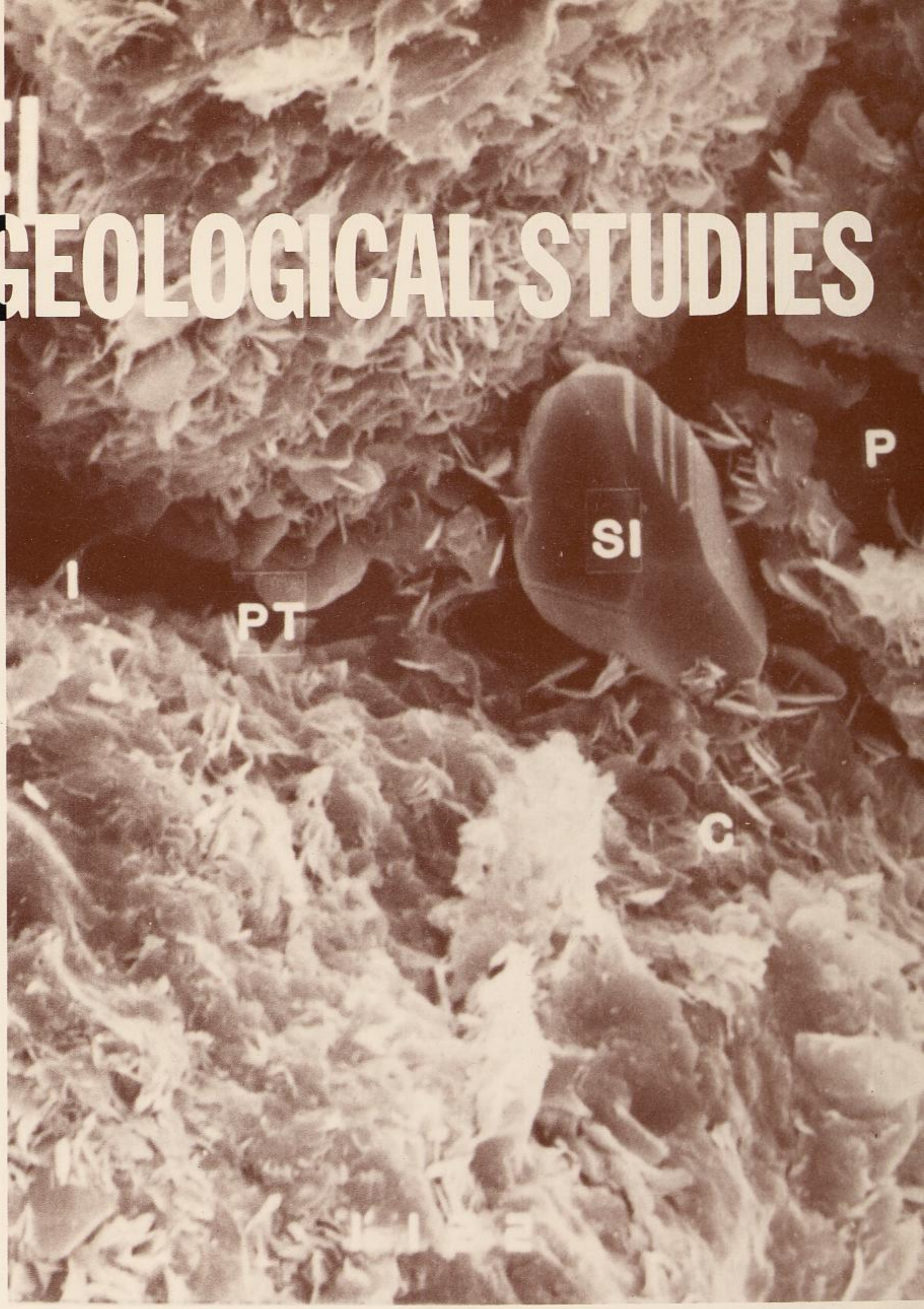
BAYLOR GEOLOGICAL STUDIES



FALL 1992

Bulletin No. 53

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 geologists in a university covers but a few years; their educations continue throughout their active lives. 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: SEM micrograph illustrating the morphologies and relationships of authigenic minerals in Wilcox Sands. (From Grau.)

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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 The original, unpublished versions of the theses, complete with appendices and bibliographies, can be found in the Ferdinand Roemer Library, Department of Geology, Baylor University,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.

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The Baylor Geological Studies Bulletin is published by the Department of Geology at Baylor University. The Bulletin is specifically dedicated to the dissemination of geologic knowledge for the benefit of the people of Texas. The publication is designed to present the results of both pure and applied research which will ultimately be important in the economic and cultural growth of the State.

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CONTENTS

Changes in the Texas Landscape Since the Advent of Europeans

Valerie A. Adkins

Changes in the physical world as a result of human presence are of increasing concern as human numbers increase and the planet remains finite. The landscape of Texas as defined by its soil, water, vegetation, landuse, animal populations, and human population is in many ways a different place from Texas prior to European exploration and settlement. A survey of the changes in the landscape from the time of the first recorded European sightings to the present is a necessary step toward developing a plan to halt or remedy deleterious changes.

Four of the ten physiographic regions in Texas were chosen for study: the Coastal Prairies, the High Plains, the Hill Country, and the Trans-Pecos. From each region a representative county was chosen for concentrated study: Calhoun, Potter, Comal, and Jeff Davis. From the observations of explorers, settlers, scientists and others a picture of the landscape at three different stages in each study area was constructed: the years of exploration by the Europeans, the years while settlement made its first changes to the landscape, and the present landscape. To complete the landscape picture three variables that did not change in historic time were catalogued: geology, topography, and the regional climate (possible changes in climate due to post-Industrial Revolution emissions were beyond the scope of this study).

Calhoun County in the Coastal Prairies is located on the Pleistocene Beaumont Formation, a massive accumulation of deltaic material. It is a very flat environment with only minor variations in topography and a subtropical climate. It was first described as a long and mid-range grassland supporting an animal population including deer, bear, javelina, prairie chickens, and enormous numbers of migrating waterfowl. The Karankawa Indians were hunter/gatherers who by using fire as a hunting tool kept woody vegetation confined to the watercourses. Today, less than 1% of the landscape remains in native grassland. Much of the county is under cultivation for rice and cotton and where there are fields for grazing, the cessation of burning has allowed woody shrubs to supplant grasses. Other very obvious signs of the human population of 21,000 include oil and gas wells, roads, fences, and buildings. All have contributed toward reducing and restricting the numbers of large animals initially described.

The High Plains, preserved from erosion by the caliche Caprock in the upper Ogallala Formation and the "beheading" of its rivers by the Pecos River, is remarkably flat. The Canadian River is the major artery of the High Plains and flows through the study area in Potter County providing sharp relief. Extreme temperatures and variable, never generous, yearly rainfall totals characterize the climate. When first described in the early nineteenth century (Table 1) it was a rich mid-grass prairie, with enormous herds of bison, mule deer, pronghorn antelope, wild turkey, wild horses, cattle, prairie chickens, and prairie dogs. Water was found either in the Canadian or its tributaries or in playas after rain. The Comanche Indians were dependent upon the bison herds for food and migrated with them. Potter County has had dramatic changes due to the explosive growth of the city of Amarillo, currently with a population of 104,000; probably a fifth of the county is urban land. The balance of the county exhibits the pattern of growth and change for the rest of the High Plains: though few in number, the human population exacts a heavy toll. After the bison were exterminated, ranching and farming exposed the soil to erosion, used the groundwater pumped from the Ogallala aquifer to the point of overdraft, and usurped the habitat of wild animals and native vegetation.

The Hill Country, located on southeastward-dipping Cretaceous bedrock and bordered by a complex series of faults forming the Balcones Escarpment, is represented by Comal County. It has a rough topography characterized by flat-topped mesas and dissected rolling hills; its climate is subtropical. Early accounts rhapsodized over the "undulating region," its profuse springs and rivers, and its varied and abundant wildlife. The human population has ballooned from only about 300 Tonkawa Indians to a current population of 53,000. This growth has been accompanied by such problems as the replacement of native grasses with woody "nuisance" shrubs whose thirsty roots contribute to the shrinking of the Edwards aquifer, and soil opened to erosion.

The Trans-Pecos has very complex stratigraphy due to the overweening Tertiary volcanics intruding into Cretaceous and older beds. This area is the southern expression of the Basin and Range with the down-faulted valleys filled partly with alluvium from the mountains. Jeff Davis County has the spectacular topography of the fault-block Davis Mountains, with the northern extension of the Lobo Valley in the west. Most of the county has a desert climate, while the semiarid Davis Mountains benefit from a rain-shadow effect. This county has shown the least amount of change, with the most notable being the replacement of former grassland with desert shrubs such as acacia and creosote.

COASTAL PRAIRIES - Represented by Calhoun County			
Variables	Era I (1528-1840)	Era II (1840-1886)	Era III (Present)
Soil	thick, clayey	no change	no change
Vegetation	long & mid-range grassland	invasion of woody shrubs, introduction of crops & ornamentals all contribute to supplanting native grasses	less than 1% original grassland - balance under cultivation or invaded by woody shrubs
Water	freshwater difficult to find between rains	no change - settlers dependant on rainwater collected in cisterns	groundwater not technologically available before now in overdraft
Landuse	hunter/gatherer - used fire as hunting tool	parts cultivated and grazed	rice, cotton, cattle - gas & oil
Animal Populations	waterfowl, prairie chickens, deer, bear, javelina,	native animals begin to be supplanted by domestic - especially large mammals	large mammals gone, migratory birds recovering from early 20th century
Human Populations	4000-6000 Karankawa Indians ranging in a ten county area	3400 in Calhoun county - natives gone	21,000 in Calhoun county

HILL COUNTRY - Represented by Comal County			
Variables	Era I (1756-1850)	Era II (1850-1880)	Era III (Present)
Soil	dark, loamy soils - generally thin except in river valleys	cultivation & grazing begins erosion particularly of thin hillside soils	erosion continues with development - efforts made to control successful, significant portion thick valley soil flooded with the creation of Canyon Lake
Vegetation	varied - tall grass prairie, forested river bottoms, limited Juniper, cacti, yucca	invasion of woody shrubs,introduction of crops & ornamentals supplanting native grasses	severe invasion of woody shrubs especially Juniper, crops & ornamentals into former grassland and forested bottoms
Water	abundant fresh springs & rivers	begins to be polluted from agricultural runoff	Edwards aquifer pumped into overdraft-streams & springs dry or with reduced flow, Canyon Lake created
Landuse	hunter/gatherer - used fire as a hunting tool	grazing on rocky uplands, valleys cultivated	urban, suburban, agriculture, sport hunting & tourism
Animal Populations	abundant & varied - bear, puma, wild turkeys, deer, songbirds, wolves, ocelots & occasional bison	decreased large mammals due to lost habitats & hunting, replaced by domestics	imbalance - recovering populations of game birds & deer with very few predators to control
Human Populations	200-400 Tonkawa Indians	5500 in Comal county - Tonkawas extinct	53,000 in Comal county

HIGH PLAINS - Represented by Potter county			
Variables	Era I (1808-1872)	Era II (1872-1889)	Era III (Present)
Soil	thick soil due to prairie biomass	beginnings of agriculture opened the soil to wind erosion	wind erosion measured in tens of tons/year on cultivated or grazed land, enormous area urbanized in Potter county
Vegetation	mid-grass prairie	destruction from overgrazing begins	native vegetation remains on the breaks of the Canadian, complete change within the city limits of Amarillo, crops replace grasses
Water	playas after inconsistent rainfall, Canadian River	no change	Ogallala aquifer mined for agriculture into overdraft, formation of Lake Meredith on the Canadian River
Landuse	natives followed bison herds	professional hunters, cattle drives, agriculture	urban, cultivation, grazing, gas & oil production
Animal Populations	bison, mule deer, pronghorn, turkeys, wild horses, feral cattle, prairie chickens, prairie dogs	bison exterminated, other native animals begin to decline	wild populat'on replaced with domestic
Human Populations	sparse Comanche presence	Comanches driven out, less than 100 permanent residents	104,000 in Potter county

TRANS PECOS - Represented by Jeff Davis County			
Variables	Era I (1800-1854)	Era II (1854-1880)	Era III (Present)
Soil	thin desert soils, alluvial soils in the bolson-filled basins and mountain valleys	exposed to erosion due to overgrazing on trails, no change over the balance	eroded in wateringspots and trails but no change over the majority
Vegetation	clumpy, short-grassprairie with acacia and creosote, succulent desert plants up to evergreenwoodland in the mountains	creosote & acacia begin to spread where grass grazed away, limited timberingin the mountains	grassland supplanted by desert shrubs, no change otherwise
Water	arid desert, semiarid mountains	no change	addition of sparse water wells, no change otherwise
Landuse	hunter/gatherer- very sparse	minimal hunting & grazing by soldiers & travelersin addition to hunter/gatherersstill present	some ranching, McDonnell Observatory& tourism in the Davis Mountains
Animal Populations	pronghorn, prairie dogs, golden eagles, bighorn sheep, javelina, cougar, mule deer	small reduction due to hunting	decline in large predators - still biotically diverse
Human Populations	about 500 Mescalero Apache ranged the entire Trans Pecos	natives declining, total population below 500 (including soldier population)	1500 in Jeff Davis county

Table 1. Summarization of the changes in the landscape of the four study areas since the advent of Europeans. Note the similarities between the areas, especially in the evolution of their vegetation.

