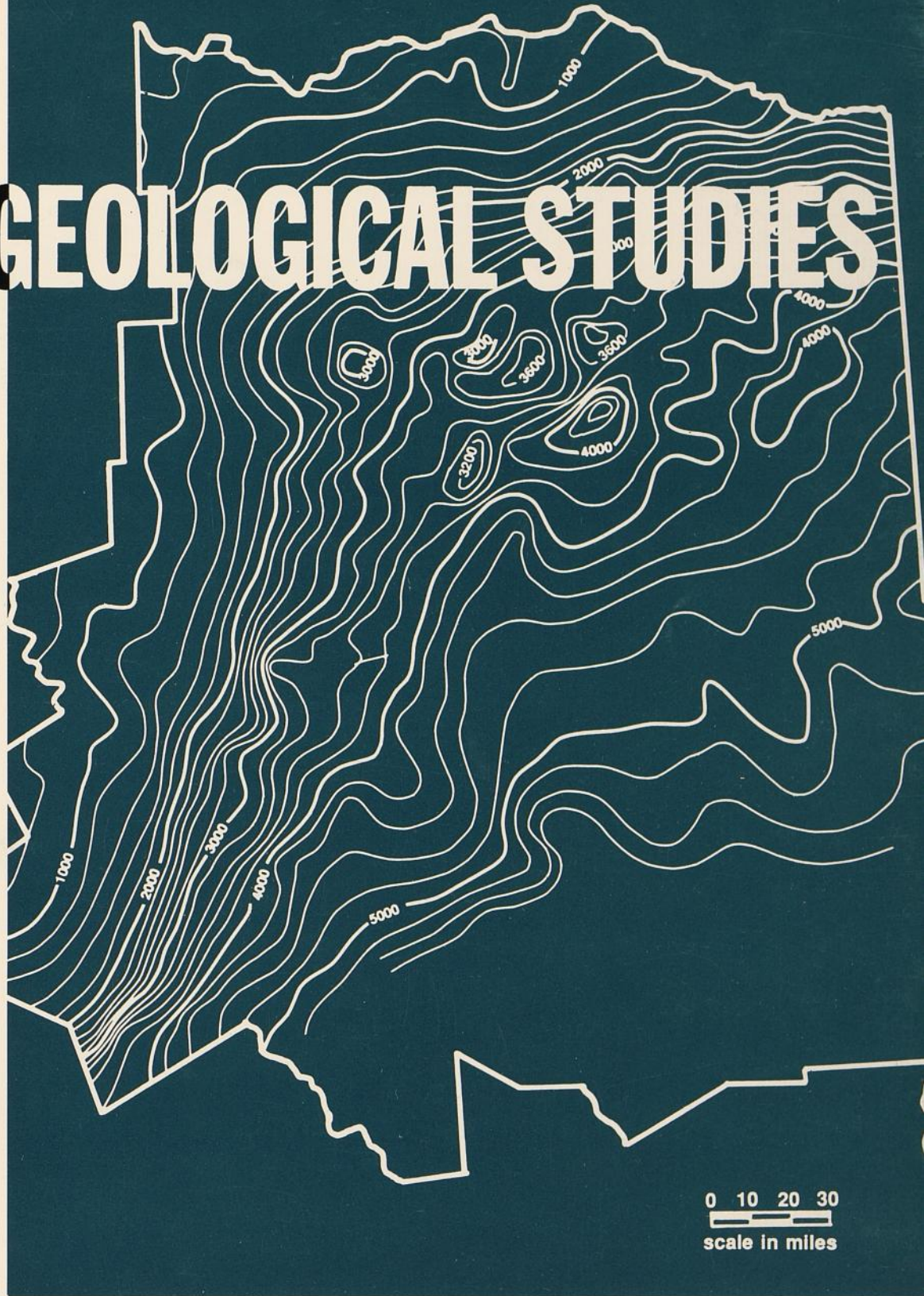# BAYLOR GEOLOGICAL STUDIES

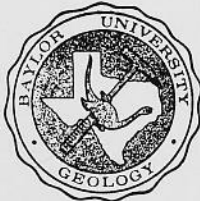## FALL 1991
Bulletin No. 52

Thesis Abstracts

"Creative thinking is more important than elaborate equipment--"

FRANK CARNEY, PH.D.
PROFESSOR OF GEOLOGY
BAYLOR UNIVERSITY
1929-1934

Objectives of Geological Training at Baylor

The training of a geologist in a university covers but a few years; his education continues throughout his active life. The purposes of training geologists at Baylor University are to provide a sound basis of understanding and to foster a truly geological point of view, both of which are essential for continued professional growth. The staff considers geology to be unique among sciences since it is primarily a field science. All geologic research including that done in laboratories must be firmly supported by field observations. The student is encouraged to develop an inquiring objective attitude and to examine critically all geological concepts and principles. The development of a mature and professional attitude toward geology and geological research is a principal concern of the department.

Cover: Trinity Group isopach map illustrating depositional trends of Trinity rocks. (From French)

BAYLOR GEOLOGICAL STUDIES

THESIS ABSTRACTS

These abstracts are taken from theses written in partial fulfillment of degree requirements at Baylor University. The original, unpublished versions of the theses, complete with appendices and bibliographies, can be found in the Ferdinand Roemer Library, Department of Geology, Baylor University, Waco, Texas.

CONTENTS

Application of Conodont Biostratigraphy to Evaluating Age Variation in the Upper Marble Falls Formation

Stephen L. Chelette

The nature and distribution of Pennsylvanian strata around the Llano Uplift in central Texas are directly associated with the development of three tectonic elements: (1) the Ouachita Foldbelt, (2) the Concho Platform, and (3) the Fort Worth Basin. The establishment of the carbonate Concho Platform and subsequent initial downwarping of the Fort Worth Basin were controlled by orogenesis in the Ouachita Foldbelt. The Llano Uplift acted as a buttress which limited subsidence of the Fort Worth Basin, while the elevated Ouachita structural belt provided significant clastic influx.

This investigation evaluates age relationships of the upper Marble Falls Formation based on conodont biostratigraphy and relates these data to existing lower Middle Pennsylvanian conodont zonation. This information is integrated and correlated with fusulinid zones previously established in the upper Marble Falls. In addition, the paleoenvironmental conditions present during Marble Falls deposition and resulting conodont biofacies are outlined.

The upper Marble Falls Formation (Atokan) is representative of limestones deposited in shelf and shelf-edge environments with subordinate shales that are exposed discontinuously around the Llano Uplift. Samples were collected from two sections: Pfluger Bluff of northeastern Kimble County in the west, and Cherokee Creek of east-central San Saba County in the north.

On the northern margin of the Llano Uplift the upper Marble Falls, which crops out at Cherokee Creek, is composed of spiculitic biomicrite with interspersed shales. As the lower Marble Falls carbonate platform was inundated following exposure, the upper Marble Falls at Cherokee Creek accumulated along the newly established off-platform shelf between the Llano Uplift and the Fort Worth Basin. As the platform foundered, shale accumulated in the relatively shallow foreland of the Fort Worth Basin and on the subsiding edges of the upper Marble Falls Platform.

The upper Marble Falls outcrop at Pfluger Bluff in the west represents algal buildups, calcarenite shoals, and shale deposited in somewhat restricted depressions well up on the open-marine carbonate shelf marginal to the Fort Worth Basin. Here, deposition of the upper Marble Falls shifted progressively westward with the continued subsidence of the upper Marble Falls Platform. Lengthy erosion of the platform on the west side of the Llano Uplift removed much of the lower Marble Falls Formation prior to the deposition of the upper Marble Falls.

Conodont faunas within the upper Marble Falls suggest the presence of two primary taxa: *Neognathodus* and *Idiognathodus*. Varying species within these two genera indicate possible evolutionary trends that provide excellent zonation and correlation of the Pfluger Bluff and Cherokee Creek sections (Fig. 1). *Neognathodus* exhibits changes in the trace of its outer margin that suggest an evolution of the species that begins in the lower portion of Cherokee Creek, equivalent to Early Atokan, and continues in the Pfluger Bluff section, which is equivalent to Middle and Late Atokan (Fig. 2). Similarly, the genus *Idiognathodus* demonstrates development of its rostral ridges from the platform onto its freeblade in the species *I. klapperi* and *I. incurvus*. These evolutionary changes can be traced between the Pfluger Bluff and Cherokee Creek sections, and when correlated with recent fusulinid studies in the area it is possible to establish relative stratigraphic relationships of western and northern outcrops (Fig. 3).

Therefore, the data obtained in the study indicate that the upper Marble Falls present in the western region is younger in age and stratigraphically higher than that which crops out in the northern and eastern regions.

The presence of certain biofacies as established by conodont assemblages provides insight to paleoenvironmental conditions. Within the Cherokee Creek section the *Cavusgnathus* biofacies is developed in the lower units, which are composed of spiculitic limestone, and indicate a prograding shallow water environment. However, the *Idiognathodus* and *Idiognathoides* biofacies that occur in the upper units of the section are developed in substantially more micritic rocks and suggest the beginning of a transgression across the platform.

In contrast, the Pfluger Bluff section contains the *Idiognathodus* biofacies with calcarenites, algal biomicrites, and micrites the predominant lithology. Here the section represents a continuance of the transgression seen at Cherokee Creek, and thus records shallow, normal-marine conditions present well up on the platform.

In conclusion, the conodont assemblages present within the upper Marble Falls concur with previous fusulinid studies in suggesting that strata on the western margin of the Llano Uplift are younger than those on the eastern margin.

Fig. 1. Conodont zonations present in the upper Marble Falls. The lower zones represent more primitive specimens of the species, while upper zones indicate more advanced specimens and the completion of the evolutionary trends.

Fig. 2. Diagram showing the evolution of the genus *Neognathodus* as examined in the upper Marble Falls. The oral outline of *N.* sp. D demonstrates perfect symmetry and is followed by an evolutionary trend towards a more asymmetrical oral trace. *N.* "*bothrops*" represents the return to a more perfect symmetry.

Fig. 3. Correlation diagram showing conodont assemblages and range variation between Pfluger Bluff and Cherokee Creek sections.

Figure 1 content:

Series	Stage	Neognathodus zonation	Idiognathodus zonation
PENNSYLVANIAN	DESM.	Neognathodus bothrops	
	ATOKAN	Neognathodus "bothrops"	Idiognathodus incurvus
		Neognathodus atokaensis (zone 4)	(zone C)
		Neognathodus sp. C (zone 3)	I. incurvus and
		Neognathodus sp. D (zone 2)	I. klapperi (zone B)
	MORROWAN	Neognathodus sp. B (zone 1)	Idiognathodus klapperi (zone A)

Figure 2 — ORAL OUTLINE / CROSS SECTION:
- Neognathodus "bothrops"
- A Neognathodus atokaensis B
- Neognathodus sp. C
- Neognathodus sp. D
- Neognathodus sp. B

Figure 3 content:

Series	Stage	Upper Marble Falls Fm.	Fusulinid Occurrences	Conodont Assemblages
PENNSYLVANIAN	ATOKAN	Pfluger Bluff	Zone of Fusulinella / Fusulinella llanoensis	Neognathodus "bothrops" / Neognathodus atokaensis
			Profusulinella apodacensis / Profusulinella regia	advanced Idiognathodus incurvus
		Cherokee Creek	Zone of Profusulinella	Neognathodus sp. C
				primitive Idiognathodus incurvus
			primitive Profusulinella	Neognathodus sp. D
	Morr.		Zone of Millerella / Eoschubertella mosquensis	Neognathodus sp. B / Idiognathodus klapperi

5

An Integrated Approach to the Exploration for a Serpentine Plug, South-Central Texas

John E. Corkill

A number of late Cretaceous volcanic centers trace the Balcones Fault Zone. These "serpentine plugs," which produced over 50 million barrels of oil by 1985, are of commercial interest to the petroleum industry. Serpentine plugs occur at relatively shallow depths below the present land surface, some under 1000 feet. For this reason, drilling associated with plugs is less expensive than with plays, which produce from greater depths. Because of the low exploration cost, serpentine plugs are quite desirable, especially to smaller petroleum companies.

This study explores the effectiveness of using the following geophysical techniques in the exploration for serpentine plugs: a) interpretation of remotely sensed data; b) interpretation of magnetic data; c) interpretation of gravity data; and d) geophysical modeling. Remote sensing was employed because several plugs have been detected on aircraft and satellite imagery. The high magnetic susceptibility of the material in many plugs makes them detectable on magnetic surveys. Because of the different rock types involved, there is a chance for rock density differences to be detected on gravity surveys. Lastly, modeling techniques may be used to check survey results and suggest possible geological models for a particular area.

The study was performed near a serpentine plug on the Steiner Ranch in Bastrop County, Texas. The ranch is located approximately 24 miles southeast of Austin, and four miles east of Utley. The plug was first located using Landsat imagery. A seismic survey was then performed over the area by a private firm. After an initial interpretation of the seismic data, a well was drilled. The well missed the main mass of the plug but penetrated 10 feet of altered pyroclastics.

Detailed gravity and magnetic surveys performed for this study consisted of 32 and 340 stations, respectively. They concentrated over and around the Landsat anomaly. The data gathered were reduced to make regionally drift-corrected Bouguer gravity and drift-corrected statistically smoothed magnetic maps (Fig. 1). Possible subsurface geophysical models came from well log and geophysical data. Models varied in depth, size, and density contrasts or magnetic susceptibilities.

Gravity and magnetic anomalies were calculated for each model using spheres to simplify the calculations. The best model consisted of a mass with high magnetic susceptibility and 1000-foot radius underlain by a similar-sized mass of dense material. The gravity model is located 250 feet deeper than the magnetic model and is slightly offset from the magnetic high (Fig. 2).

The geophysical model led to a possible geological model. The dense mass was interpreted as being composed predominantly of unaltered basalt. The mass with the high magnetic susceptibility was interpreted as altered volcanic ash.

The geological interpretation is that the eruption of this volcano was focused on its northeastern flank. The tephra from the eruption settled on this same northeastern side, but part was swept southwestward by the prevailing water current of the late Cretaceous seas in this area. The volcanic strata penetrated by the test well are most likely composed of this reworked tephra.

This study found a relationship among overhead imagery, gravity data, and magnetic data and made the following interpretations:

1. The overhead imagery displayed features that were produced by the buried plug.
2. A gravity "high" over the area was an expression of dense igneous core.
3. A magnetic, dipolar anomaly, slightly offset from the gravity "high," was produced by the altered pyroclastic rock that once constituted a volcanic cone.

The study found modeling of the geophysical data a useful tool for quality assurance of the data as well as for final interpretation. Therefore, it is possible to use inexpensive means of exploration for serpentine plugs. The combination of the four tools discussed proved effective in locating the main mass of the plug and should have similar results with other serpentine plugs.
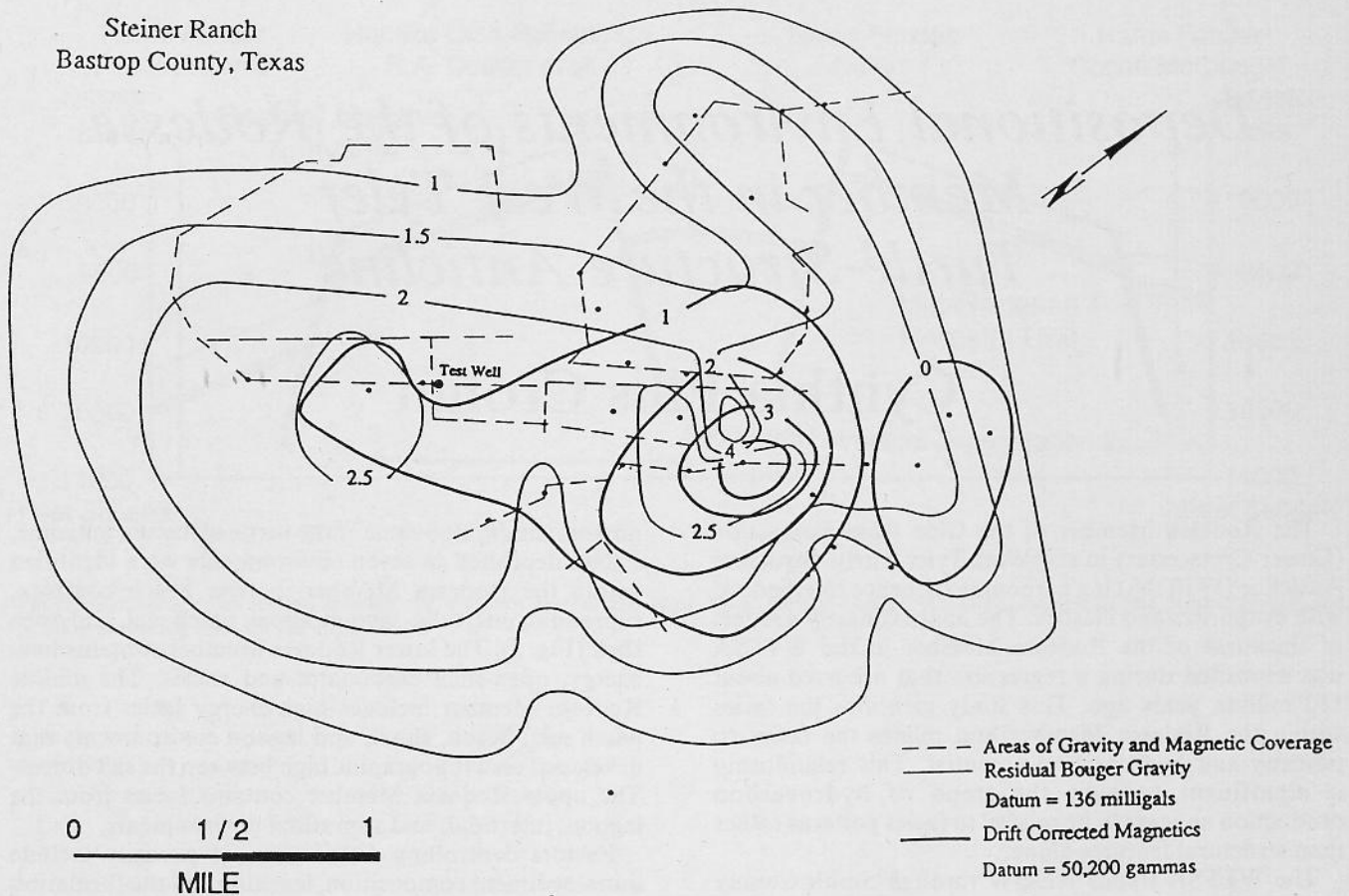
Fig. 1. Gravity and magnetic map of Steiner Ranch, Bastrop County, Texas.

Steiner Ranch
Bastrop County, Texas

- - - Areas of Gravity and Magnetic Coverage
——— Residual Bouger Gravity
Datum = 136 milligals
—— Drift Corrected Magnetics
Datum = 50,200 gammas
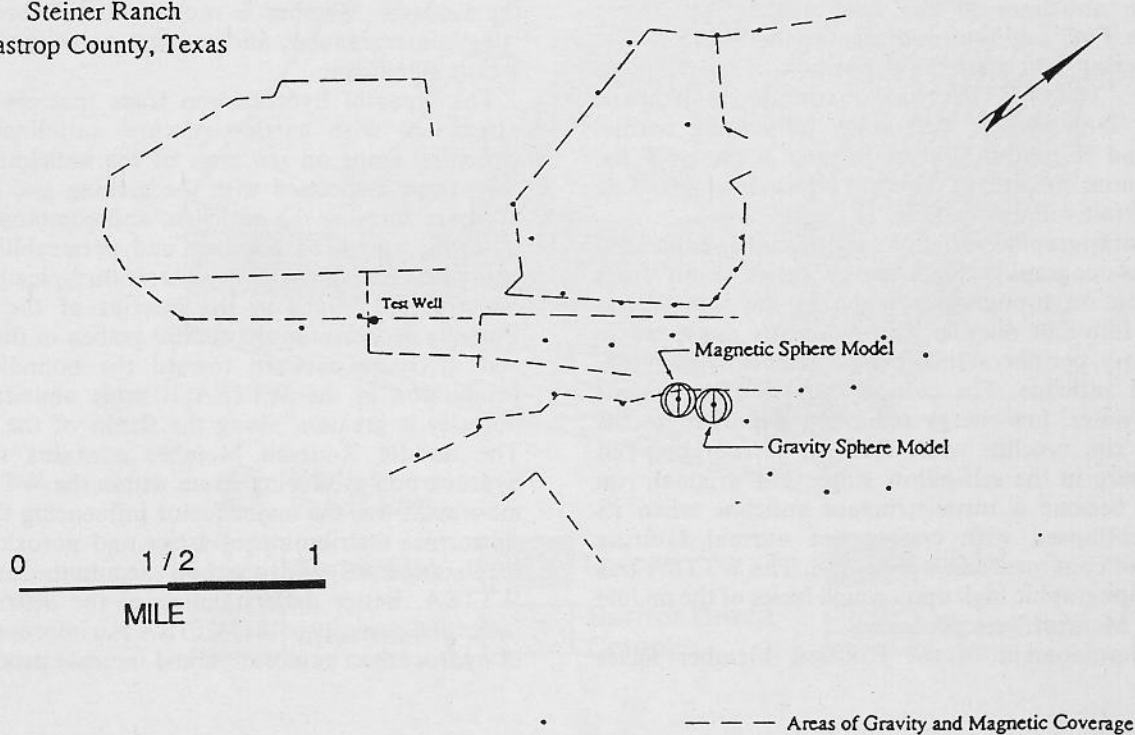

- - - Areas of Gravity and Magnetic Coverage

Fig. 2. Location of gravity and magnetic models.

7

Depositional Environments of the Rodessa Member in the West Tyler Turtle-Structure Anticline

Cynthia Ellis Cronin

The Rodessa Member of the Glen Rose Formation (Lower Cretaceous) in the West Tyler Turtle-Structure Anticline (WTTSA) is a carbonate sequence interbedded with evaporites and clastics. The approximately 430 feet of thickness of the Rodessa Member in the WTTSA was deposited during a regression that occurred about 110 million years ago. This study identifies the facies within the Rodessa Member and relates the facies to porosity and hydrocarbon potential. This relationship is significant because the trend of hydrocarbon production appears to be related to facies patterns rather than structural features alone.

The WTTSA trends NE-SW through Smith County and western Henderson County in northeast Texas. The WTTSA is located in the East Texas Salt Dome Province in the central part of the East Texas Basin, and is an important hydrocarbon-producing structure. The mobilization of the Louann Salt led to the development of salt diapirs, salt-cored anticlines or pillows, and turtle-structure anticlines in the East Texas Salt Dome Province. Four salt domes adjacent to the WTTSA were active during and after the deposition of the Rodessa Member. The WTTSA has a complex, northeast-trending fault system with many bifurcating normal faults and a central graben formed because of the gravitational collapse of adjacent strata during the late stages of salt withdrawal (Fig. 1).

Lithostratigraphic variations are primarily controlled by paleotopography. High-energy facies result from deposition on topographic highs as the salt pillows evolved into salt diapirs. The sediments deposited in the primary, peripheral sink formed the core of the turtle-structure anticline. The core of the WTTSA consists of deep-water, low-energy sediments deposited in the original, rim syncline while the four surrounding salt domes were in the salt-pillow stage. The original, rim syncline became a turtle-structure anticline when its flanks collapsed with consequent normal faulting because of continued salt withdrawal. The WTTSA was a paleotopographic high upon which facies of the middle Rodessa Member were deposited.

The development of the Rodessa Member facies mirrors the development of the turtle-structure anticline. Facies deposited in seven environments were identified within the Rodessa Member: barrier beach complex, supratidal, intertidal, lagoon, shoal, patch reef, and open shelf (Fig. 2). The lower Rodessa Member contains low-energy, open-shelf carbonates and shales. The middle Rodessa Member includes high-energy facies from the patch reef, beach, shoal, and lagoon environments that developed on a topographic high between the salt domes. The upper Rodessa Member contains facies from the lagoon, intertidal, and supratidal environments.

Factors controlling distribution of porosity include initial sediment composition, leaching and the formation of moldic and vuggy porosity, and compaction. Porosity is best developed in the high-energy packstones and grainstones of the beach and shoal facies, which only occur within the middle Rodessa Member. The greater the carbonate fraction within the high-energy facies, the greater the porosity, because most of the porosity in the Rodessa Member is moldic. Some cores contain vuggy, intergranular, and fracture porosity that can be locally significant.