Surface-Groundwater Study, Washita Prairie, Central Texas: An Integrated Approach

Gilbert T. Bernhardt

The area of investigation is located approximately 12 miles northwest of Waco, Texas, in north-central McLennan County. The 76.8 acre watershed is located 1 mile west of F.M. 2409 and is a subwatershed in the Childress Creek Basin, a subbasin of the Brazos River System. The investigative site is located in the Washita Prairie, a physiographic subprovince of the Grand Prairies of Texas. All members of the Georgetown Formation crop out in the watershed. Two major soil series, Aledo series and Crawford series, are represented in the study site. A large portion of the watershed, 69.12 acres or 90%, is covered by Aledo soils.

Five principal methods of monitoring were established at seven locations on the site. Runoff plots were the main method for monitoring the soil zone. An interceptor trench was used to observe flow in the upper intermediate zone and a shallow piezometer (HSW) was established to monitor the lower intermediate zone. The deep zone was monitored through a deeper piezometer (HDW). A weir was placed in the watershed tributary for stream flow observations. All sites were monitored from May 1, 1990, through April 30, 1991.

Three water-bearing zones (soil zone, intermediate zone, and deep zone) with four general flow paths (quick flow, lateral flow, intermediate flow, and deep flow) have been determined to exist in the highly fractured, unconfined aquifer system (Fig. 1). The majority of quick flow occurs at the base of the O soil horizon where it either contributes to tributary total flow, infiltrates into the A soil horizon, or evaporates.

Infiltration and percolation of water into and through the soil zone is mostly macropore flow. High soil storage ranging from 67% in the A1 horizon to approximately 22% at the base of the R horizon is the location of important supplies of potential stream water. A rainfall intensity of 1.2 inches of water percolating through the soil in one hour would produce sufficient head to drive water through the R horizon and into the upper intermediate zone. Large, intense storms between 1.9 inches and 3.9 inches are needed to saturate the lower intermediate zone. Most water passing in the intermediate zone moves vertically downward through interconnected fractures. Because most of the vertical flow component recharges the deep flow zone, the majority of the remaining 1.1% (combined intermediate flow and groundwater re-evaporation) of total yearly precipitation in the intermediate zone is very likely dominated by the horizontal flow component (matrix flow, along bedding planes, and through horizontal fractures) (Fig. 2). The HDW piezometer appeared to reflect the delayed reaction of the water table to precipitation throughout the updip Childress Creek Basin rather than the monitored watershed.

Fracture density and fracture opening widths seemed to control permeability and specific yield. Surface resistivity soundings in combination with in-situ permeability tests were used to derive permeability and specific yield values for the watershed.

The total flow measured for the monitor year was 323,171 cubic feet or 4.1% of yearly precipitation (Fig. 2). Intermediate flow and quick flow contribute only a small percentage of total flow, and deep flow does not contribute any. Therefore, soil zone lateral flow contributes the majority of total flow in the watershed for a modeled contribution of 4.9% of yearly precipitation or 84.5% of total flow.

Testing water for electrical conductivity (EC) is an effective method of determining water-bearing zones in an unconfined aquifer. The study suggested that stream hydrographs can be separated into flow components by plotting EC zonal boundaries on a combined EC/stream hydrograph. The effect of storm intensity on groundwater flow contribution to the tributary can be determined by comparing EC/stream hydrographs for several storms of varying intensities.

The SWRRB model with a groundwater component was used to estimate the water budget for the watershed. Two procedures were utilized to evaluate the model: comparing daily model height to HDW piezometer water heights; and comparing average daily model flow to actual average daily stream total flow. The model groundwater height underestimated the actual piezometer water height by 6% for an overall efficiency of 94% (actual height divided by model height), and the model total flow overestimated actual stream flow by approximately 37.5% for an efficiency of 62.5%.

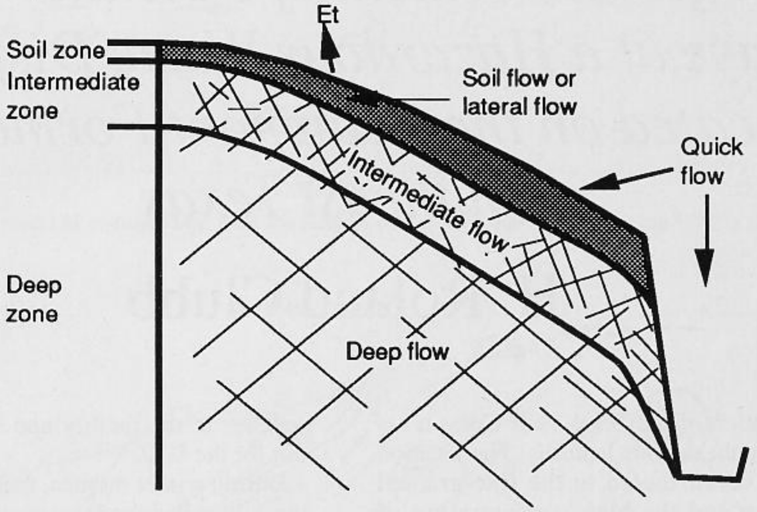


Fig. 1. Diagram showing three water-bearing zones with four general flow paths have been determined to exist in the watershed.

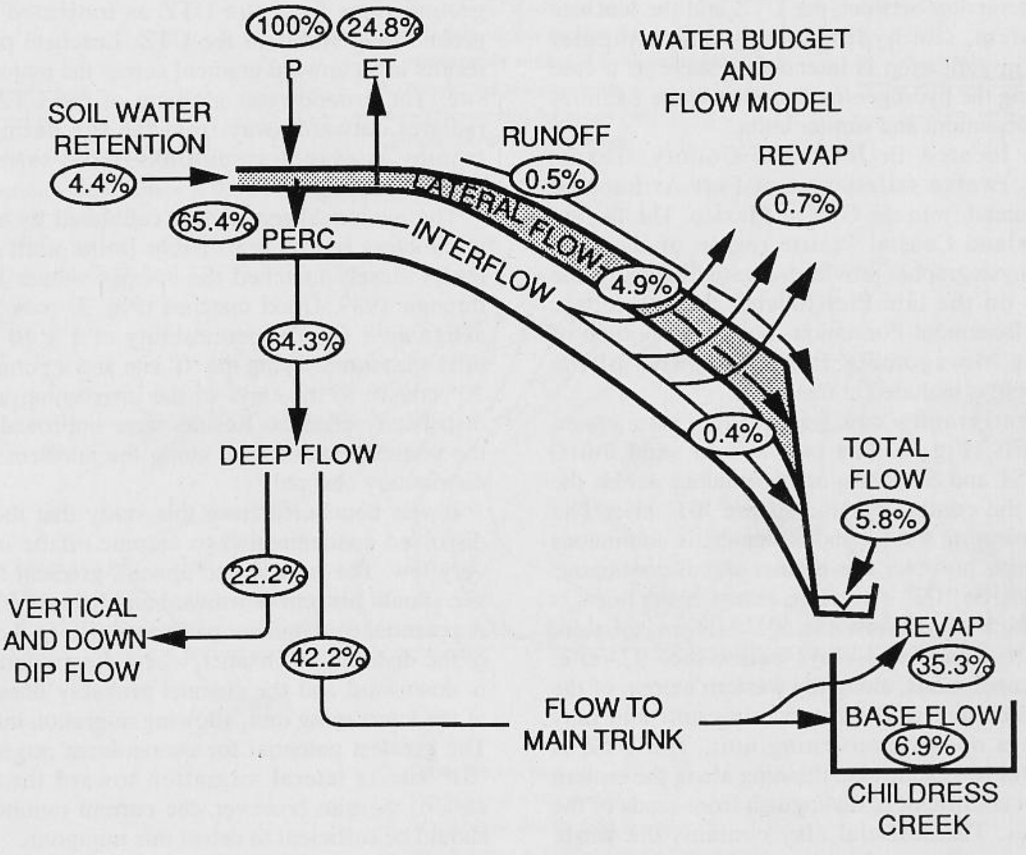


Fig. 2. Diagram of the water budget. All percentages shown are based on total yearly precipitation (P=100%) and the arrows indicate modeled flow paths. Total flow is composed of runoff, lateral flow, and interflow. Revap is re-evaporation.

Hydrogeologic Assessment of Potential Contaminant Pathways at a Hazardous Waste Disposal Site Located on the Beaumont Formation, Southeast Texas

H. Roland Clubb

The Beaumont Formation of the Texas Gulf Coast hosts several hazardous and nonhazardous landfills. The location of these facilities can be attributed to the fine-grained nature of the formation and the high concentration of industries and municipalities. Due to the complex stratigraphy of the Beaumont deposits and various site activities, conditions required for analytical assessment of the hydrogeology of these waste facilities cannot be met. Under these circumstances, numerical modeling is an alternative. This investigation assesses the hydrogeologic characteristics of shallow aquifers at a hazardous waste facility located on the Beaumont Formation. The major points of study include the interaction between the upper transmissive zone (UTZ) below the site and the underlying aquifers, the interaction between the UTZ and the leachate collection system, site hydrogeology, and computer modeling. The investigation is intended to serve as a case study in assessing the hydrogeology at other waste facilities located on the Beaumont and similar units.

The site is located in Jefferson County, Texas, approximately twelve miles west of Port Arthur and thirteen miles inland from the Gulf of Mexico. The facility is in the Grassland Coastal Prairie region of the Gulf Coastal Plain physiographic province. Stratigraphically, the site is located on the late Pleistocene, fluvial deltaic deposits of the Beaumont Formation. The upper portion of the underlying Montgomery Formation, also of the Pleistocene epoch, is included in this study.

The site stratigraphy can be divided into seven hydrologic units (Fig.1). The two lowest sand units, designated the S1 and S2 sands, are continuous across the site except in the central portion of the '01' site. The middle clay, separating the S2 and S1 sands, is continuous below the '01' site, however it is thinner and discontinuous below much of the '02' site. The intervening unit is composed of thick clay below the '01' site and of thin, interbedded silty sands and clays below the '02' site. Distributary channel sands, along the western margin of the '02' site, are included in the intervening unit and may breach the clays of the intervening unit. The UTZ is relatively uniform across the site, thinning along the eastern margin, where it is difficult to distinguish from sands of the intervening unit. The surficial clay contains the waste trenches at the facility and serves as the upper confining unit for the UTZ.

During winter months, recharge to the UTZ occurs in the agricultural uplands surrounding the facility and in the lower marshes (Fig. 1). Some upward seepage of groundwater occurs along the margin of the uplands once groundwater has rebounded from the lower summer levels. Groundwater of the UTZ generally flows westward toward the thinner clays of the intervening unit, recharging the deeper sands. In the immediate vicinity of the site, groundwater flows toward the facility (Fig. 2) due to both decreased recharge in the landfill area and leachate production. Leachate from the major producing trenches of the '02' site (Fig. 2) predominantly originates as groundwater from the UTZ as indicated by depressed groundwater levels in the UTZ. Leachate production also results in an upward gradient across the majority of the '02' site. The groundwater gradient of the UTZ reverses and radiates outward away from the site during the summer months as evapotranspiration in the surrounding areas exceeds recharge.

The numerical model was calibrated by adjusting input parameters within reasonable limits until the computed levels closely matched the average winter levels of 1986 through 1989. Good matches (Fig. 3) were obtained after assigning a vertical permeability of 1×10^{-8} cm/sec to the thick clays underlying the '0' site and a permeability of 1×10^{-6} cm/sec to the clays of the intervening unit east of the distributary channel. Results were improved by increasing the vertical conductance along the northern portion of the distributary channel.