The types of hydrocarbon traps that are generally associated with turtle-structure anticlines include structural traps on the crest of the anticline, normal-fault traps associated with the arching and collapsing of strata forming the anticline, and combination traps involving enhanced porosity and permeability on the crest of the anticlines. Past exploration typically focussed on structural highs in the interior of the WTTSA. Porosity decreases in the central graben of the WTTSA and increases outward toward the bounding faults. Production in the WTTSA is most abundant where porosity is greatest, along the flanks of the structure. The middle Rodessa Member contains the major hydrocarbon-producing strata within the WTTSA. Salt movement was the major factor influencing the current subsurface distribution of facies and porosity and the localization of hydrocarbon accumulations in the WTTSA. Better understanding of the distribution of facies and porosity in the WTTSA can improve the focus of hydrocarbon exploration and increase production.
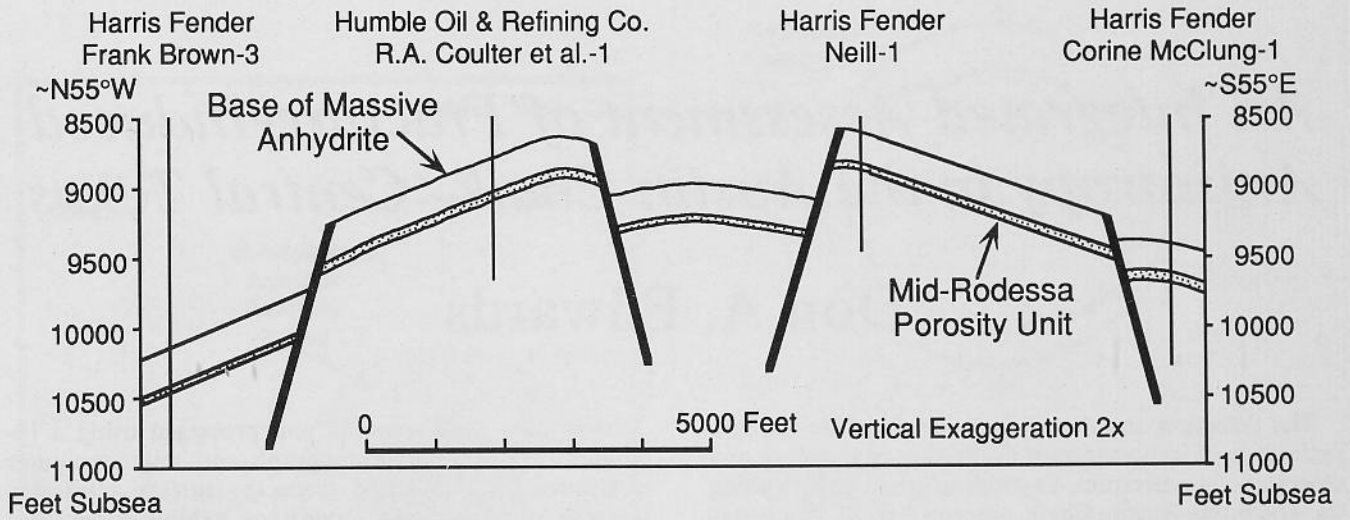
Fig. 1. Structural cross section through the northern part of the West Tyler Turtle-Structure Anticline, illustrating the central graben and primary producing areas on the upper flanks.
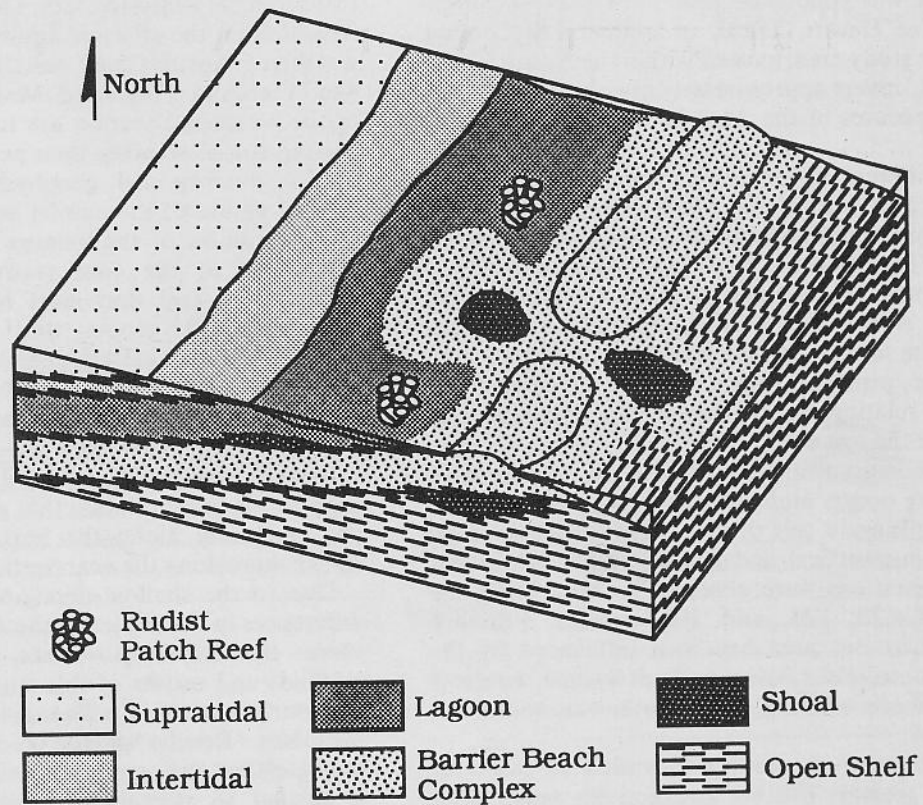

Fig. 2. Diagrammatic block diagram showing the distribution of depositional environments present in the middle Rodessa Member in the West Tyler Turtle-Structure Anticline.

An Integrated Assessment of Fracture-Induced Anisotropy in the Austin Chalk, Central Texas

Don A. Edwards

The detection and description of subsurface fracture systems is of importance in evaluating engineering and reservoir characteristics. Expanding urban growth along the fractured Austin Chalk outcrop belt in Texas has increased the potential for pollution of the Austin Chalk's shallow groundwater system. The significance of fracturing in the Austin Chalk is further highlighted by the vertically fractured Austin Chalk petroleum reservoirs located in south Texas. Knowledge of subsurface fracture systems will be necessary in evaluating fractured hydrocarbon reservoirs and in designing pollution prevention and remediation programs. This study is a site-specific evaluation within a shallow Austin Chalk groundwater system; it integrates geophysical and geological methods of investigation in order to assess the effect of local fractures on fluid movement.

The study was conducted near the southeast corner of the city of Hewitt, Texas, in southern McLennan County. The study area, located within the Austin Chalk outcrop belt, covers approximately one square mile and contains exposures of the Atco Member of the Austin Chalk.

Several different investigations were conducted at a test site located within the study area. Geophysical investigations included seismic and azimuthal resistivity surveying. The seismic investigations consisted of multicomponent shear-wave profiles recorded using surface and borehole methods. Geological data were obtained from local outcrops, recovered core, well logs, and aquifer pumping tests. Figure 1 shows the geometrical relationship of the various investigations conducted at the test site.

Outcrop measurements indicate that the predominant fracture strike occurs along the azimuth of 035 degrees. Fractures striking in this direction typically have long and continuous vertical and lateral traces. Additional fracture orientations were observed striking along the azimuths of 070, 120, and 160 degrees. Fracture development in this area has been influenced by the regional tectonics of the Balcones Fault System, a narrow band of northeast-striking, down-to-the-east-southeast, normal faults.

Azimuthal resistivity surveys identified an east-west direction of greatest fracture connectivity rather than identifying individual fracture strikes. Different coefficients of electrical anisotropy as well as the different shapes of the apparent resistivity ellipses indicate anisotropy and heterogeneity at the test site (Fig. 2).

Seismic investigations focussed upon the use of multicomponent shear-wave profiling techniques. The seismic data were acquired and processed using a 12-channel engineering seismograph and microcomputer software. Data collected from the surface refraction surveys and borehole recordings exhibit directional variations in velocities and signal amplitude, two of the expected effects of shear-wave propagation through an azimuthally anisotropic medium (Fig. 3). Computer rotation of paired horizontal geophone data identified the faster shear-wave polarization directions, and therefore fracture strikes, as 075 degrees from the surface refraction data and 035 degrees from the borehole recordings (BHRs). These two trends are coincident with near-vertical fracture sets observed in local outcrops.

Additional data were obtained from four boreholes placed at the test site for use in constant rate pumping tests. Each of the wells was logged using a portable logging system. Well 2 (Fig. 1) was cored from the surface to a depth of twenty-five feet. The recovered core samples indicate that the effective aquifer section lies within the weathered Austin Chalk section between the depths of 4 to 11 feet and is fractured. Most of the fracture surfaces in the weathered section are low-angle and horizontal parting surfaces rather than near-vertical, as suggested by the outcrop and geophysical investigations. The layered nature of the aquifer section was confirmed by the correlation of the gamma and resistivity well log signatures to the core recovery. This correlation identified several thin marl beds present within the effective aquifer section that are not present in the recovered core. The influence of these layers upon the movement of fluid was observed during the pumping of an open hole as water cascaded down into the borehole from bedding plane and low-angle fracture surfaces within the weathered section. The pumping test results support the interpretation that groundwater flow occurs predominantly along the horizontal parting surfaces rather than along the near-vertical fracture surfaces.

Due to the shallow depth of investigation and the differences in the nature of the Austin Chalk in outcrop versus the deeper subsurface, the application of the methods and results of this study should be limited to near-surface Austin Chalk engineering and groundwater problems. Results of the geophysical investigations indicate that the azimuthal anisotropy at the test site is related to the presence of near-vertical fracture systems. Each method of investigation proved to be effective in providing useful data which collectively led to a more detailed understanding of the natural fracture system and how the fractures influenced the movement of groundwater at the test site.
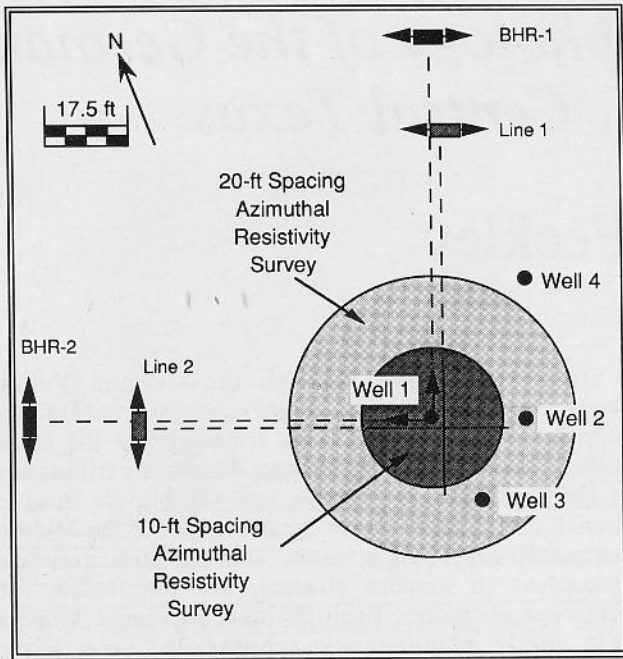
Fig. 1. Map showing the location and geometrical relationship of the investigations conducted at the test site. Shown are the acquisition orientations of the shear-wave refraction and borehole recordings (BHRs), the azimuthal resistivity survey coverage, and the configuration of the wellbores.
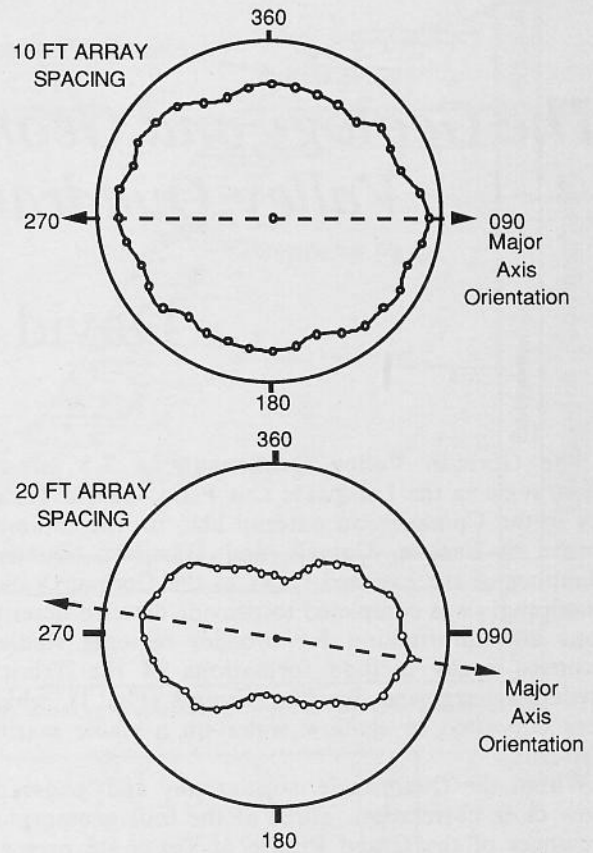
Fig. 2. Apparent resistivity ellipses generated from the 10-foot and 20-foot array spacing azimuthal resistivity surveys. The coefficients of electrical anisotropy are 1:1.11 and 1:1.73 for the 10-foot and 20-foot surveys, respectively.
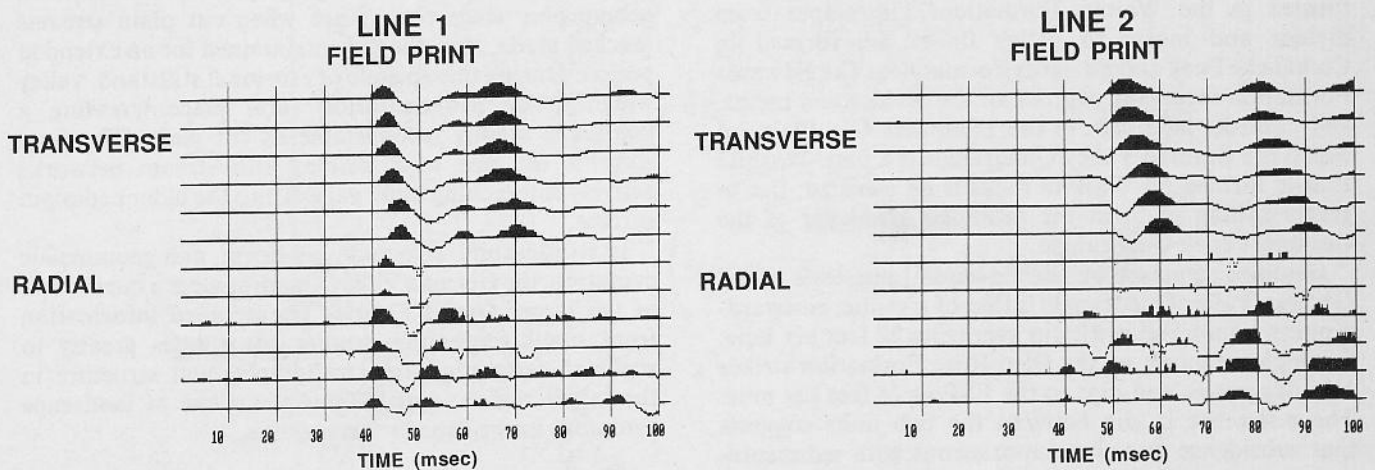
Fig. 3. Surface refraction records from lines 1 and 2. Shown are the signals recorded by the transverse (crossline) and radial (inline) horizontal geophones. Line 1 contains the faster shear-wave velocity data, noted by the faster arrival time and the steeper slope of the refraction arrivals.

11

The Geology and Geomorphology of the German Valley Quadrangle, Central Texas

David L. Feckley

The German Valley Quadrangle, a 7.5 minute quadrangle in the Lampasas Cut Plain, central Texas, lies in the Comanchean outcrop belt, on the common corner of Bosque, Coryell, and Hamilton counties. Mapping of the exposed rocks in the German Valley Quadrangle was completed to provide detailed descriptions and information for broader regional studies. Exposed rocks include formations of the Trinity, Fredericksburg, and Washita Groups (Fig. 1), which were deposited in shallow water on a stable marine platform.

Within the Quadrangle, stratigraphy and landscape show close correlation. Three of the four geomorphic provinces of the Grand Prairie of Texas are present, each reflective of a specific stratigraphic unit.