It was concluded from this study that the potential for dissolved contamination to migrate offsite undetected was very low. The inward and upward gradient below the '02' site should prevent downward and lateral offsite migration. A potential contaminant pathway exists in the northern area of the distributary channel, where the groundwater gradient is downward and the channel probably breaches the clays of the intervening unit, allowing migration into the S1 sand. The greatest potential for contaminant migration from the '01' site is lateral migration toward the southern and eastern margin; however, the current monitoring program should be sufficient to detect this migration.

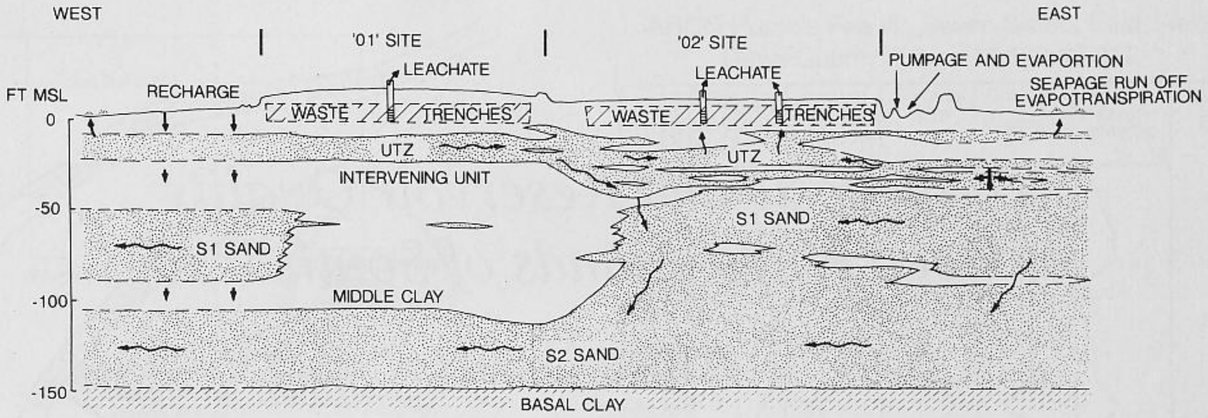


Fig. 1. Site geology and conceptual model of hydrogeology. Note the location of the distributary channel of the UTZ in the central portion of the cross section.

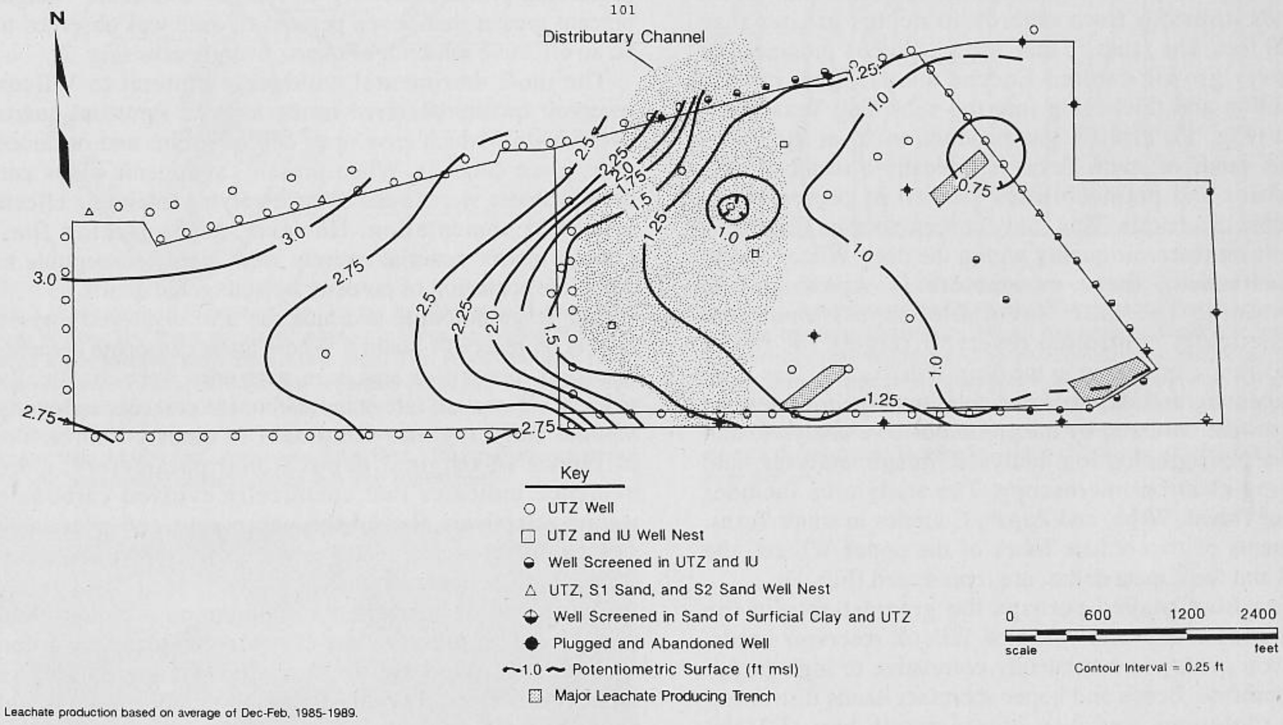


Fig. 2. Average potentiometric surface of the UTZ, January-March, 1986-1989, with location of major producing waste trenches.

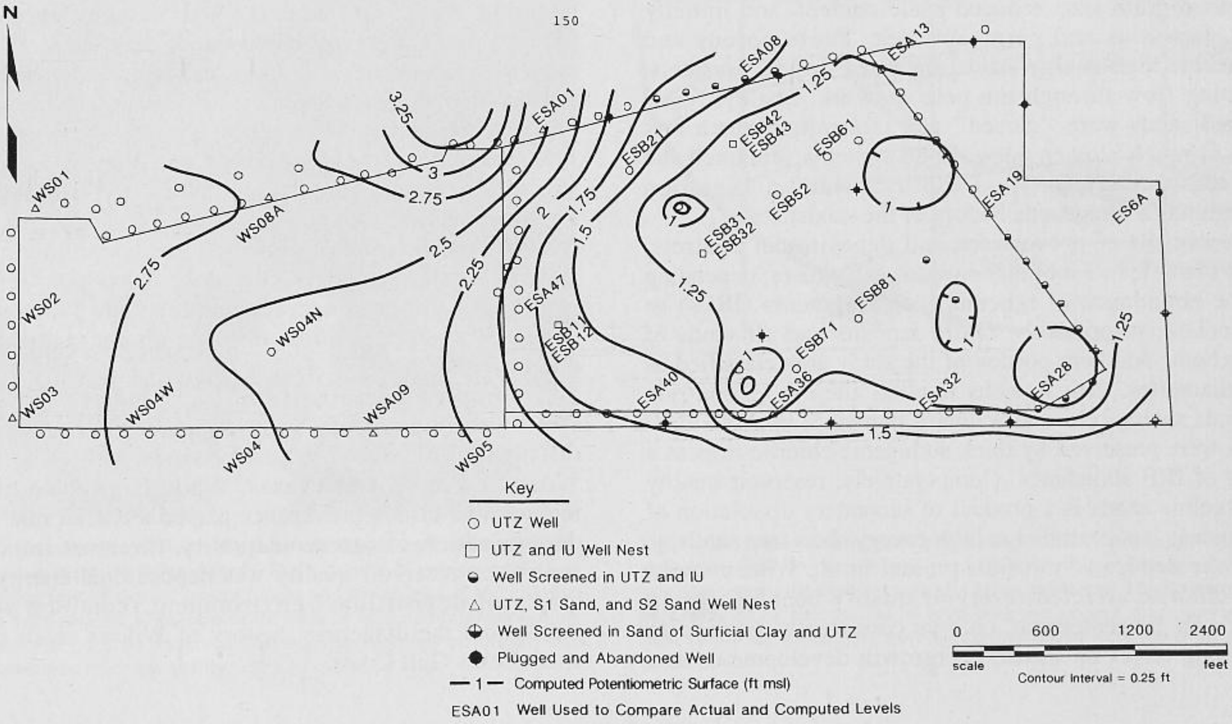


Fig. 3. Modeled potentiometric surface for the UTZ for January-March, 1986-1989.

Diagenesis and Reservoir Quality of Deep Wilcox Sands of South Texas

Anne Grau

The upper Wilcox of the southern Texas Gulf Coast extends downdip from outcrop to depths greater than 14,000 feet. The sands in this "deep" Wilcox prograde out and over growth-faulted Eocene shelf edges, rapidly expanding and thickening into the subsiding Texas Gulf Coast (Fig. 1). Prolific gas production from the upper Wilcox sands of south Texas is typically a result of high porosities and permeabilities created or preserved by favorable diagenesis. This study concentrates on diagenetic controls on reservoir quality within the deep Wilcox sands. Understanding these parameters is significant in determining the most favorable depositional and diagenetically controlled reservoir targets for future hydrocarbon exploration in the deep Wilcox.

Diagenetic and depositional relationships to reservoir quality were observed by integration of core analyses, thin section petrography, log analyses, image analyses, and scanning electron microscopy. The study area includes parts of Duval, Webb, and Zapata Counties in south Texas. Sediments of two deltaic lobes of the upper Wilcox, the Duval and the Zapata deltas, are represented (Fig. 1).

Deposition played perhaps the greatest role in the distribution and preservation of Wilcox reservoir sands. Reservoir quality is consistently correlative to high-energy environments. Beach and upper-shoreface sands distributed along shorelines, and distributary mouth bars (DMBs) deposited in delta-front settings are characterized by increased grain size, reduced shale content, and initially high porosities and permeabilities. These porous and permeable high-energy sands remained "open" systems, allowing flow through the pore network. Shaley, finer-grained sands were "closed" and transmitted much less fluid at much slower rates. Open systems remained the selected pathway for fluid and hydrocarbon migration throughout the diagenetic history of the sandstones.

As a result of provenance and depositional controls, sands classified as sublitharenites or subarkoses, depending on the abundance of igneous rock fragments (IRFs) or plagioclase, respectively. DMB deposits and all sands of the extreme southern portion of the study area classified as sublitharenites, their igneous fraction altering to iron-rich minerals such as chlorite. Primary porosities in these same sands were preserved by thick authigenic chlorite rims as a result of IRF abundance. Comparatively, reservoir quality in shoreline sands is a product of secondary dissolution of plagioclase, concentrated in high-energy shoreface sands.

Of the authigenic minerals present in the Wilcox sands, only chlorite affected reservoir quality beneficially. In significant concentrations, chlorite consistently displays an inhibiting effect on quartz overgrowth development, thus preserving primary porosity. In fact, a "threshold" weight percent greater than seven percent chlorite was observed to be an effective inhibitor of quartz overgrowths (Fig. 2).

The most detrimental authigenic mineral to Wilcox reservoir quality occurred in the form of syntaxial quartz overgrowths, which enveloped detrital grains and occluded pore space (Fig. 3). When present, authigenic clays and detrital shales were found to have varying inhibiting effects on quartz cementation. However, sands lacking fine-grained matrix material entirely were highly susceptible to complete occlusion of porosity by authigenic quartz.

Late-stage dolomite and ankerite also displayed inverse effects on reservoir quality. Where these carbonate cements occurred, porosities and pore networks were drastically reduced. However, late-stage carbonate cements reflecting basinal fluid regimes continued to clearly exhibit the influence of original depositional parameters. Core evidence indicates that chemically evolved carbonate waters selectively flowed through porous and permeable sands prior to widespread descension of the sedimentary column into basinal carbonate regimes.

The timing of generation and migration of acidic fluid was crucial to preservation of reservoir quality. Carbon dioxide, released by thermal maturation of source sediments, selectively moved through the most porous and permeable pathways, thus allowing dissolution to occur in "open," high-energy sands. Following carbon dioxide in both time and space, migrating hydrocarbons aided in the preservation of reservoir quality in Wilcox sands. Gas that moved and collected in porous and permeable sands was effective in reducing both quartz cementation and late-stage carbonate cementation in some instances.