The Glen Rose Prairie is developed on the Glen Rose Formation of the Trinity Group. The Lampasas Cut Plain is formed on Fredericksburg rocks. The Washita Prairie is formed on the outcrop belt of Georgetown rocks of the Washita Group (Fig. 2).

The eastern margin of the Glen Rose Prairie merges with the Lampasas Cut Plain in the southwestern part of the German Valley Quadrangle. The Glen Rose Prairie is a rolling to stairstep landscape carved from limestones, marls, and sands of the Glen Rose Formation. The Lampasas Cut Plain is a dissected dip plain, marked by distinctive mesas and divides capped by the Edwards Limestone. Narrow divides are separated by wide valleys formed in the Walnut Formation. The slopes from divides and mesas to valley floors are formed in Comanche Peak and Edwards Formations. The Edwards Formation forms the caprock of the divides and mesas, and controls landform in the Lampasas Cut Plain, of which the German Valley Quadrangle is a part. Washita Prairie formed on Washita rocks is an elevated, flat to gently rolling plain in the southeast quadrant of the German Valley Quadrangle.

Geologic structure on the Edwards Limestone in the German Valley Quadrangle is that of a gentle, eastward-dipping homocline, with dip averaging 20 feet per mile. Geologic structure on the Glen Rose Formation strikes N15 degrees E, and dips to the ESE at 28 feet per mile. The difference in dip between the two units suggests that subsidence was contemporaneous with sedimentation between the times of deposition of these two formations.

Streams that flow through the German Valley Quadrangle belong to three major river systems: (1) Kelly Branch and Coryell Creek are tributaries of the Leon River; (2) Neils Creek and Boggy Branch are tributaries of the North Bosque system; and (3) Middle Bosque Branch and Goldys Branch are tributaries of the Middle Bosque River. These streams, and ancestral drainage antecedent to modern streams, are responsible for landscape evolution. Each drainage system is located in a unique physiographic subprovince. Leon River tributaries are responsible for dissection of the Glen Rose Prairie, North Bosque drainage formed the Lampasas Cut Plain, and Middle Bosque drainage formed the Washita Prairie (Fig. 2).

Landscape evolution in the German Valley region parallels that of the wider Grand Prairie. The oldest landscape is preserved on the highest divides and in the youngest rock. Thus, the Lampasas Cut Plain has been modified from the Washita Prairie, and the Glen Rose Prairie has been modified from the Lampasas Cut Plain.

Geomorphic processes in this region include dissection by surface water and groundwater, leading to slope retreat and valley widening. Landscape evolution began with a "time zero surface," the earliest landscape of which a record remains. As dissection etched into the "time zero surface," the Edwards Formation was breached and entrenchment took place, establishing the drainage pattern for the initial Lampasas Cut Plain. A third geomorphic stage took place when cut plain streams reached grade, a profile they maintained for an extended period. During this episode of erosional stillstand, valley widening by pedimentation took place, creating a landscape readily recognizable as cut plain. The final stage is the one now visible, with stream networks actively entrenching inner valleys into the older pediplain surface.

In stratigraphy, structure, landform, and geomorphic evolution, the German Valley Quadrangle is a microcosm of the larger Grand Prairie. The detailed information from small geographic studies contributes greatly to regional descriptions of stratigraphy and structure in the larger region, and to interpretations of landscape evolution in the broader perspective.
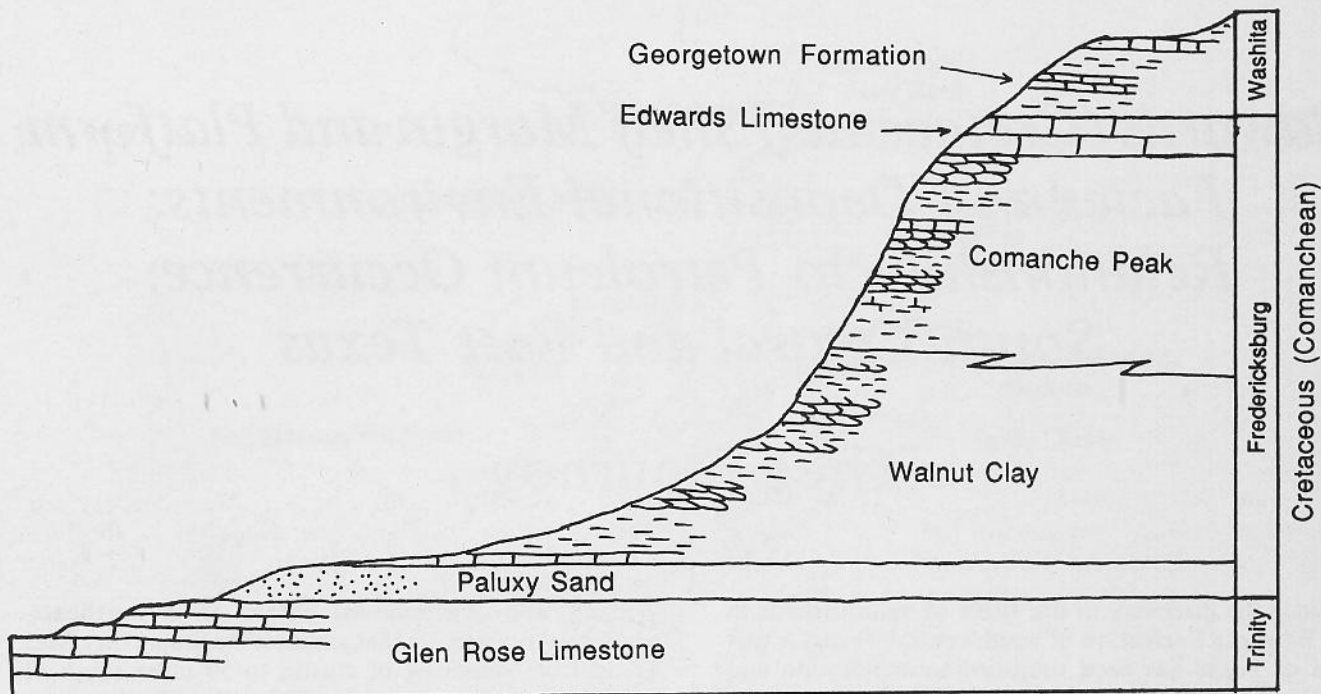
Fig. 1. Profile and section of Cretaceous rocks in the German Valley Quadrangle showing relationship between stratigraphy and landform.
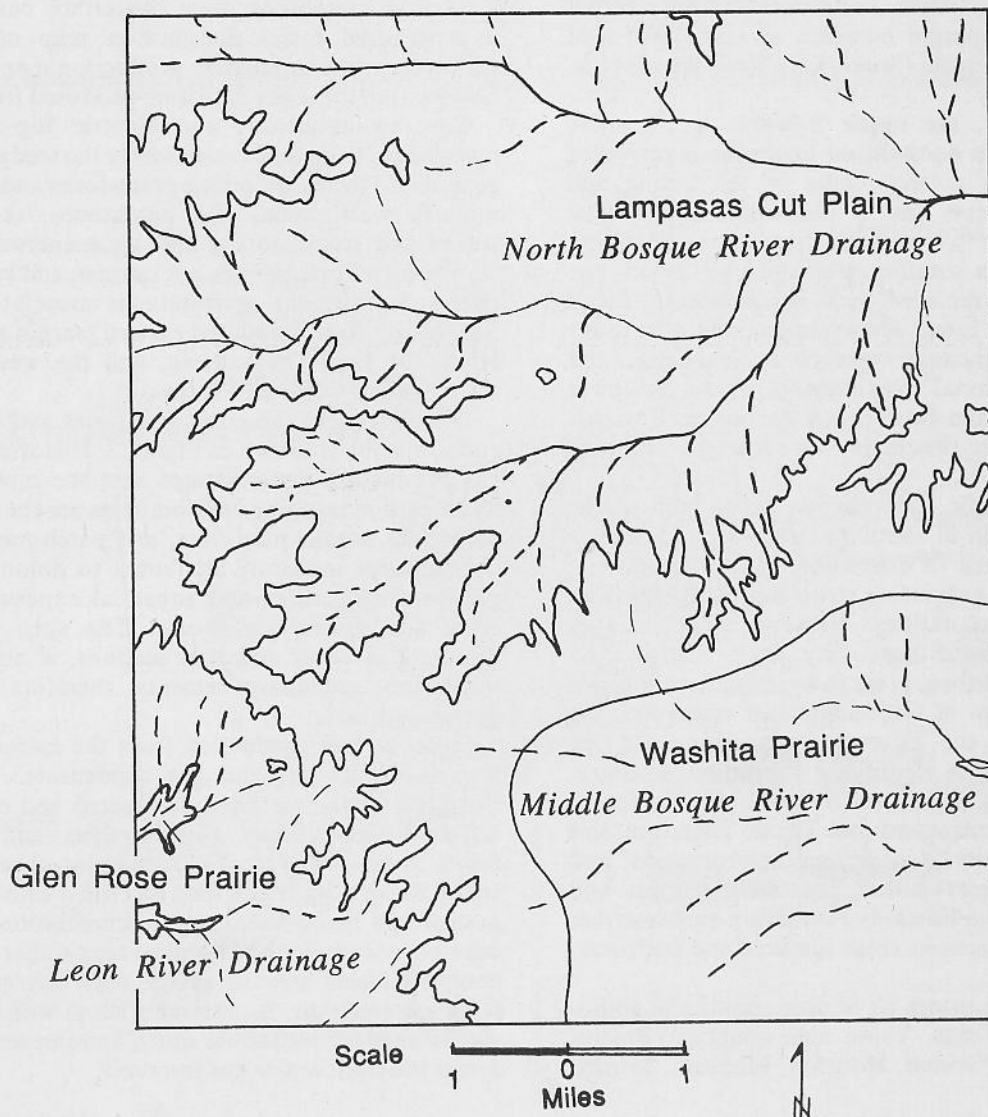

Fig. 2. Drainage networks and physiographic regions of the German Valley Quadrangle.

13

Edwards (Cretaceous) Shelf Margin and Platform Facies and Depositional Environments: Relationships to Petroleum Occurrence, South-Central and East Texas

Greg Flournoy

Since the discovery in the 1920s of hydrocarbons in the Edwards Formation of south-central Texas, a vast area of Texas has been subjected to exploration and development of the Lower Cretaceous. In Texas, the Edwards is characterized by marine carbonates deposited on a shallow stable platform and separated from a deeper basin by a shelf margin complex of carbonate sand bodies, banks, and reefs (Stuart City Reef Trend) (Fig. 1).

In south Texas, the upper Edwards is the main reservoir rock. This dolomitized limestone is displaced by up-to-the-coast normal faults of the Luling and Sample fault systems and is positioned against less permeable Upper Cretaceous limestones. Moving northeastward into south-central and east Texas, the upper Edwards is replaced by a less permeable facies equivalent to the lower Georgetown, and the lower Edwards becomes the reservoir rock. Facies changes and associated depositional environments within the lower Edwards, rather than fault-controlled upper Edwards reservoirs, become the main hydrocarbon trapping mechanisms.

Due to the prolific hydrocarbon production of the Edwards Formation in south Texas, numerous studies have been conducted to determine facies, depositional environments, and subsurface structures that influenced hydrocarbon accumulations. However, fewer studies exist regarding the Stuart City shelf margin and associated back platform areas in south-central and east Texas. The absence of fault-controlled reservoirs, the greater depths to the Edwards Formation, and the increased difficulty in identifying subsurface stratigraphic hydrocarbon traps all contribute to the decreased interest in south-central and east Texas. Therefore, this study identifies facies, depositional environments, and subsurface structures within the shelf margin and platform areas in the Edwards Formation and describes the relationships between these features and hydrocarbon accumulations.

The study area includes all of nine counties in south-central and east Texas. These nine counties (Brazos, Burleson, Fayette, Grimes, Houston, Madison, Trinity, Walker, and Washington) extend in a northeast-southwest trending arc that parallels the Stuart City Reef Trend from southeast of Austin to 50 miles south of Tyler (Fig. 1). Data from over 220 wells including more than 600 feet of Edwards Formation core were analyzed. Twelve cross-sections, four subsurface contour maps, a generalized facies distribution map of the lower Edwards, and a cumulative production map of Edwards fields within the study area were produced from the data.

Core examinations and electric log evaluations revealed four regional facies within the study area. These generalized facies (dolomitic grainstones and packstones, mollusk wackestones and packstones, skeletal mudstones and wackestones, and algae-encrusted miliolid coral mollusk grainstones, packstones, and boundstones) reflect depositional environments associated with the Stuart City Reef Trend, the eastern margin of the Belton High, the East Texas Basin, and the western end of the Angelina-Caldwell Flexure.

Distribution of these regional facies and depositional environments is shown in Figure 2. Historically, oil and gas production demonstrates that the most favorable hydrocarbon trapping environments are the dolomitized carbonate shoals, platforms, and patch reefs. Porosity development is mainly attributed to dolomitization of platform carbonates and subaerial exposure of patch reefs and grainstone shoals. The shelf margin, as observed in cores and thin sections, is almost totally filled with secondary cements; therefore porosity is greatly reduced.