Structurally, reservoir sands are concentrated off-structure in many of the growth-faulted, roll-over anticline traps that make up the majority of Wilcox fields. Due to the roll-over and rotation of sands into the controlling growth fault, sands that were deposited along paleo-highs (such as beach and upper-shoreface sands) have shifted to a structurally lower position, bringing poorer quality sands on top of structure (Fig. 4).

A complex combination of parameters including structure, deposition, and diagenesis controlled the distribution of reservoir quality sands within the upper Wilcox sands of south Texas. While large-scale basinal regimes and distant provenance played a crucial role in the determination of reservoir quality, the most important control on reservoir quality was depositional energy. The effect of depositional environment remained strong throughout the diagenetic history of Wilcox sands of the south Texas Gulf Coast.

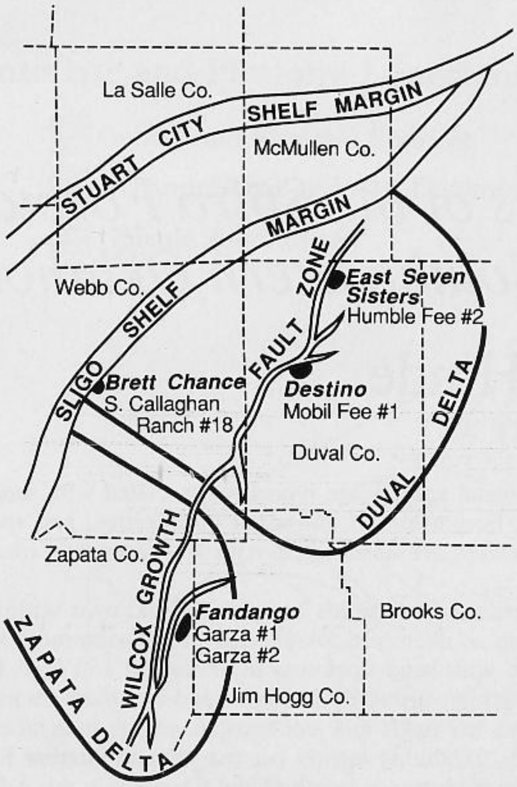


Fig. 1. Location map illustrating the Destino and Fandango Deltas of the deep Wilcox. The deltas prograded across the Cretaceous Stuart City and Sligo Shelf Margins onto the Eocene shelf. The Wilcox Growth Fault Zone represents the shelf edge that separated the rapid, deep expanded Wilcox deposition from shallow section. East Seven Sisters, Destino, and Fandango Fields represent gas production from the deep Wilcox at depths greater than 14,000 feet. Production from Brett Chance Field represents shallow, unexpanded sands at depths less than 10,000 feet.

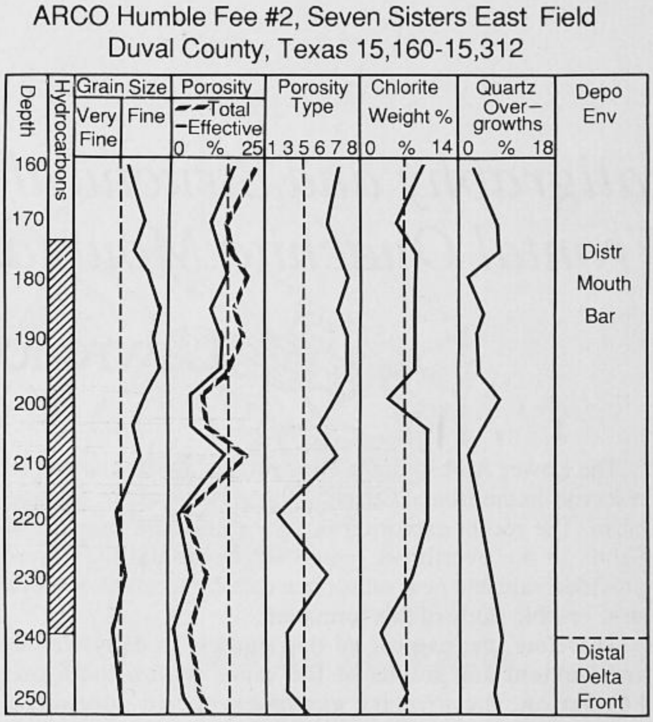


Fig. 2. Graph displaying relationships between depositional environment, diagenesis, and reservoir quality of deep Wilcox sands. Producing sands of this core represent Distributary Mouth Bar settings. Grain size, porosity, and porosity type (approximating permeability) are increased in this setting. Porosity type seven represents a combination of preserved primary and secondary porosity. Primary porosity is preserved by thick chlorite rims which inhibit quartz overgrowth cementation; this relationship is strongly demonstrated in samples where chlorite weight percent exceeds seven percent.

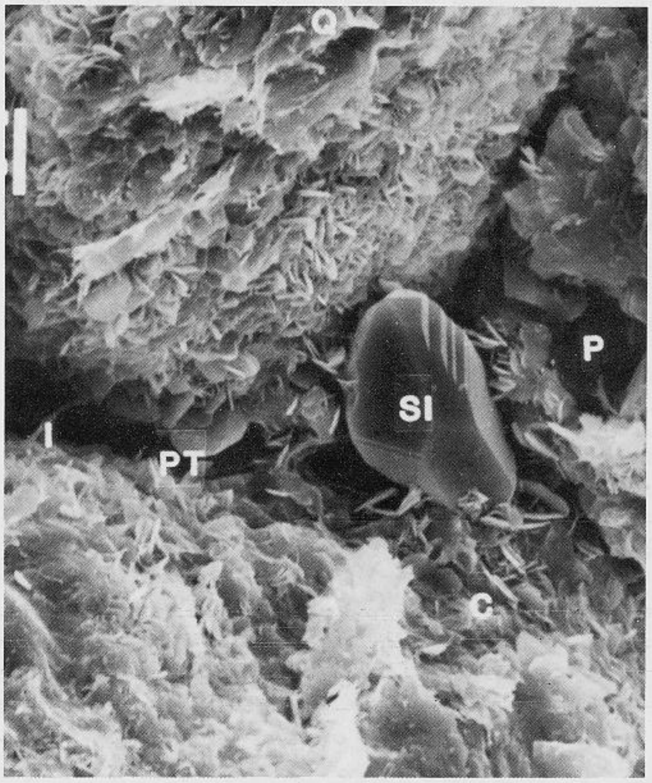


Fig. 3. SEM micrograph illustrating the morphologies and relationships of authigenic minerals in Wilcox Sands. Platy chlorite (C) aligns parallel to the grain surface of detrital quartz (upper and lower left). If the chlorite lining is thick enough, silica cement (SI) will be inhibited from nucleating and porosity (P) will be preserved. The hairy morphology of illite (I) can be detrimental to reservoir quality.

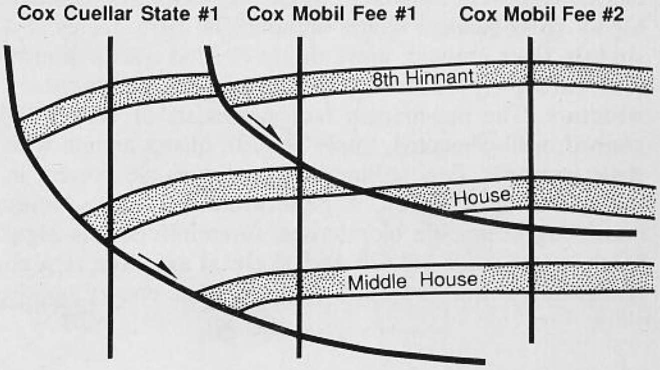


Fig. 4. The relationship of wells penetrating Wilcox strata to growth faults at Destino field. In deep Wilcox production, wells penetrating sands off-structure toward the fault are typically better producers. This scenario may be explained by the rotation of high reservoir quality sands toward the fault following deposition, moving the paleo-high to a lower structural position.

Stratigraphy and Structural Styles of the Spiro Formation, Frontal Ouachita Mountains, Southeastern Oklahoma

Lawrence K. Hinde

The Lower Atokan Spiro Formation is a well-known gas reservoir in the frontal Ouachita thrust belt and the Arkoma basin. The recent explosion in gas exploitation from Spiro Sands in the overthrust region of the frontal Ouachitas provided valuable new subsurface data for a comprehensive stratigraphic study of this formation.

Therefore, the purpose of this study is to delineate the areal extent and trends of the sands within the Spiro Formation, the primary gas reservoir. In additon, a stratigraphic model for this depositional system is needed to predict reservoir quality facies in the subsurface.

The area of focus of this study is in southeastern Oklahoma within the frontal Ouachita Mountains. Here the Spiro Formation crops out as thrust-repeated ridges in a narrow belt approximately 50 miles long and 5 miles wide between the Choctaw and Ti Valley faults. The study area lies within Townships 1 to 5 North and Ranges 12 to 21 East in Atoka, Pittsburg, and Latimer Counties, Oklahoma.

The Spiro Formation consists of laterally interfingering sandstone, shale, and limestone that can be categorized into bar crest, bar flank, bar margin, interbar, and platform limestone facies (Fig. 1). Sand bars deposited in a shallow marine, shelf environment were derived from reworking of late Morrowan fluvio-deltaic Foster "channel sands" (Fig. 2).

The crest facies consists of fine- to medium-grained, moderately well-cemented, thick- to very thick-bedded, highly cross-bedded, quartz arenite. The flank facies is a slightly finer grained, more thinly bedded quartz arenite with minor ripple marks as the primary sedimentary structure. The bar-margin facies consists of very fine-grained, well-cemented, thinly bedded, quartz arenite with shale interbeds. Few sedimentary structures are present in the bar-margin facies. A generalized interbar facies consisting of spicule biomicrites, foraminiferal and algal biomicrites, and oolitic and skeletal sparites is also recognized within the Spiro (Fig. 1). High-energy oolitic and skeletal sparites are typically associated with sand bar crests. Foraminiferal and algal biomicrites, and spicule biomicrites are associated with lower energy interbar facies.

Three sand bar fields are presently known within the Spiro in southeastern Oklahoma. The easternmost is the largest, with sand thickness in excess of 150 feet. Here, sands exhibit primarily bar crest and bar flank facies. To the west, bar fields thin and become smaller in areal extent (Fig. 2), exhibiting mostly bar margin and interbar facies. Spiro isopach trends, north of the Choctaw in the Arkoma basin, are concordant with net Spiro Sand trends in the frontal Ouachitas south of the Choctaw. Spiro "channels" are interpreted as high-energy, sand bar crest facies. West of the limit of sand deposition the Spiro exists as a platform limestone equivalent. Here, the Spiro consists of oolitic and skeletal sparites, foraminiferal and algal biomicrites, and spicule biomicrites which exhibit a series of shoaling upward sequences. South of the present-day Pine Mountain fault, slope and basinal sediments accumulated. To the east of the outcrop belt (along the frontal zone), the Spiro grades into a shale facies.

Field measurements of cross-bed orientations indicate a southwestward migration of sand bars. In addition, palinspastic restoration of thrust sheets confirms northeast-southwest paleodepositional trends and establishes sand bar field geometries (Fig. 2).

Late Pennsylvanian compressional tectonism has produced a narrow belt of thrust faults and repeated stratigraphic sequences, which crop out in the frontal Ouachita Mountains. Differences in thrusting styles are apparent from variations in the number of thrust imbrications in surface exposures. These variations are interpreted to be caused by upthrown blocks of deep-seated normal faults acting as thrust ramps. Lithologic variations concordant with changes in structural styles indicate possible reactivation of syndepositional normal faulting.