Hydrocarbon production from the Edwards Formation is mostly gas and gas condensate. Three large Edwards fields have been discovered and each records different depositional environments and associated facies. A tidal inlet or channel developed perpendicular to the Stuart City Reef Trend and filled with high-energy grainstones forms the largest accumulation of gas. An adjacent accumulation of grainstones and/or a patch reef complex facies leeward of the shelf margin is also a large gas reservoir. A carbonate shoal with high-energy grainstones occurs farther north and farther inland and forms the third major gas reservoir.
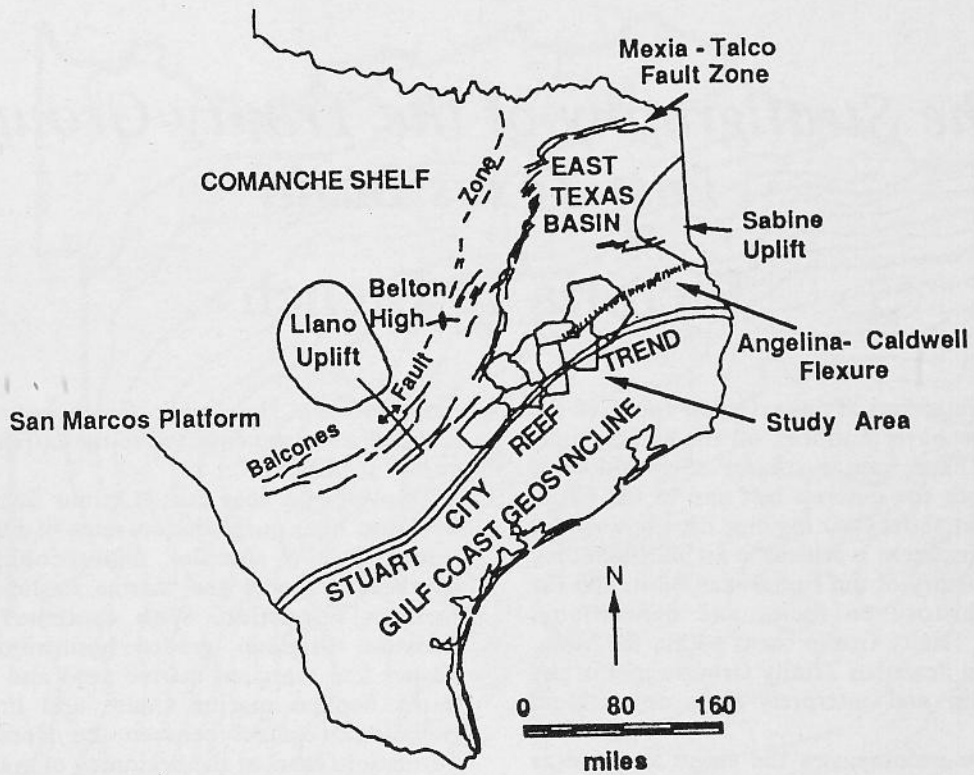
Fig. 1. Regional depositional and structural features of south-central and east Texas and their relationships to the study area.
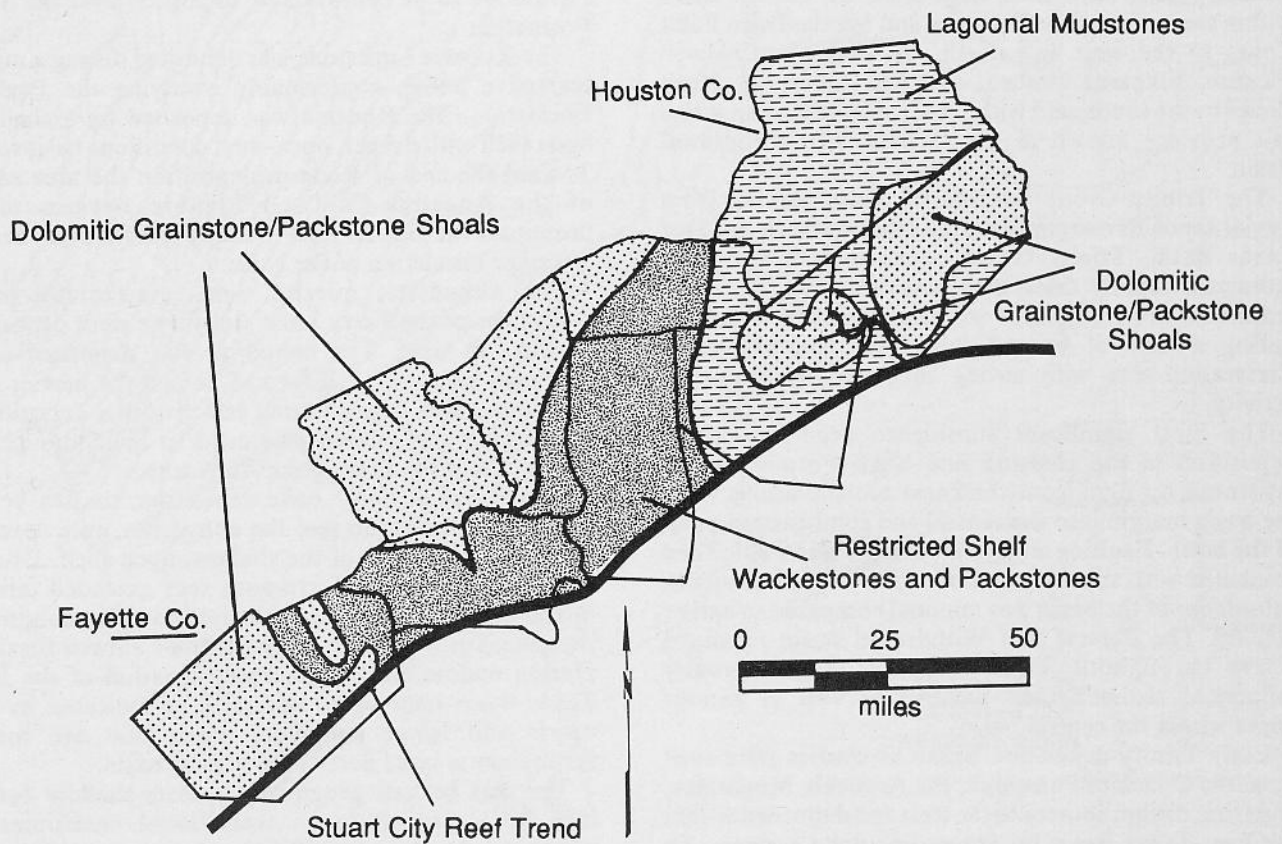

Fig. 2. Distribution of the four regional facies and associated depositional environments within the nine-county study area.

The Stratigraphy of the Trinity Group, East Texas Basin

Victoria L. French

The Lower Cretaceous, Trinity Group rocks of the East Texas Basin have produced oil for a long time, and while they have been a subject of considerable discussion on both the outcrop belt and in the basin, little has been said about their regional distribution and character. This treatment is critical to an understanding of the tectonic history of the East Texas Basin and the effect of this history on facies and depositional environments of Trinity Group rocks within the basin. This investigation describes Trinity Group rocks of the East Texas Basin and interprets their depositional history.

The study area encompasses the entire East Texas Basin, a 56-county area of northeast Texas. Within the basin the Trinity Group is composed of Comanchean aged rocks of the Lower Cretaceous System and includes rocks of the Hosston, Sligo, Pearsall, Rodessa, Ferry Lake Anhydrite, and Rusk Formations. Major areas of structure that influenced deposition of Trinity rocks within the basin are the Balcones and Mexia-Talco Fault Zones to the west and north, the Angelina-Caldwell Flexure, Elkhardt Graben, and Mt. Enterprise Fault Zones to the south, and within the central basin an active salt province known as the Central Salt Withdrawal Basin.

The Trinity Group consists of facies varying from fluvial sands to marginal marine limestones. In the East Texas Basin, Trinity Group rocks form a wedge of sediments rapidly thickening eastward (Fig. 1). These sediments are interpreted as being initially deposited during a time of basinal subsidence and oscillating Cretaceous seas with strong influence by structural activity.

The most significant subsidence occurred during deposition of the Hosston and Sligo Formations, as evidenced by significant thickness accumulations from the basin margin into the central and southeastern parts of the basin. Faulting along the Mexia-Talco Fault Zone coincided with subsidence. Following Sligo deposition, subsidence of the basin was minimal compared to earlier activity. The Central Salt Withdrawal Basin remained active throughout Trinity deposition and greatly influenced sedimentation patterns as well as various facies within the central basin.

Early Trinity deposition began as clastics were shed from the Ouachita Paleohigh, the Arbuckle Mountains, and from distant sources to the west and deposited within the East Texas Basin by prograding delta systems. To the west, sediment was first deposited in topographically low areas of the Wichita Paleoplain as channel fill and point bar deposits. Toward the basin, fluvial sands were deposited as destructive delta facies where streams emptied into the lower Cretaceous sea. Marine sedimentation was confined to the extreme southeastern part of the basin.

Transgressing seas caused minor fluctuations in sea level and high progradation rates of the delta system, resulting in a complex depositional sequence of interbedded fluvial and marine clastics typical of the Hosston Formation. With continued transgression Hosston sediments graded basinward from fluvial clastics and marginal marine sand and shale facies to thinly bedded marine shales and limestones. The gradational contact between the Hosston and Sligo Formations marked the beginning of marine deposition and the end of fluvial deltaic deposition in the southern basin.

As Cretaceous seas continued to transgress, larger portions of the East Texas Basin were inundated, allowing the shales and limestones of the Pearsall Formation to be conformably deposited over the Sligo Formation.

The Rodessa Limestone was deposited during a minor regressive phase, conformably overlying the Pearsall Formation. The Rodessa was deposited on a shallow, open shelf with deeper, open-shelf conditions basinward. Toward the end of Rodessa deposition the area south of the Angelina-Caldwell Flexure became more prominent as barrier reef buildup resulted in nearly complete restriction of the basin.

The anhydrite, micrite, and low-skeletal-grain limestones of the Ferry Lake Anhydrite were deposited during this time. The anhydrite was deposited as a restricted lagoonal shelf formed behind the barrier reef complex which began during late Rodessa deposition. The barrier reef system continued to build throughout deposition of the Ferry Lake Anhydrite.

At the end of Ferry Lake deposition, the sea began its final transgression and the anhydrites were covered by Rusk Limestones of the shallow, open shelf. During Rusk deposition the Cretaceous seas extended farther inland than ever before and the reef complex continued its upward growth along the Angelina-Caldwell Flexure. During middle Rusk deposition, isolation of the East Texas Basin once again occurred, as indicated by the upper and lower anhydrite zones that are found throughout a large part of the central basin.

The seas became progressively more shallow during late Rusk deposition as transitional environments advanced basinward. Clastics began to dominate deposition until Rusk sediments graded into the overlying Paluxy sands and shales of the Fredericksburg Group.
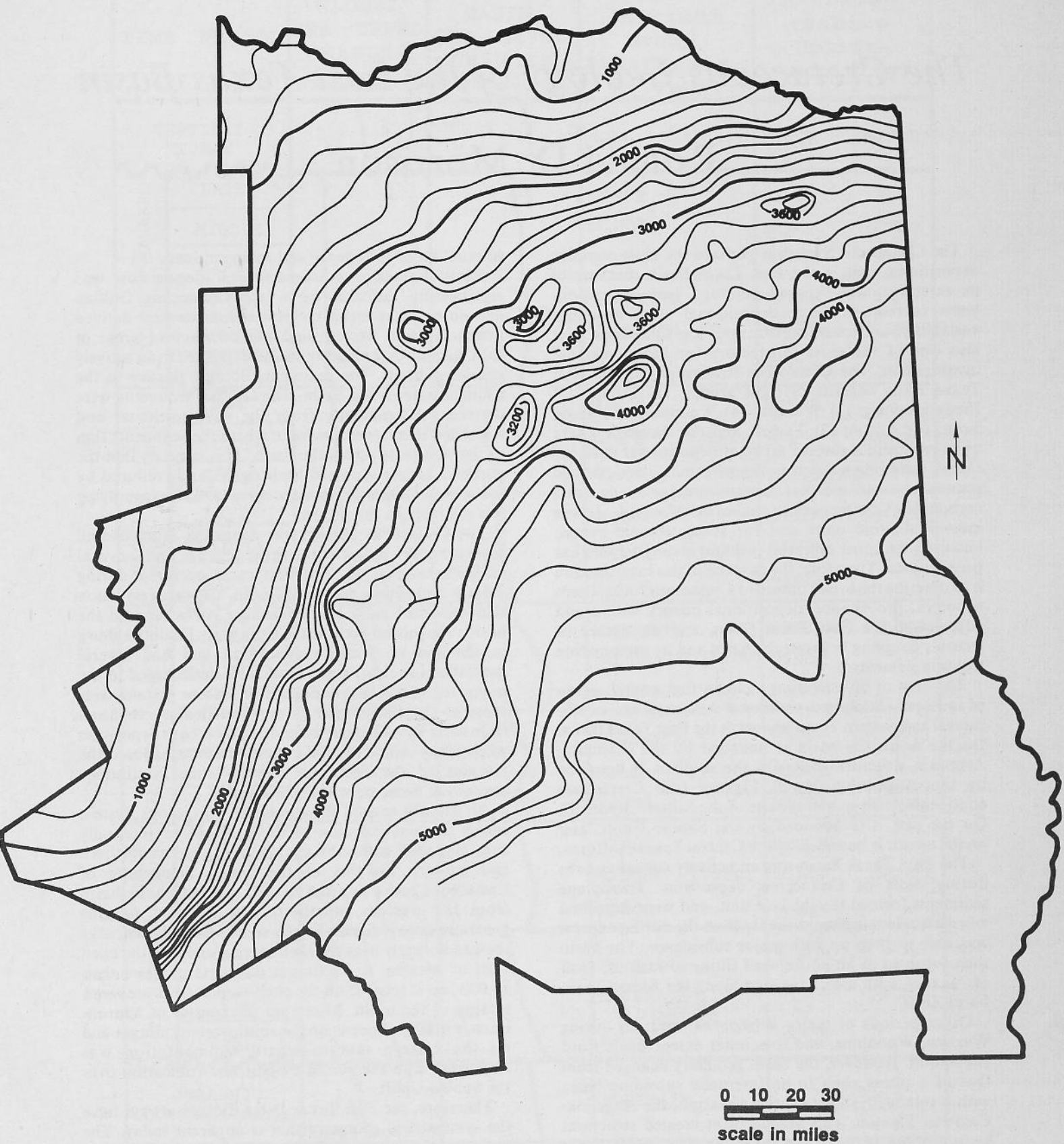
Fig. 1. Trinity Group isopach map illustrating depositional trends of Trinity rocks. Note the pattern of thickening that occurs from the basin margin on the west and north into the southeastern parts of the basin. This thickening indicates that subsidence was active in the basin during Trinity deposition, accompanied by faulting along the Mexia-Talco Fault Systems. Thick and thin trends within the central part of the basin are the result of salt movement in the Central Salt Withdrawal Basin.