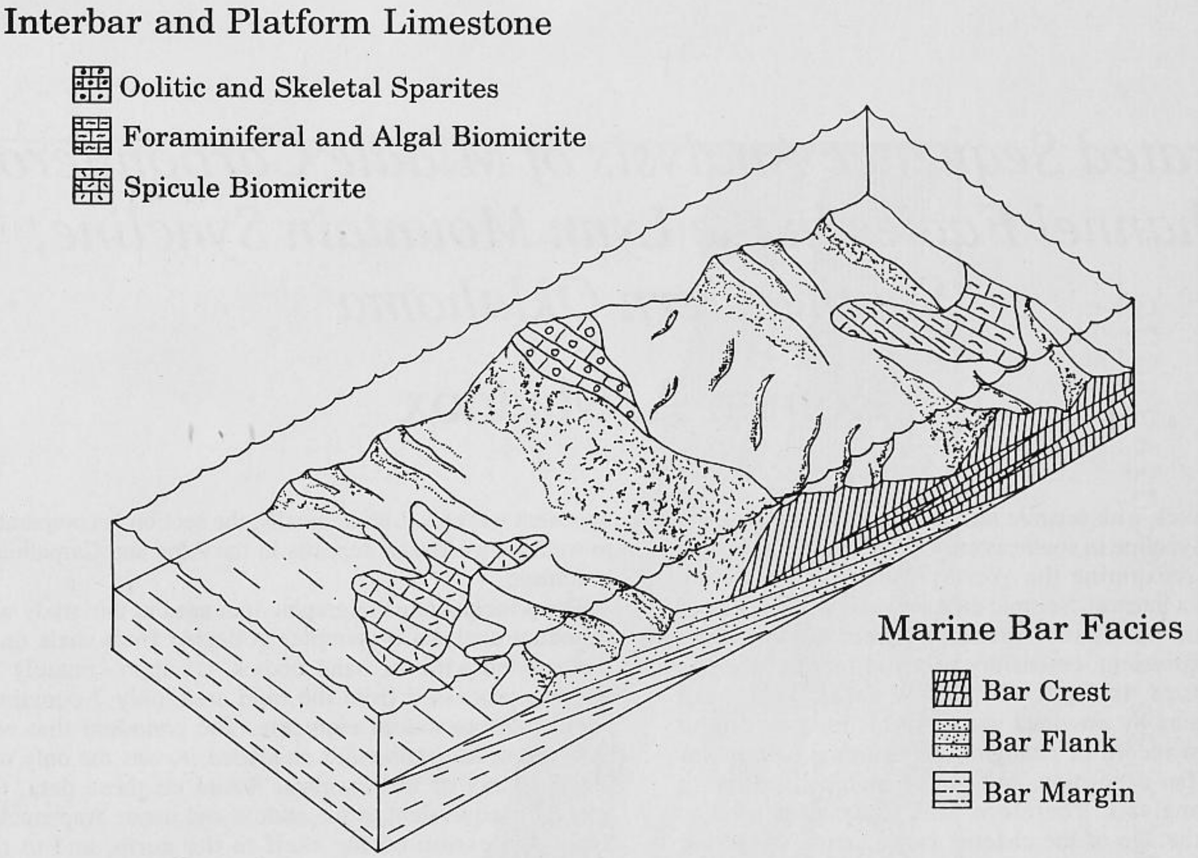


Fig. 1. Shallow marine shelf bar model showing siliciclastic carbonate relationships. High-energy oolitic and skeletal spatites are typically associated with sand bar crests. Foraminiferal and algal biomicrites and spicule biomicrites are associated with lower energy interbar facies. The platform limestone facies consists entirely of all of the above-mentioned limestones in a series of shoaling sequences.

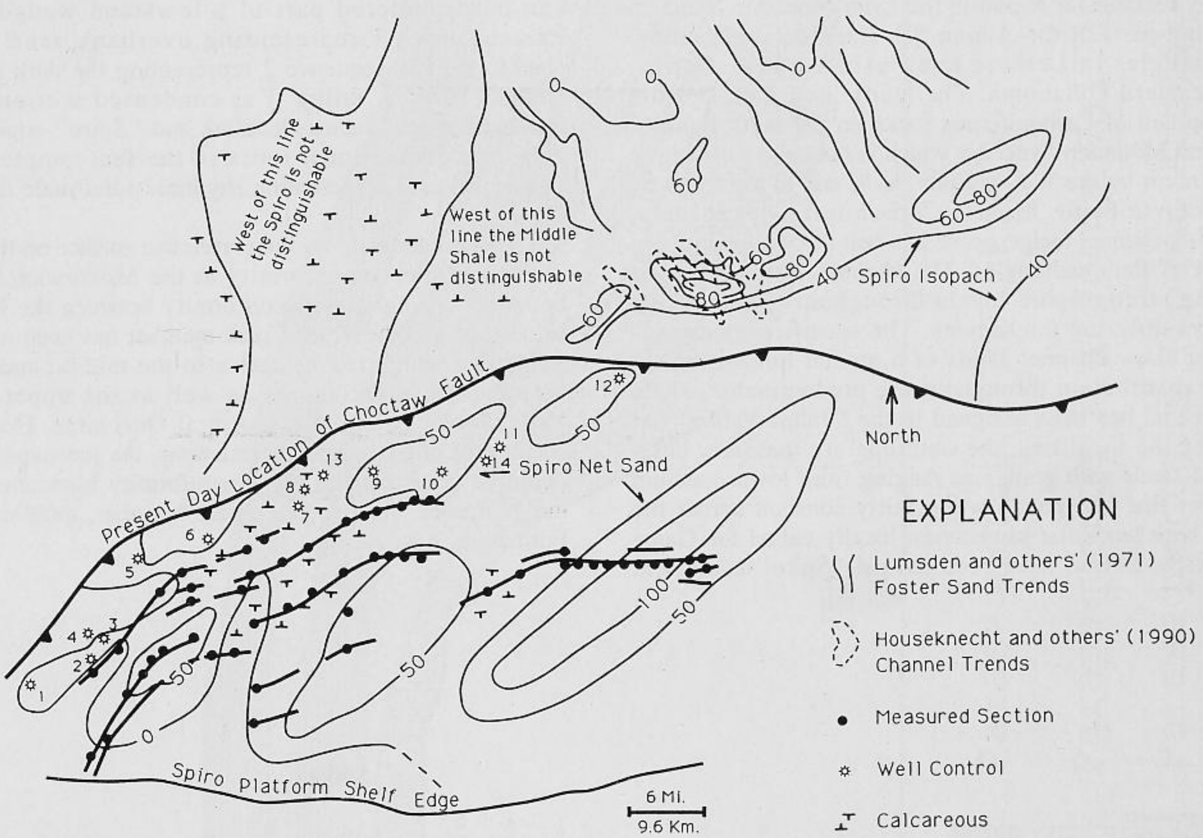


Fig. 2. Net Spiro Sands on palinspastic base map. Structure was palinspastically removed to recreate the paleodepositional shelf. Spiro Sand thickness ranges from 0 to 140 feet. Three sand bar tracts can be delineated. These sands thin and decrease in areal extent from east to west as proximity to Foster Sands decrease. Spiro isopach trends, north of the Choctaw in the Arkoma basin, are concordant with net Spiro Sand trends in the frontal Ouachitas south of the Choctaw. Spiro "channels" are interpreted as high-energy sand bar crest facies.

Integrated Sequence Analysis of Middle Carboniferous Channel Facies in the Lynn Mountain Syncline, Southeastern Oklahoma

Roman A. Maddox

Recent work with seismic and well log data in the Lynn Mountain Syncline in southeastern Oklahoma has exhibited a need to reexamine the Wesley/Game Refuge/Johns Valley/Atoka interval. Seismic data suggest the existence of channelized sands that recent workers have termed "Spiro"-equivalent, ostensibly to avoid more confusing nomenclature. In light of the new data, along with interpretations by previous workers, this interval can be viewed as a record of changing depositional patterns of submarine fan deposition, and can be incorporated into a sequence analysis. Therefore, this study attempted to determine the age of the channel facies, using integrated sequence stratigraphic methods, and its relationship with similar age units in adjacent areas.

The study area is a fifteen-mile-long by five-mile-wide, roughly rectangular region in the Lynn Mountain Syncline spanning parts of the Albion SE, Honobia, and Ludlow Quadrangles in LeFlore and Pushmataha Counties, southeastern Oklahoma. The study area included the outcrop belt of Carboniferous rocks on the north flank of the Lynn Mountain Syncline, which is bounded structurally to the north by the Windingstair Fault, and to the south by the Octavia Fault. Middle Carboniferous exposures, including channel facies, occur in a belt across the northern quarter of the quadrangles. The channel facies occurs at varying stratigraphic levels throughout the belt, and displays differing thicknesses. The specific outcrops of interest show channel sands of a medial fan setting, in varied distribution throughout the predominantly shale section that has been assigned to the "Johns Valley." At most of the localities, the outcrops are massive, buff-colored sands with grain size ranging from lower medium to upper fine and good sorting fairly constant across the belt. These lenticular sandstones, locally called the Game Refuge Sandstone, have been termed "Spiro"-equivalent by recent workers. Lithologically, the section is comparable to well-known flysch deposits in the Alps and Carpathians of Europe.

The principal biostratigraphic tool used in this study was conodont analysis of samples collected from shale units intercalated with the sand bodies. Of approximately 25 samples processed from the field area, only 7 contained identifiable conodont elements. The conodont that was recognized, *Idiognathoides ouachitensis*, was the only one found in any of the samples. Based on these data, the interval is equivalent to the middle and upper Wapanucka-Spiro succession on the shelf to the north, and to the McCully and upper Bloyd Formations to the northeast.

The depositional scenario that best matches the available data is a lowstand systems tract model. The study interval can be considered part of a lowstand wedge, with Parasequence 1 representing overbank sand facies (Jackfork); Parasequence 2 representing the dark pelagic shales ("Johns Valley") as condensed sections, and channelized sand facies (Jackfork and "Spiro"-equivalent) as active depositional lobes in the fan complex; and Parasequence 3 representing rhythmic sand/shale deposits (Fig. 1).

The best candidate for the correlative surface on the shelf is the regional unconformity at the Morrowan/Atokan boundary. A regional disconformity between the Kessler Limestone and the Trace Creek member has been noted in Arkansas, which is correlative to the middle and upper Wapanucka in Oklahoma as well as the upper Johns Valley/lower Atoka in the central Ouachitas. However, because of unconstrained correlations, the lowstand wedge could be equivalent to the disconformity associated with the "Caprock" of the Dye Shale Member, middle Bloyd Formation, Arkansas.

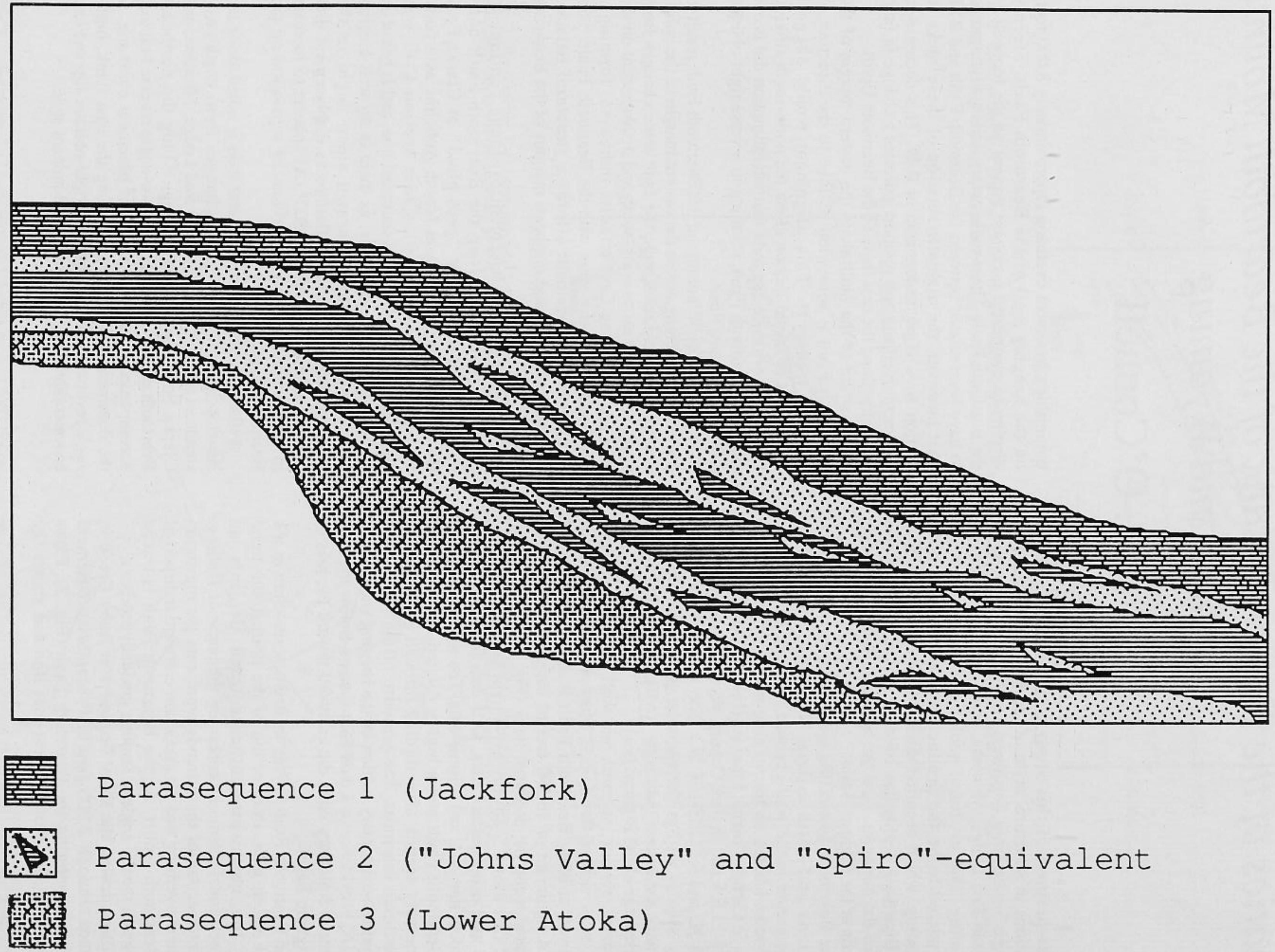


Fig. 1. Preliminary diagram of sequence interpretation of the study interval. More biostratigraphic data is needed to further refine this model.