The Cretaceous Geology of the East Texas Basin

Ronald D. Morrison

The Cretaceous System is perhaps the most complex depositional unit in the East Texas Basin. Because of its extensive, well-exposed outcrops, easy outcrop-to-basin correlation, large depositional area, lithologic variability, and characteristic well log signatures, it is also one of the most satisfactory for broad regional investigation. The Cretaceous stratigraphy in the East Texas Basin consists of eight groups: (1) Trinity; (2) Fredericksburg; (3) Washita; (4) Woodbine; (5) Eagle Ford; (6) Austin; (7) Taylor; and (8) Navarro. These units represent a diverse array of depositional environments, including restricted evaporite units, major deltaic sequences, and normal marine sands, muds, and carbonates. Comprehensive studies exist for each of these individual lithic units and for some tectonic events; however, a unified synthesis of basin history largely has been ignored. Therefore, the purpose of this investigation is to describe the broad nature of Cretaceous rocks, basin tectonics, provenance, depositional history within and adjacent to the East Texas Basin, and the nature of tectonic coupling between the basin and its surrounding tectonic elements.

The area of investigation includes the general region of southern Oklahoma, southwest Arkansas, and north-central and eastern Texas known as the East Texas Basin. On the north the basin is bounded by the Ouachita-Arbuckle structural belt. On the south it is bounded by the Angelina-Caldwell Flexure (the Cretaceous continental margin and the site of the Stuart City Reef). On the east it is bounded by the Sabine Uplift, and on the west it is bounded by the Central Texas Platform.

The East Texas Basin was an actively subsiding area during most of Cretaceous deposition. Trinity-age sediments formed the thickest unit, and were deposited when abundant sediment supply from the north and west was able to keep up with major subsidence. The basin then subsided as an entire shelf tilting toward the Gulf of Mexico, with major faulting along the Mexia-Talco Fault Zone.

Other periods of major subsidence occurred during Washita, Woodbine, and to a lesser extent Eagle Ford deposition. However, the basin geometry changed from that of a tilting shelf to an internally subsiding basin with a relatively stable southern margin, the Angelina-Caldwell Flexure. This arrangement created structural inequilibrium between the subsiding East Texas Basin and the North Louisiana Basin. Therefore, the Sabine Uplift (an arch) formed between the two basins to compensate for the instability. The Sabine Uplift was periodically active, apparently in response to continued internal basin subsidence and sediment load.

Early Cretaceous Comanchean deposition was significantly different from late Cretaceous Gulfian deposition. Comanchean clastic sediments were derived primarily from western and northern source areas of the Ouachita-Arbuckle trend and deposited in an actively subsiding basin. The sediments became thicker to the southeast across the basin. The Gulfian sediments were derived predominantly from the west-northwest and deposited in a less active basin where the sediments thin to the southeast across the basin. This suggests that the northern source area had been significantly reduced by the end of Comanchean deposition and was supplying less sediment to the region.

The Cretaceous System was deposited as an overall transgressive pulse with three cycles and several oscillations (Fig. 1). The first cycle occurred during Trinity deposition and ended with a major regression that deposited early Fredericksburg rocks far into the basin. The second cycle lasted from early Fredericksburg to the end of Washita deposition and had several oscillations in relative sea level. This cycle ended in the major regression that deposited Woodbine deltaics over most of the East Texas Basin. The final cycle lasted from early Woodbine to the end of Cretaceous deposition when many minor to moderate oscillations exposed the margins of the basin to erosion while continuous deposition occurred within the basin.

An isopach map of the combined Cretaceous System shows the configuration of the basin as an internally subsiding shelf with substantial faulting on the northern and western margins of the basin. Thickening of Cretaceous rocks into the central portion of the basin from the western, northern, and eastern margins generally kept it filled. To the south, Cretaceous rocks thicken abruptly over the shelf margin and into the open Gulf of Mexico. A maximum thickness of more than 10,000 feet is located on the shelf slope on the southern margin of the basin. Minimum thicknesses of approximately 6500 feet occur on the southwestern margin and on the eastern margin where sedimentation was associated with the periodic uplift and truncation over the Sabine Uplift.

Therefore, the East Texas Basin did not always have the symmetrical geometry that is apparent today. The basin subsided as a tilting shelf during early and late Cretaceous time. Only middle Cretaceous time had internal basin subsidence resulting in the bowl-shaped appearance.

TIME PERIOD		GLOBAL SEA LEVEL CHANGES TRANS.....REG	EAST TEXAS BASIN SEA LEVEL CHANGES TRANS......REG	SUBSIDENCE (Maximum Group thickness in feet)	FAULTING (Sabine Uplift activity)
TERTIARY MIDWAY				NONE (1800)	MINOR (MINOR)
NAVARRO	LATE			MINOR	MINOR
NAVARRO	MIDDLE			MINOR	MINOR (NONE)
NAVARRO	EARLY			MINOR (2600)	MINOR
TAYLOR	LATE			MODERATE	MINOR
TAYLOR	MIDDLE			MODERATE	MINOR (NONE)
TAYLOR	EARLY			MODERATE	MINOR
AUSTIN	LATE			MINOR	MINOR
AUSTIN	MIDDLE			MINOR (700)	MINOR (NONE)
AUSTIN	EARLY			MINOR	MODERATE
EAGLE FORD	LATE			MINOR	MODERATE (MAJOR)
EAGLE FORD	MIDDLE			MINOR (900)	MINOR
EAGLE FORD	EARLY			MINOR	MINOR
WOODBINE	LATE			MODERATE	MODERATE (MAJOR)
WOODBINE	MIDDLE			MODERATE (1000)	MINOR
WOODBINE	EARLY			MODERATE	MINOR
WASHITA	LATE			MODERATE	MINOR (MINOR)
WASHITA	MIDDLE			MINOR (1500)	MINOR (MODERATE)
WASHITA	EARLY			MAJOR	MAJOR (MODERATE)
FREDER-ICKSBURG	LATE			MINOR	MINOR
FREDER-ICKSBURG	MIDDLE			MINOR (1000)	MINOR (NONE)
FREDER-ICKSBURG	EARLY			MINOR	MODERATE
TRINITY	LATE			MODERATE	MINOR
TRINITY	MIDDLE			MODERATE (5600)	MINOR (NONE)
TRINITY	EARLY			MAJOR	MAJOR
JURASSIC COTTON VALLEY				MODERATE (?)	MODERATE (MINOR)

Fig. 1. Summary of Cretaceous history within the East Texas Basin. Global sea level changes correlate with major sedimentation changes in the East Texas Basin. Cretaceous rocks were deposited as an overall transgressive sequence, interrupted by several oscillations in shoreline position. Two major regressions, correlating with major global regressions, occurred within the East Texas Basin. Major subsidence within the basin occurred primarily during early to middle Cretaceous deposition, in two major episodes: one during early Trinity deposition and the second during early Washita deposition. Subsidence was relatively minor during the remainder of Cretaceous time. Major faulting along the Mexia-Talco Fault Zone coincided with major subsidence within the basin. The Sabine Uplift on the eastern margin of the basin was active primarily during middle Cretaceous deposition.

Hydrocarbon Potential of the
Central Sudan Rifts

Randall R. Pharis

Petroleum companies have been prospecting for hydrocarbon production in rifts for almost thirty years. Important discoveries include the North Sea, Campos Basin in Brazil, and the Gulf of Suez. Rift exploration in Africa has occurred on both the east and west coasts and in interior Mesozoic rifts. Three intercratonic rifts are located in Sudan. These rifts are the Southern Sudan Rift, the White Nile Rift, and the Blue Nile Rift.

The source rocks in most highly productive rift areas were deposited during a restricted marine phase of their development. There are, however, productive rift basins in which deposition throughout the history of the basin was entirely continental. These basins are sourced by organic-rich shales deposited during a lacustrine phase. Examples of productive continental rift basins include the Campos Basin in Brazil, the Lower Congo Basin on the west coast of Africa, and the Southern Sudan Rift.

This investigation examines four continental rift basins in central Sudan, to delineate their structural, stratigraphic, and geochemical framework, and to evaluate their hydrocarbon potential. The three basins are located immediately south of Khartoum, Sudan, Africa, between latitudes 12° 0′ 0″ N and 15° 0′ 0″ N, and longitudes 29° 30′ 0″ E and 34° 0′ 0″ E.

The Central Sudan Rifts consist of the White and Blue Nile Rifts. The study area includes four basins in the rifts: the Kosti, Bara, Daraqil, and Khartoum Basins (Fig. 1). The structural framework of these basins is a result of four phases of tectonic activity which began in Late Jurassic time. These phases include: (1) Late Jurassic to Cretaceous breakup of Pangea; (2) Late Cretaceous shift in plate motions; (3) Tertiary opening of the Red Sea; and (4) onset of oceanic spreading in the Red Sea (Fig. 1).

Basin subsidence curves for the six wells drilled in the study area indicate that the effect of the rifting phases was varied among the basins. Phase I rifting in the White Nile Rift was restricted to the Bara Basin, while phase II rifting shifted to the Kosti Basin. This caused a prolonged period of erosion in the Bara Basin in which the sediments corresponding to the source rocks of the southern Sudan oil fields were either not deposited or were eroded away. Phase III rifting in the White Nile Rift was again located in the Bara Basin. The Daraqil Basin was only affected by Tertiary rifting. Phases I, II, and IV were active in the Khartoum Basin.

The basins in the central Sudan rifts are actually half-grabens, linked together into a chain by transfer zones. The most common plan view geometry for these chains is sinusoidal. This results from a reverse in polarity of each succeeding half-graben.

Stratigraphy in the central Sudan grabens is related to the four phases of tectonism. These phases can be further subdivided into pre-, syn-, and post-rift sediments. There is no complete stratigraphic section in any of the basins of the White Nile Rift. By compiling the stratigraphy from each of the three White Nile basins, a complete stratigraphic section can be derived. This section is equivalent to the stratigraphic column for the Southern Sudan Rift. Stratigraphy for the Blue Nile Rift is derived from the three wells in the Khartoum Basin.

Continental rifts, by nature, contain rapid shifts in depositional facies in both the vertical and lateral directions. Consequently, there is a delicate balance between the deposition of source versus reservoir rock facies. If the lacustrine water level is low or fluctuates, the deposition of coarse clastics is favored. However, if the lacustrine water level remains high for significant periods of time, the deposition of organic-rich lacustrine sediments is favored. The environment in the central Sudan rifts favored the deposition of well-oxidized clastic sediments. Geochemical data from the six wells drilled in the study area reveal a lack of significant amounts of organic-rich source rock occurring below the oil generation window. The greatest concentration of rich organic shales in the central Sudan rifts occurs in the Khartoum Basin. Mathematical calculations using the **BasinMod** computer program indicate that an economic field (reserves of >100,000,000 bbls) in the Khartoum Basin would drain the oil generated from the entire basin. This occurrence is not physically feasible. Consequently, the hydrocarbon potential for the basins in the central Sudan rifts is limited.
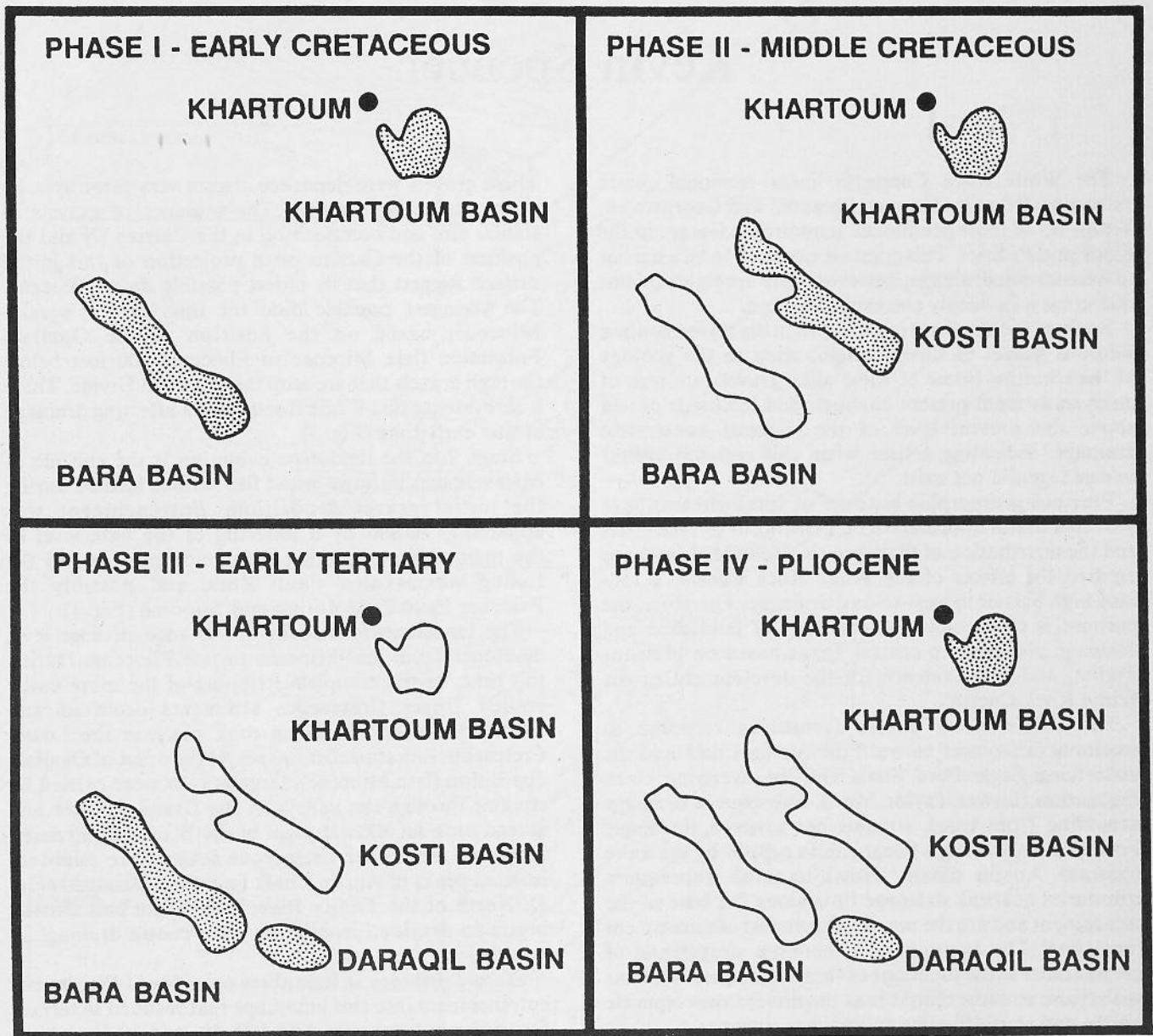
Fig. 1. Conceptual maps depicting the central Sudan basins which were actively subsiding during each of the four tectonic phases discussed. Stippled basins in each map were undergoing active subsidence. Scale is approximately 1:8,000,000.