Kinematics of the Eastern Flank of the Beartooth Mountains, Montana and Wyoming

Patrick J. O'Connell

The purpose of this study was to investigate the variations in structural style of the Beartooth Fault as it changes strike from northwest-southeast to north-south between Red Lodge, Montana, and Clarks Fork Canyon, Wyoming. The structural geology of the study area is interpreted to be the product of regional horizontal shortening, which occurred during the Laramide orogeny. The Beartooth Uplift has been tectonically transported toward the northeast, with the northeast corner overriding the axis of the Bighorn Basin.

The Beartooth Mountains are located in south-central Montana and northwestern Wyoming. The area of investigation is the well-exposed "eastern front" of the Beartooths located on the western margin of the Bighorn Basin in Carbon County, Montana (between Tps. 7-9 S. and Rs. 19-21 E.), and in Park County, Wyoming (between Tps. 56-58 N. and Rs. 103-104 W.). The western limit of the study area is within the outcrop of the Precambrian basement; the eastern limit is the Tertiary overlap along the western edge of the Bighorn Basin.

Gravity, surface, seismic, and well data from an area three miles west of Red Lodge, Montana, indicate that the northwest-striking Beartooth Fault is dipping 25° to 35° SW. A minimum of 16,500 feet of basement overhang is estimated along the northeast flank (Fig. 1). Cross section A-A' lies along a southwest-northeast line and was developed using surface data, well data from the Amoco Beartooth unit A-1, and seismic data. The well encountered the Beartooth Fault and a highly rotated-to-overturned sedimentary section after drilling through 8,500 feet of Precambrian basement. The presence of the rotated and overturned sedimentary section on the hanging wall of fault BTF (A) is evidence of a dual fault system. Below the BTF (A), the sedimentary units dip eastward toward the axis of the Bighorn Basin.

The Beartooth Fault begins to strike north-south at the Grove Creek area. Intersection of the north-south trend with the northwest-southeast trend presents an interpretational dilemma concerning the angle of faulting. The intersection of these trends represents the maximum basement overhang and the maximum eastward transport of the Beartooth Uplift. As the Beartooth Fault is traced southward, the dip angle of faulting gradually steepens.

Phillips drilled the Ruby Federal 1 at Ruby Creek in Montana through 2,000 feet of Precambrian basement before encountering the Beartooth Fault (Fig. 2). Cross section B-B' lies along a west-east line and shows the diminishing basement overhang (approximately 8,000 feet) on the hanging wall of the Beartooth Fault. Steeply dipping-to-overturned rocks are present on the footwall of the Beartooth Fault. These sedimentary units are interpreted to have been rotated between the Beartooth Fault and BTF (A); however, the dramatic rotation of these rocks in section A-A' is not recognized in B-B'. This decrease in basement overhang and rotation indicates a change in fault geometry along the east flank of the Beartooth Uplift.

The strike of the fault along the eastern margin of the Beartooth Fault is somewhat oblique to the direction of tectonic transport. This alignment would suggest component of lateral motion along the north-south striking fault. Field evidence suggests that lateral motion did occur along the Beartooth Fault, resulting in reverse right-oblique slip along the east flank.

Steeper angles of faulting on the Beartooth Fault result in decreased shortening across the eastern margin of the uplift. Southward from Line Creek, the fault trace changes from northeast-southwest to north-south and displacement on the BTF(A) and Line Creek faults increases, forming a displacement transfer zone with the Beartooth Fault. This transfer of displacement affords a structural balance between the eastern and northeast margins of the Beartooth Range.

Displacement and basement overhang continue to diminish southward along the Beartooth Fault until displacement eventually "goes blind" at Clarks Fork Canyon, creating the Canyon Mouth Anticline as a fault-propagation fold (Fig. 3). Cross section C-C' was developed along a northwest-southeast line, and is based on surface and seismic data only, as there is no well control. The Beartooth Fault dips at a steep angle in the Precambrian basement, and flattens as displacement dies into the sedimentary section. BTF (A) appears to increase in displacement, offsetting the loss of separation on the Beartooth Fault.

A distinctive change in structural style is noted along the Beartooth Fault as the strike changes from northwest-southeast to north-south between Red Lodge, Montana, and Clarks Fork Canyon, Wyoming. Along the northeast Beartooth margin at Red Lodge, low-angle reverse faulting, accompanied by large amounts of basement overhang, is the dominant style. However, along the east flank, high-angle reverse faulting, displaying right-oblique slip and less basement overhang, becomes the dominant style.

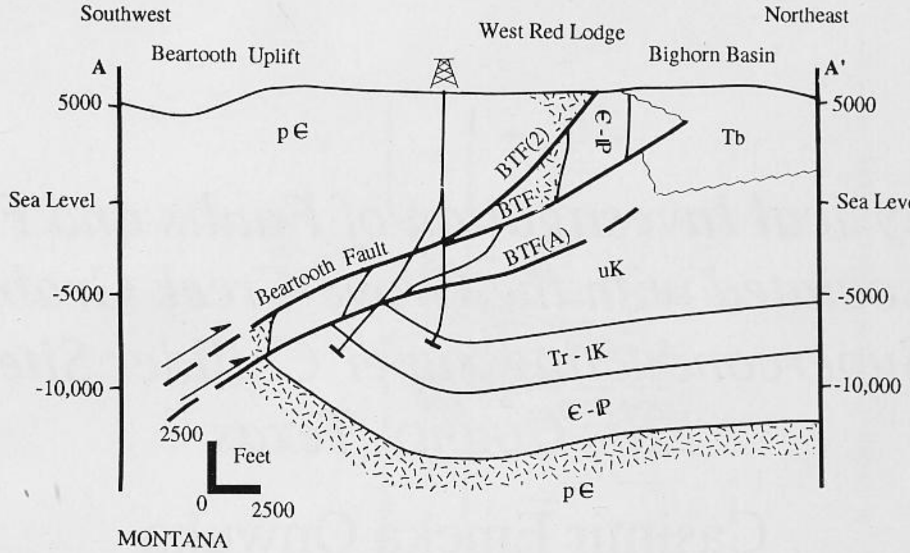


Fig. 1. Cross section A-A' is along a southwest-northeast line across the northeast margin of the Beartooth Uplift (west of Red Lodge, Montana). Low angle faulting with large amounts of basement overhang are characteristic of this segment of the uplift.

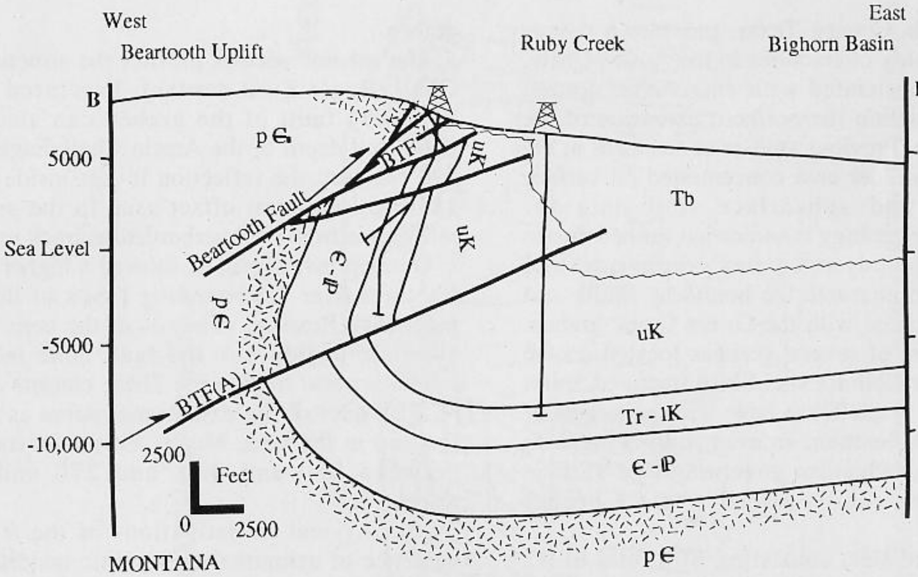


Fig. 2. Cross section B-B' (approximately 5 miles south of A-A') is along an east-west line across the eastern margin of the Beartooth Uplift. Section B-B' indicates a similar overall geometry to A-A'; however, less basement overhang and less rotation of the sedimentary section are present.

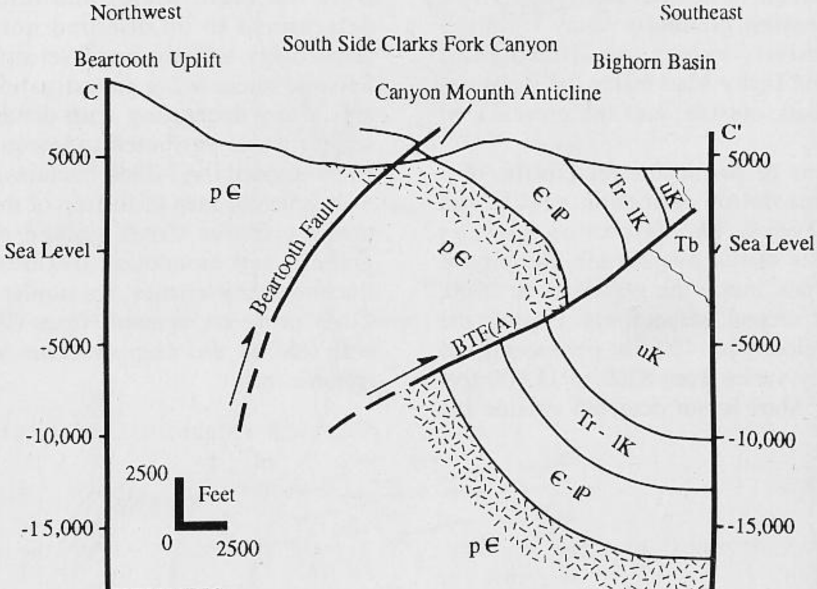


Fig. 3. Cross section C-C' (approximately 15 miles south of B-B') lies on a northwest-southeast line across the east flank of the uplift.. The Beartooth Fault is dipping steeply to the west-southwest with the displacement decreasing and dying into the sedimentary section producing the Canyon Mouth Anticline as a fault-propagation fold.

A Geophysical Investigation of Faults and Fractures Associated with the Grove Creek Graben, Superconducting Super Collider Site, Ellis County, Texas

Casimir Emeka Onwuka

The geology of Ellis County, Texas, provides a unique environment for the study of fractures in the Austin Chalk. These fractures are associated with *en echelon* normal faults believed to be within the northern extension of the Balcones Fault System. Previous studies of fractures in the Austin Chalk in the collider area concentrated on surface geologic mapping and subsurface well data for interpretations. Surface geology is somewhat limited due to poor exposures. This study integrates geophysical and geological methods to characterize bounding faults and fracture patterns associated with the Grove Creek graben. This structure is typical of several grabens located on the Superconducting Super Collider site. Since fractured zones in the Austin Chalk in south Texas have become targets of intense hydrocarbon exploration, an evaluation is made as to whether the same mechanism governing near-surface fracturing and faulting can be extended to the deeper subsurface.

Three resistivity profiles, consisting of a total of 15 individual soundings, were conducted across the width of the Grove Creek graben. The resistivity profiles and cross sections showed the graben to be characterized by low resistivity values increasing gradually away from the graben. The low resistivity values are attributed to fracturing, the presence of Taylor Marl inside the graben as compared to Austin Chalk outside, and the presence of water inside the graben.