Drainage Evolution Across the
White Rock Cuesta, Central Texas

Kevin Spencer

The White Rock Cuesta, a linear erosional cuesta extending 250 miles between Sherman and Georgetown, Texas, is the most prominent geomorphic feature in the Blackland Prairies. This cuesta is expected to be a barrier to west-to-east drainage; however, there are eight streams that cross it in deeply entrenched valleys.

Some of the smaller stream basins in the region contain siliceous gravel of fluvial origin, alien to the geology of their basins. Some of these alien gravels are tens of miles away from present channels and hundreds of feet above the present level of the regional consequent drainage, indicating a time when this regional barrier to drainage did not exist.

Previous geomorphic histories of trunk streams have provided useful information on Pleistocene terrace levels and the distribution of high gravels. However, they have omitted the effects of the White Rock Cuesta, a 150-foot-high barrier to west-to-east drainage. Therefore, the purpose is to develop a chronology of landscape and drainage evolution in central Texas based on previous studies, and new evidence for the development of the White Rock Cuesta.

The White Rock Cuesta formed in response to erosional differences between the Austin Chalk and the underlying Eagle Ford Shale and the overlying Ozan Formation (Lower Taylor Marl). Subsequent drainage extending from trunk streams has lowered the Eagle Ford Prairie, leaving a linear cuesta capped by the more resistant Austin Chalk. North-to-south subsequent tributaries of trunk drainage flow along the base of the escarpment and are the major instruments of escarpment formation. The escarpment is therefore steeper and of greater relief at the junctions of these subsequent streams with trunk streams than it is at the divides that separate north- and south-flowing subsequent streams.

Evidence for the initial stage in the evolution of the central Texas landscape is contained in lag gravels on top of the highest divides within the Washita Prairie, the Lampasas Cut Plain, and on the Callahan Divide.

These gravels were deposited over a very large area by eastward-flowing streams. The presence of gravels of similar size and composition in the Carrizo (?) and the position of the Carrizo on a projection of this initial surface suggest that its oldest possible date is Eocene. The youngest possible date for this surface is mid-Miocene, based on the position of the Ogallala Formation (late Miocene to Pliocene) 200 feet below the high gravels that are atop the Callahan Divide. There is no evidence of a White Rock Cuesta affecting drainage at that early time (Fig. 1).

Stage 2 in the landscape evolution is the episode of entrenchment into the broad flat surface formed during the initial gravel deposition. Entrenchment was apparently caused by a lowering of the base level of the major rivers resulting from movement along the Luling-Mexia-Talco Fault Zone and possibly the Balcones Fault Zone during mid-Miocene (Fig. 1).

The landscape formed by the change in base level developed from mid-Miocene to late Pliocene. During this time, nearly complete stripping of the more easily eroded Upper Cretaceous sediments occurred and considerble valley widening took place in the Lower Cretaceous limestone landscape. At the onset of Ogallala deposition (late Miocene), large gravels were carried by streams through the valleys in the Grand Prairies and spread onto an alluvial plain in the Blackland Prairies. Although the Upper Cretaceous shales were removed, isolated peaks of Austin Chalk limestone remained (Fig. 1). North of the Trinity River, the cuesta had already begun to develop, prohibiting cross-cuesta drainage in that region.

Stage 3 includes at least three episodes of Pleistocene entrenchment into this landscape that resulted in terrace formation at approximately 100, 60, and 30 feet above the present floodplain of most major central Texas streams. These episodes of entrenchment lowered the landscape, resulting in the emergence of the White Rock Cuesta as we see it today (Fig. 1).

Stage 1

Edwards Limestone

Austin Chalk

Stage 2

Edwards Limestone

Austin Chalk

Stage 2-Late

Edwards Limestone

Austin Chalk
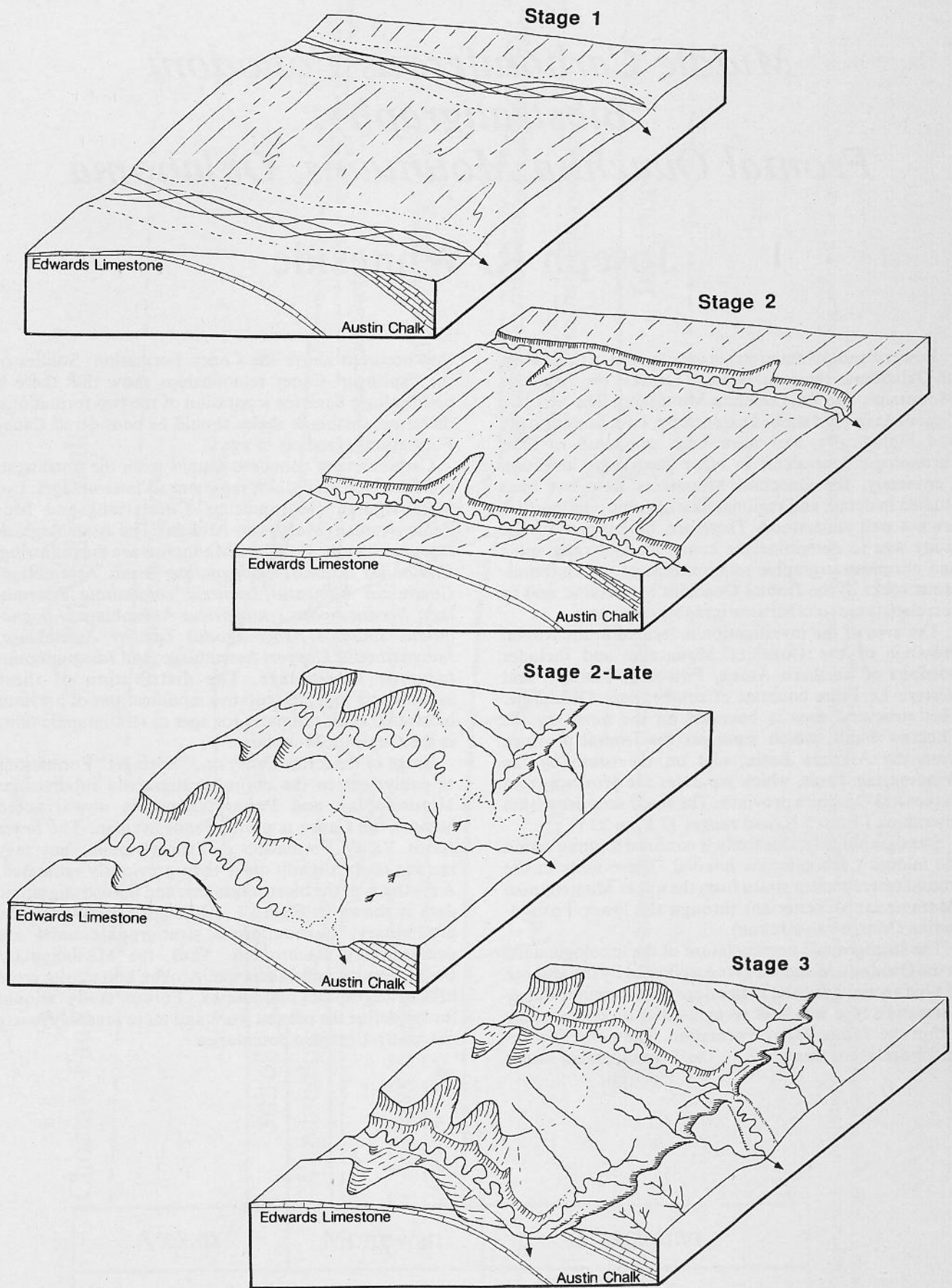
Stage 3

Edwards Limestone

Austin Chalk

Fig. 1. Stages in the evolution of drainage across the White Rock Cuesta.

23

Middle Carboniferous Conodont Biostratigraphy: Frontal Ouachita Mountains, Oklahoma

Joseph R. Whiteside

Lower Pennsylvanian strata are exposed in three areas of Oklahoma: the southwestern Ozarks, the Arbuckle Mountains, and the Ouachita Mountains. The first two regions have been studied extensively, both lithologically and biologically, and have been compared to their chronologic equivalents in other geographic localities. Conversely, the Ouachita Mountains have not been studied in detail, and regional stratigraphic relationships are not well understood. Therefore, the purpose of this study was to determine the conodont biostratigraphic and chronostratigraphic relationships of the Carboniferous rocks of the frontal Ouachita Mountains, and to correlate these to other stratigraphic sequences.

The area of the investigation is located in the frontal province of the Ouachita Mountains and includes portions of northern Atoka, Pittsburg, Latimer, and western Le Flore counties of southeastern Oklahoma. This structural area is bounded on the north by the Choctaw Fault, which separates the frontal province from the Arkoma Basin, and on the south by the Windingstair Fault, which separates the province from the central Ouachita province. The study area lies within townships 1 S. to 5 N. and ranges 12 E. to 23 N.

Stratigraphically, this study is confined to units within the middle Carboniferous interval. These units in the frontal belt represent strata from the upper Mississippian (Meramecian?-Chesterian) through the lower Pennsylvanian (Morrowan-Atokan).

The stratigraphic nomenclature of the lithologic units in the Ouachita Mountains is complicated by the absence of type sections for the formations. The original Caney Formation type was later recognized as an olistostrome within the Johns Valley Formation. The name "Springer" Formation was given to the Pennsylvanian shales that occurred above the Caney Formation. Studies of the "Springer"-Caney relationships show that there is no lithologic basis for separation of the two formations; therefore, the black shales should be considered Caney Formation regardless of age.

Carboniferous conodont faunas from the northwestern Ouachita Mountains represent six assemblages: two Mississippian (Meramecian?-Chesterian) and four Pennsylvanian (Morrowan-Atokan). The assemblages as recognized in the Ouachita Mountains are the following: *Gnathodus texanus/Kladognathus tenuis* Assemblage; *Gnathodus bilineatus/Lochreia commutata* Assemblage; *Neognathodus symmetricus* Assemblage; *Idiognathodus sinuosus/Neognathodus bassleri* Assemblage; *Idiognathodus klapperi* Assemblage; and *Idiognathodus incurvus* Assemblage. The distribution of these assemblages suggests tentative modifications of previous biostratigraphic estimates for ages of stratigraphic units in the Ouachita Mountains.

Usage of the terms Caney and "Springer" Formations as equivalent to the chronostratigraphic subdivisions Mississippian and Pennsylvanian is unwarranted because the Caney is partly Pennsylvanian. The lower Johns Valley Formation is Pennsylvanian, but may include rocks slightly older than previously estimated. A synthesis of the biostratigraphic and lithostratigraphic data is shown in Figure 1. Although observations are preliminary, Carboniferous stratigraphic units are demonstrably diachronous. Thus, the Mississippian/Pennsylvanian and Morrowan/Atokan boundaries cross lithostratigraphic boundaries. Future study should further refine the present work and more precisely locate chronostratigraphic boundaries.
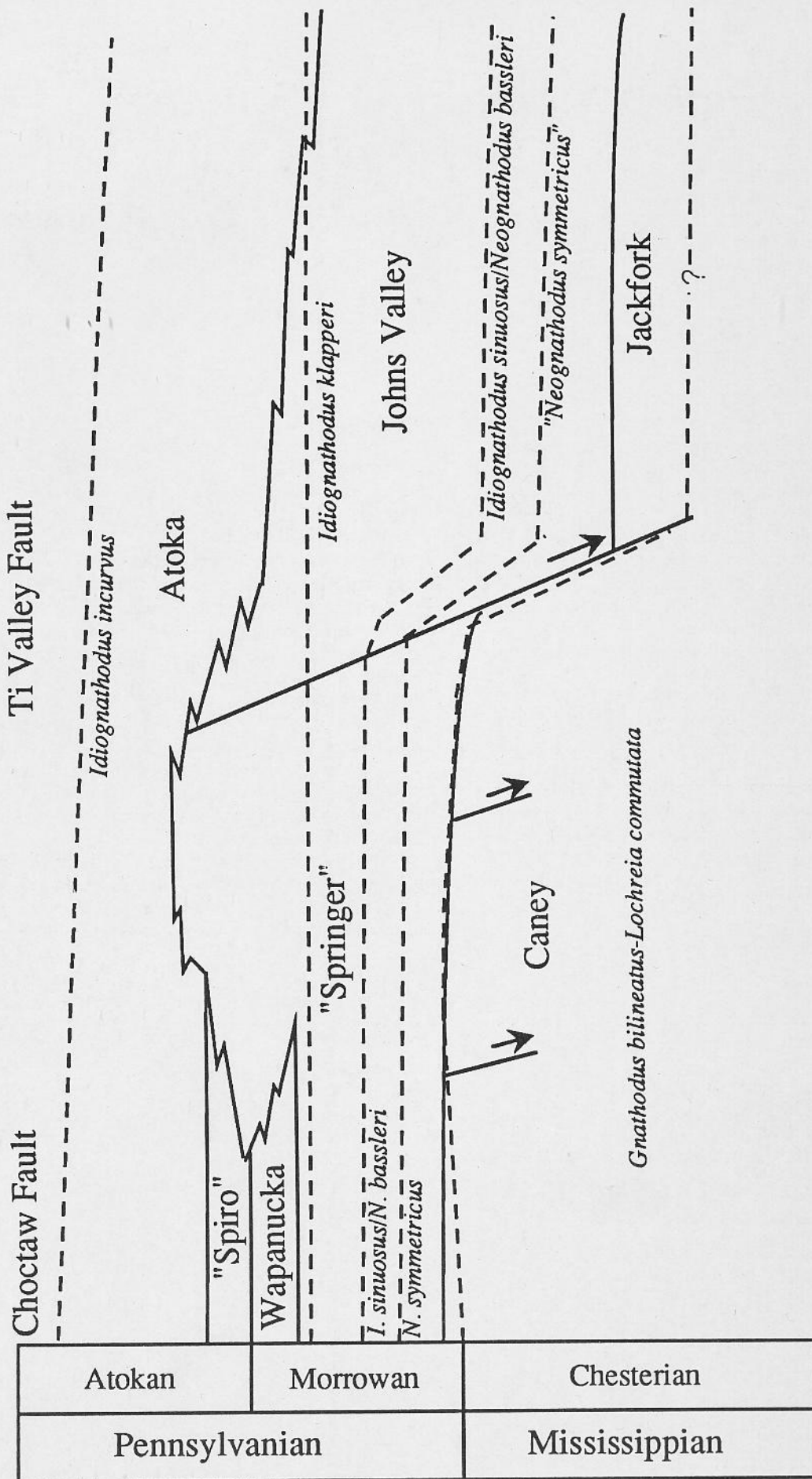
Fig. 1. Diagrammatic cross section showing relationships of lithostratigraphic and biostratigraphic data. Note the diachronous relationships of the units and the changes in nomenclature. Major environmental changes occur at Windingstair Fault, possibly reflecting syndepositional faulting or rapid slope break.

BAYLOR GEOLOGICAL
PUBLICATIONS

Baylor Geological Studies*

1. Holloway, Harold D., 1961, The Lower Cretaceous Trinity aquifers, McLennan County, Texas: Baylor Geological Studies Bull. No. 1 (Fall). Out of print.
2. Atlee, William A., 1962, The Lower Cretaceous Paluxy Sand in central Texas: Baylor Geological Studies Bull. No. 2. (Spring). Out of print.
3. Henningsen, E. Robert, 1962, Water diagenesis in Lower Cretaceous Trinity aquifers of central Texas: Baylor Geological Studies Bull. No. 3 (Fall). Out of print.
4. Silver, Burr A., 1963, The Bluebonnet Member, Lake Waco Formation (Upper Cretaceous), central Texas—A lagoonal deposit: Baylor Geological Studies Bull. No. 4 (Spring). Out of print.
5. Brown, Johnnie B., 1963, The role of geology in a unified conservation program, Flat Top Ranch, Bosque County, Texas: Baylor Geological Studies Bull. No. 5 (Fall). Out of print.
6. Beall, Arthur O., Jr., 1964, Stratigraphy of the Taylor Formation (Upper Cretaceous), east-central Texas: Baylor Geological Studies Bull. No. 6 (Spring). Out of print.
7. Spencer, Jean M., 1964, Geologic factors controlling mutation and evolution—A review: Baylor Geological Studies Bull. No. 7 (Fall). Out of print.
†8. Part I: Geology, 1965, Geology and urban development by Peter T. Flawn; Geology of Waco by J. M. Burket: Baylor Geological Studies Bull. No. 8 (Spring). Out of print.
†9. Part II: Soils, 1965, Soils and urban development of Waco by W. R. Elder: Baylor Geological Studies Bull. No. 9 (Fall). $5.00.
†10. Part III: Water, 1966, Surface waters of Waco by Jean M. Spencer: Baylor Geological Studies Bull. No. 10 (Spring). $5.00.
†11. Part III: Water, 1976, Subsurface waters of Waco by Siegfried Rupp: Baylor Geological Studies Bull. No. 11 (Fall). $5.00.
†12. Part IV: Engineering, 1967, Geologic factors affecting construction in Waco by R. G. Font and E. F. Williamson: Baylor Geological Studies Bull. No. 12 (Spring). Out of print.
†13. Part V: Socio-Economic Geology, TBA, Economic geology of Waco and vicinity by W. T. Huang; Geology and community socio-economics—A symposium coordinated by R. L. Bronaugh: Baylor Geological Studies Bull. No. 13 (Fall). Not yet published.
†14. Part VI: Conclusions, TBA, Urban geology of greater Waco—Summary and recommendations by Editorial Staff: Baylor Geological Studies Bull. No. 14 (Spring). Not yet published.
15. Boone, Peter A., 1968, Stratigraphy of the basal Trinity (Lower Cretaceous) sands, central Texas; Baylor Geological Studies Bull. No. 15 (Fall). $5.00.
16. Proctor, Cleo V., 1969, The North Bosque watershed, Inventory of a drainage basin: Baylor Geological Studies Bull. No. 16 (Spring). Out of print.
17. LeWand, Raymond L., Jr., 1969, The geomorphic evolution of the Leon River system: Baylor Geological Studies Bull. No. 17 (Fall). Out of print.
18. Moore, Thomas H., 1970, Water geochemistry, Hog Creek basin, central Texas: Baylor Geological Studies Bull. No. 18 (Spring). Out of print.
19. Mosteller, Moice A., 1970, Subsurface stratigraphy of the Comanchean Series in east central Texas: Baylor Geological Studies Bull. No. 19 (Fall). Out of print.
20. Byrd, Clifford Leon, 1971, Origin and history of the Uvalde Gravel of central Texas: Baylor Geological Studies Bull. No. 20 (Fall). Out of print.
21. Brown, Thomas E., 1971, Stratigraphy of the Washita Group in central Texas: Baylor Geological Studies Bull. No. 21 (Fall). Out of print.
22. Thomas, Ronny G., 1972, The geomorphic evolution of the Pecos River system: Baylor Geological Studies Bull. No. 22 (Spring). Out of print.
23. Roberson, Dana Shumard, 1972, The paleoecology, distribution and significance of circular bioherms in the Edwards Limestone of central Texas: Baylor Geological Studies Bull. No. 23 (Fall). Out of print.
24. Epps, Lawrence Ward, 1973, The geologic history of the Brazos River: Baylor Geological Studies Bull. No. 24 (Spring). Out of print.
25. Bain, James S., 1973, The nature of the Cretaceous-pre-Cretaceous contact in north-central Texas: Baylor Geological Studies Bull. No. 25 (Fall). Out of print.
26. Davis, Keith W., 1974, Stratigraphy and depositional environments of the Glen Rose Formation, north-central Texas: Baylor Geological Studies Bull. No. 26 (Spring). Out of print.
27. Baldwin, Ellwood E., 1974, Urban geology of the Interstate Highway 35 growth corridor between Belton and Hillsboro, Texas: Baylor Geological Studies Bull. No. 27 (Fall). $5.00.
28. Allen, Peter M., 1975, Urban geology of the Interstate Highway 35 growth corridor from Hillsboro to Dallas County, Texas: Baylor Geological Studies Bull. No. 28 (Spring). $5.00.
29. Belcher, Robert C., 1975, The geomorphic evolution of the Rio Grande: Baylor Geological Studies Bull. No. 29 (Fall). $5.00.
30. Flatt, Carl Dean, 1976, Origin and significance of the oyster banks in the Walnut Clay Formation, central Texas: Baylor Geological Studies Bull. No. 30 (Spring). Out of print.
31. Dolliver, Paul Noble, 1976, The significance of Robert Thomas Hill's contribution to the knowledge of central Texas geology: Baylor Geological Studies Bull. No. 31 (Fall). $5.00.
32. Pool, James Roy, 1977, Morphology and recharge potential of certain playa lakes of the Edwards Plateau of Texas: Baylor Geological Studies Bull. No. 32 (Spring). $5.00.
33. Bishop, Arthur L., 1977, Flood potential of the Bosque basin: Baylor Geological Studies Bull. No. 33 (Fall). $5.00.
34. Hayward, Chris, 1978, Structural evolution of the Waco region: Baylor Geological Studies Bull. No. 34 (Spring). $5.00.
35. Walker, Jimmy R., 1978, Geomorphic evolution of the Southern High Plains: Baylor Geological Studies Bull. No. 35 (Fall). $5.00.
36. Owen, Mark Thomas, 1979, The Paluxy Sand in north-central Texas: Baylor Geological Studies Bull. No. 36 (Spring). $5.00.
37. Bammel, Bobby H., 1979, Stratigraphy of the Simsboro Formation, east-central Texas: Baylor Geological Studies Bull. No. 37 (Fall). $5.00.
38. Leach, Edward Dale, 1980, Probable maximum flood on the Brazos River in the city of Waco: Baylor Geological Studies Bull. No. 38 (Spring). $5.00.
39. Ray, Bradley S., 1980, A study of the crinoid genus *Camarocrinus* in the Hunton Group of Pontotoc County, Oklahoma: Baylor Geological Studies Bull. No. 39 (Fall). Out of print.
40. Corwin, Linda Whigham, 1982, Stratigraphy of the Fredericksburg Group north of the Colorado River, Texas: Baylor Geological Studies Bull. No. 40 (Spring). $5.00.
41. Gawloski, Ted, 1983, Stratigraphy and environmental significance of the continental Triassic rocks of Texas: Baylor Geological Studies Bull. No. 41 (Spring). $5.00.
42. Dolliver, Paul N., 1984, Cenozoic evolution of the Canadian River basin: Baylor Geological Studies Bull. No. 42 (Spring). $5.00.
43. McKnight, Cleavy L., 1986, Descriptive geomorphology of the Guadalupe Mountains, south-central New Mexico and West Texas: Baylor Geological Studies Bull. No. 43 (Spring). $5.00.
44. Matthews, Truitt F., 1986, The petroleum potential of "serpentine plugs" and associated rocks, central and south Texas: Baylor Geological Studies Bull. No. 44 (Fall). $5.00.
45. Surles, Milton A., Jr., 1987, Stratigraphy of the Eagle Ford Group (Upper Cretaceous) and its source-rock potential in the East Texas Basin: Baylor Geological Studies Bull. No. 45 (Fall). $5.00.
46. Rapp, Keith Burleigh, 1988, Groundwater recharge in the Trinity Aquifer, central Texas: Baylor Geological Studies Bull. No. 46 (Spring). $5.00.
47. Anderson, L. Marlow, 1989, Stratigraphy of the Fredericksburg Group, East Texas Basin: Baylor Geological Studies Bull. No. 47 (Spring) $5.00.
48. Fall, 1989, Thesis Abstracts: Baylor Geological Studies Bull. No. 48. $5.00
49. Hawthorne, J. Michael, 1990, Dinosaur track-bearing strata of the Lampasas Cut Plain and Edwards Plateau, Texas: Baylor Geological Studies Bull. No. 49 (Spring). $5.00.
50. Fall, 1990, Thesis Abstracts: Baylor Geological Studies Bull. No. 50. $5.00.
51. Pettigrew, Robert J., Jr., 1991, Geology and flow systems of the Hickory Aquifer, San Saba County, Texas: Baylor Geological Studies Bull. No. 51 (Spring). $5.00

Baylor Geological Society

101-138, 147-149, 151: Out of print. For titles see earlier Baylor Geological Studies Bulletins.
139. Urban development along the White Rock Escarpment, Dallas, Texas, 1978. $3.00.
140. Paluxy Basin: Geology of a river basin in north central Texas, 1979. $3.00.
141. Geomorphic evolution of the Grand Prairie, central Texas, 1979. $3.00.
142. The nature of the Cretaceous-precretaceous contact, central Texas, 1979. $4.00, a professional level guidebook.
143. The geology of urban growth, 1979. $3.00.
144. A day in the Cretaceous, 1980. $3.00.
145. Landscape and landuse, 1980. $3.00.
146. Southeastern Llano country, 1983. $3.00.
150. Pre-Pennsylvanian geology of the Arbuckle Mountain region, southern Oklahoma, 1987. $10.00.

*Publications available from Baylor Geology Department, Baylor University, Waco, Texas 76798. Prices include postage, handling and sales tax. Baylor Geological Studies bulletins out of print may be available as photo copies.

†Part of **Urban Geology of Greater Waco**, a series on urban geology in cooperation with Cooper Foundation of Waco.

BAYLOR UNIVERSITY GEOLOGY