Seismic investigations of the structures consist of a 3000-foot-long, high-resolution reflection profile and several refraction surveys. The refraction surveys established the velocities of the overburden, the Taylor Marl, and the Austin Chalk inside the graben to be 1500, 4800, and 7600 feet per second, respectively. Outside the graben the overburden velocity is 1400 feet per second and the Austin Chalk velocity varies from 8200 to 11,000 feet per second. The Taylor Marl is not detected outside the graben.

The seismic section profiles the structure of the Austin Chalk/Eagle Ford contact. Fractured zones and one boundary fault of the graben can also be identified. Estimated depth of the Austin Chalk/Eagle Ford contact is 390 feet, but the reflection is lost inside the graben. The 155-foot optimum offset used in the survey precluded reflections from the overburden/bedrock interface.

Outcrop investigations showed a higher concentration of fractures near the bounding faults of the graben and at monocline flexures. Analysis of the core from an inclined borehole drilled into the fault zone indicated that the fractures occur in clusters. These clusters are interpreted to be a product of the extensional stress associated with the faulting in the area. Major and minor fracture sets strike between 050 and 090, and 270 and 290 degrees, respectively.

Geophysical investigations of the fractures showed evidence of azimuthal anisotropic conditions in the area. Azimuthal resistivity surveys indicated that electrical anisotropy decreases with depth as well as with distance from the fault. Major and minor fracture sets were determined to be oriented northeast and northwest, respectively, with the major set striking parallel to the fault. Seismic shear-wave investigations indicated azimuthal anisotropy decreasing with distance from the fault. The anisotropy is attributed to unequal horizontal stress and stress-aligned fluid-filled fractures.

A structure map of the top of the Austin Chalk indicates that the Grove Creek graben plunges northeast. The grabens and monocline flexures, with their associated fracture characteristics, are similar to those found in Austin Chalk prospects in south Texas (Fig. 1), an indication that both shallow and deep structures were caused by the same tectonic forces.

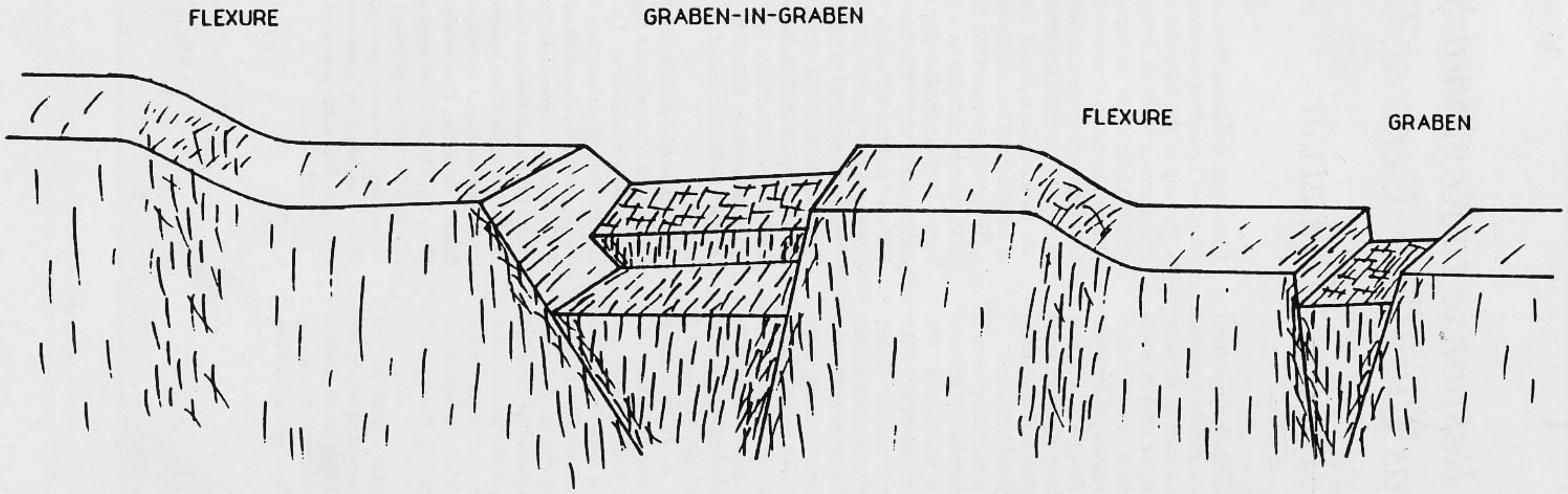


Fig. 1. Schematic model of the structures in the study area. The model shows relative location of flexures to grabens and the fracture characteristics associated with each structure. Intensity and density of fractures are highest in the grabens because of brecciation of the chalk from relative movement of the block.

Geomorphic Response to Regional Structure, Lampasas Cut Plain, Central Texas

Bradley C. Parish

The Lampasas Cut Plain is the modified northern extension of the Edwards Plateau. It is a greatly dissected dip plain, now recognized by the general level of its many remnantal summits, which dominate all the country south of the Brazos River, between the Western Cross Timbers and the Balcones Fault Zone. This region of dramatic landscapes has long been of interest, first because it best reveals the stratigraphy of Fredericksburg (Comanchean) rocks, and second because of the beautiful and apparently simple correlations between stratigraphy and landscape.

However, in recent years it has drawn increasing interest because the once "simple and clear" correlations between stratigraphy and landform have been questioned. The landscape of the Lampasas Cut Plain is apparently older than previously supposed, with a far more complex history involving more controls than once were recognized. Within this complex history, one of the major unanswered questions now involves the role of geologic structure in the evolution of Cut Plain landscapes. Therefore, this investigation describes the geologic structure in the Lampasas Cut Plain and relates this structure to landforms and their evolution in this major geomorphic region. The area of this study is located in central and west-central Texas. The physiographic provinces of major importance are the Lampasas Cut Plain and the Callahan Divide. The Callahan Divide, the Colorado-Brazos River drainage divide, lies west of the Lampasas Cut Plain. No physiographic "break" separates the Callahan Divide from the Lampasas Cut Plain. However, the eastern Callahan Divide and western margin of the Lampasas Cut Plain are characterized by a significant difference in structural dip and possibly in structural history. The study area covers approximately 17,000 square miles depicted on four sheets of the Texas Geologic Atlas Series: Abilene, Brownwood, Dallas, and Waco.

Throughout the study area, the Edwards Limestone, the caprock that armors the divides and mesas that define the Cut Plain, is approximately 15 to 30 feet in thickness. These minor variations in thickness are caused mainly by reef growth and facies changes with the Comanche Peak Limestone, and even these are insignificant in the overall pattern of Edwards Limestone.

The top of the Edwards Limestone is the most easily recognized, the most extensive, and the most reliable structural datum in the region of the Cut Plain. No other unit in the entire Cretaceous section provides the clear lithologic, geophysical, and topographic "signatures" typical of Edwards Limestone across the Trinity Shelf and into the East Texas Basin. For these reasons it was chosen as the structural horizon for this study.

The configuration of the Edwards surface at the close of its deposition was that of a regionally near-flat plain with minor local anomalies due to reef growth. The present configuration of the Edwards Limestone is that of a gently eastward-dipping homocline with minor monoclinal "steps" interrupting the gently inclined surface.

From the western margin of the study area along the Callahan Divide to the western margin of the Cut Plain, the average dip of the Edwards is approximately 5 feet per mile. From the western to the eastern margin of the Cut Plain, the average dip of the Edwards is approximately 15 feet per mile. Dip direction is generally east across the study area.

Lineaments within the study area identified from LANDSAT photographs may correlate with subsurface structural features (Fig. 1). These lineaments appear to control drainage orientation, the margins of major drainage divides, and the orientation of valleys and interfluves.

The surface expression of the western margin of the Fort Worth Basin is defined as the "Leon Lineament Zone" (Fig. 2). This zone contains lineaments that generally trend in a northwest-southeast direction and parallel the Leon River. Faults within the Fort Worth basin and faults that extend from the Llano Uplift may control the orientation of the northern margins of drainage divides in the Lampasas Cut Plain. Other lineaments within the study area are most likely controlled by continent-wide structural features that generally define the structural grain of Texas.

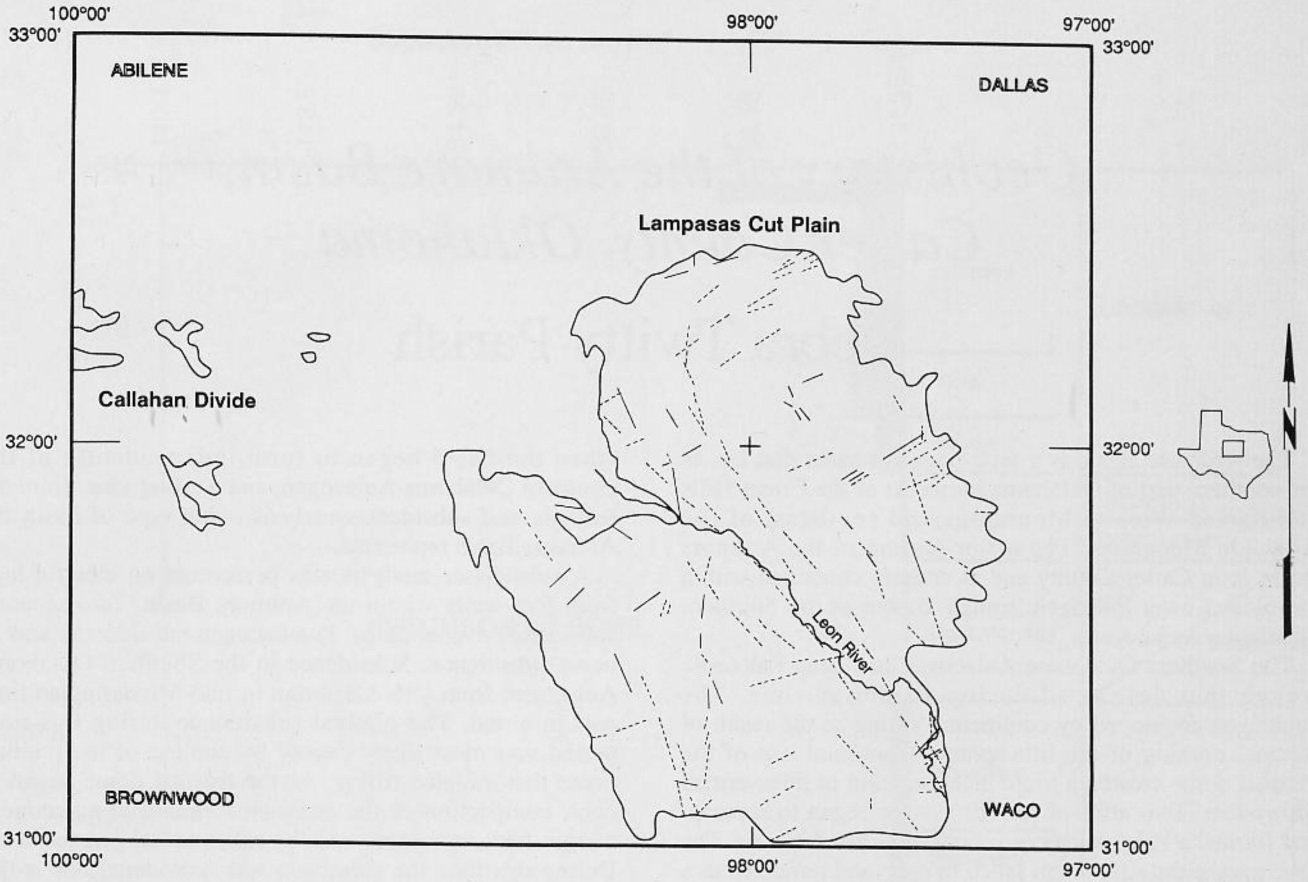


Fig. 1. Lineaments across the Lampasas Cut Plain identified from LANDSAT photographs. These lineaments, which may be surface expressions of subsurface phenomena, appear to control drainage orientation, the orientation of major drainage divides, and the orientation of valleys and interfluves.

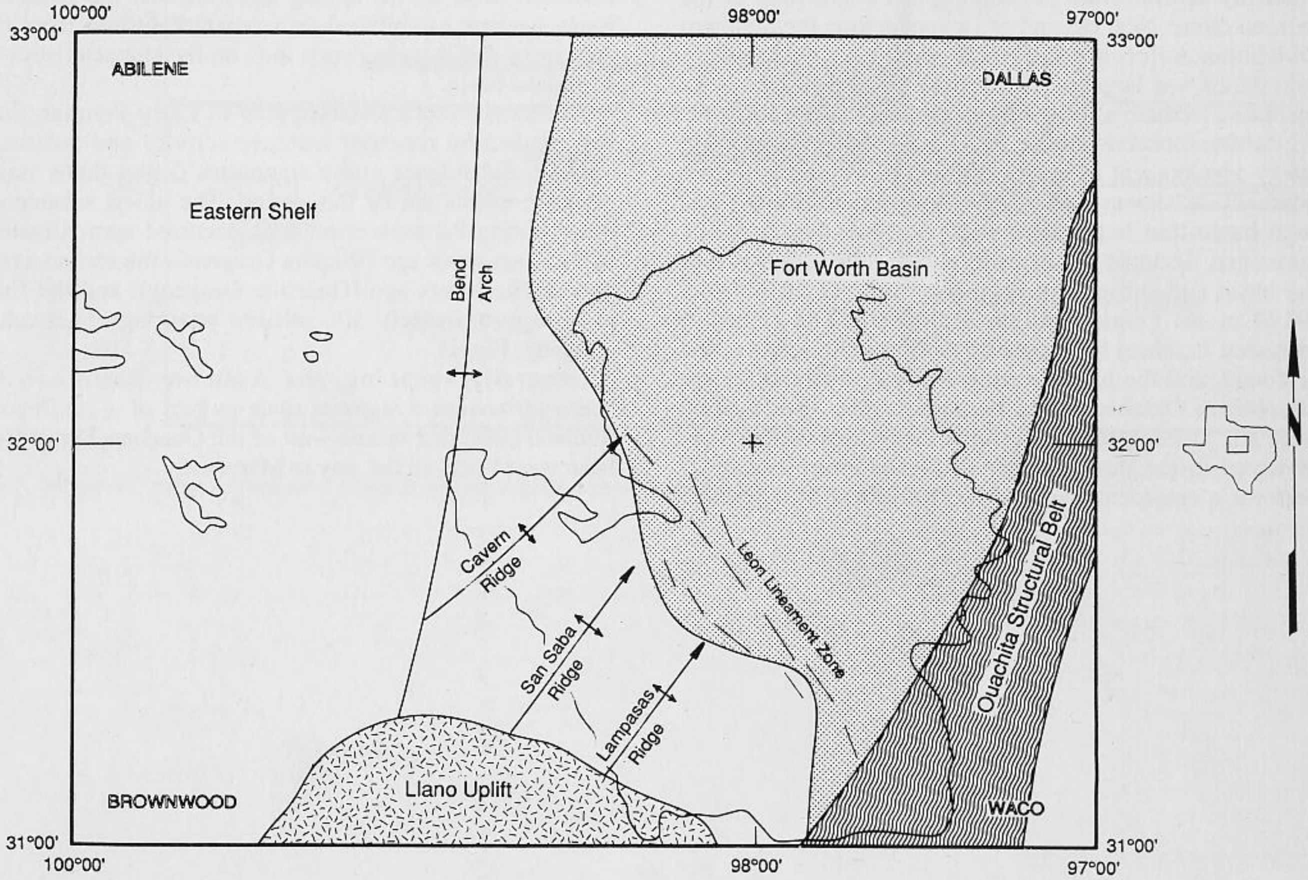


Fig. 2. Subsurface structural features that may be expressed on the surface as lineaments or lineament zones. The most conspicuous is the western margin of the Fort Worth Basin, which is represented on the surface by the "Leon Lineament Zone" that parallels the Leon River

Geohistory of the Ardmore Basin, Carter County, Oklahoma

Debra Twitty Parish

The Ardmore Basin is a fault-bounded basin that lies in the southern part of Oklahoma northeast of the Criner Hills and buried Wichita Mountains and southeast of the Arbuckle Mountains. The major portion of the Ardmore Basin is in Carter County and is entirely contained within the older Lower Paleozoic trough known as the Southern Oklahoma Aulacogen.

The Southern Oklahoma Aulacogen is a deep Paleozoic trough that developed during Cambrian time. The aulacogen developed by continental rifting as the result of thermal doming of the lithosphere. Continual rise of the thermal dome created a triple plate junction or three-armed rift system. Two arms of the rift system began to separate and formed a Paleozoic ocean south of North America. The third arm of the rift system failed to open and remained as a subsiding rift valley (or aulacogen). After rifting ceased, presumably in the Cambrian, the aulacogen began to gradually subside from the cooling and contracting of the thermal dome. Near the end of Devonian time the Southern Oklahoma Aulacogen ceased to exist as a basin where subsidence was largely controlled by thermal mechanisms. Increased tectonic activity, beginning in Late Mississippian time and associated with the developing Ouachita fold belt, led to development of basins and uplifts within the former Southern Oklahoma Aulacogen. The Ardmore Basin is one such basin that began to develop independently of the aulacogen. Tectonic mechanisms allowed the subsidence of the basin and subsequent deposition of over 30,000 feet (9144 m) of Pennsylvanian sediments. The effect of increased sediment load, coupled with tectonic activity, was profound, and the basin became a major structural feature of southern Oklahoma. The purposes of this investigation were to: 1) interpret the tectonic mechanisms that were involved in the development of the Ardmore Basin; 2) perform a subsidence analysis of the basin; 3) determine when the basin began to form independently of the Southern Oklahoma Aulacogen; and 4) determine, from the tectonic and subsidence analysis, what type of basin the Ardmore Basin represents.

A subsidence analysis was performed on electric logs from five wells within the Ardmore Basin. Two separate subsidence events exist: 1) aulacogen subsidence, and 2) basin subsidence. Subsidence in the Southern Oklahoma Aulacogen from Late Cambrian to mid-Mississippian time was minimal. The gradual subsidence during this time period was most likely caused by cooling of the thermal dome that initiated rifting. As the thermal dome began to cool, compaction of the sediments enhanced aulacogen-margin fault movement and the entire aulacogen subsided. During this time the aulacogen was considered one major system, but during Chesterian (Mississippian) time, major subsidence began and continued until Wolfcampian (Early Permian) time. It was during this time that the Ardmore Basin became established as a separate system from the aulacogen and its subsidence took on the characteristics of a foreland basin.

Subsidence from Mississippian to Early Permian time was caused by renewed tectonic activity and sediment loading. Subsidence curve signatures depict three major orogenic events during this period. The oldest subsidence event during Pennsylvanian time occurred approximately 330 million years ago (Wichita Orogeny), the second event 306 million years ago (Ouachita Orogeny), and the final event approximately 300 million years ago (Arbuckle Orogeny; Fig. 1).

Generally speaking, the Ardmore Basin can be characterized on a regional scale as part of a continuous foreland basin that occurs west of the Ouachita Thrust Belt from west Texas all the way to Maryland.

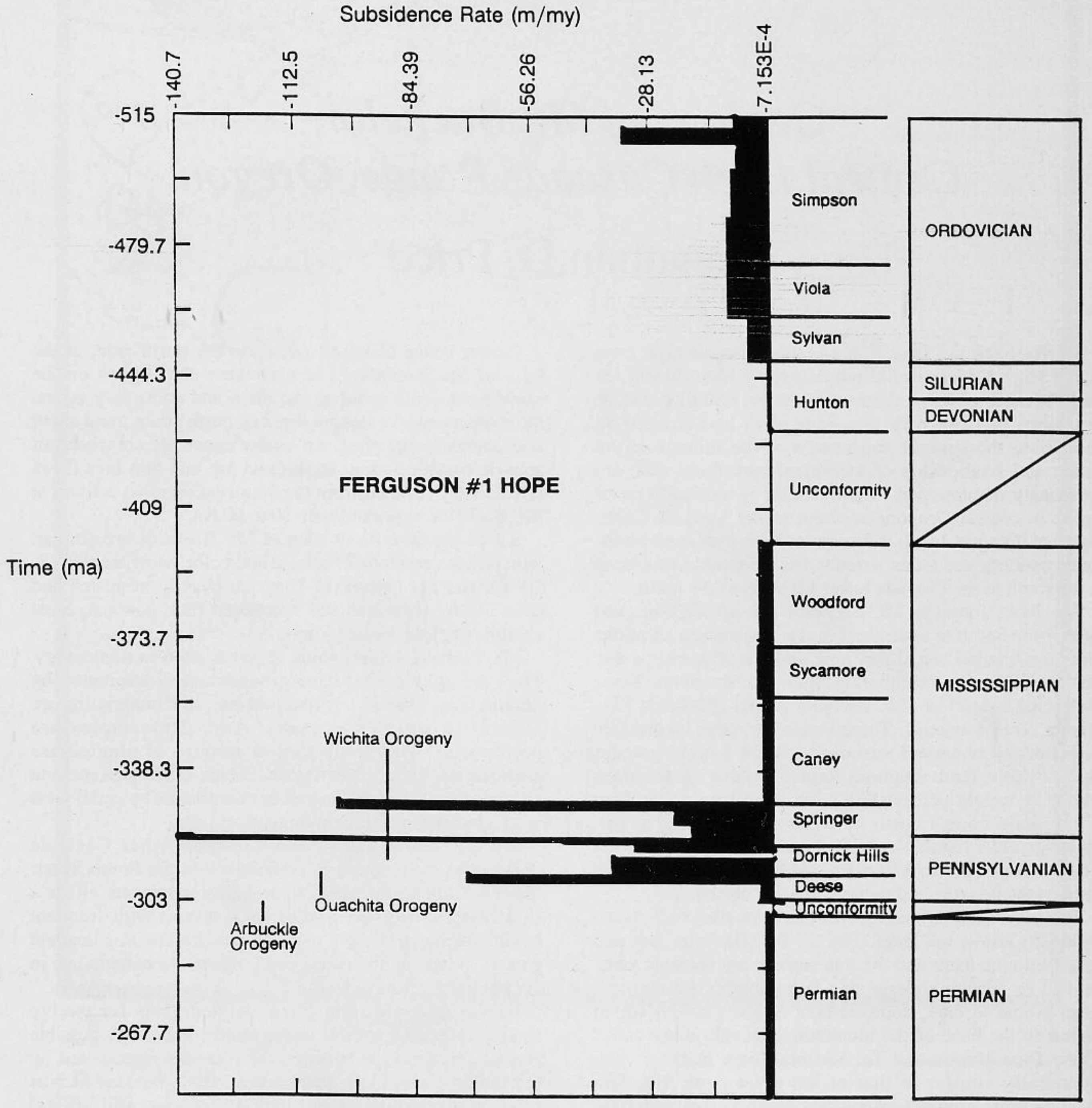


Fig. 1. Subsidence rate versus time curve depicting major subsidence with orogenic events and associated time periods.

Geology of Mt. Bachelor, Central High Cascade Range, Oregon

Jonathan D. Price

Mt. Bachelor is a typical, but smaller-than-average, cone in the High Cascade continental arc. It was chosen for study because of its moderate size, its accessibility, and its exposures of fresh rock. Previous work had focused on describing the general appearance of the mountain; the nature and relationship of individual rock units were not previously documented. Mt. Bachelor is located west of Bend, in central Oregon, adjacent to the Cascade Lakes highway (Oregon 46). It is associated with a chain of north-south trending vents that extends from Sheridan Mountain in the south to the Cascade Lakes highway in the north.

The rocks found at Mt. Bachelor are calcalkaline, and range from basalt to andesite (Fig. 1). The earliest eruptions formed a basaltic shield that now underlies the main cone, perhaps similar to neighboring Sheridan Mountain. Three coalescing cones form Mt. Bachelor proper (Bachelor, Pine Marten, Tot Mountain). These cones are made of andesite with limited chemical variation (56-59 weight percent SiO_2). Finally, flank eruptions formed basaltic cinder cones (about 51 weight percent SiO_2) and lava flows at the base of the main cone's north side. To the northeast of Mt. Bachelor, older basaltic-andesite lava flows and scoria were erupted from Tumalo Mountain. Additionally, Pleistocene-age rhyodacite crops out to the north and northwest.

The main cone (Qbma) of Mt. Bachelor rises to 2,763 m (9,065 ft) above sea level (Fig. 1). Mt. Bachelor has two false summits; these and the true summit are volcanic vents marked by blocky andesite and large bombs. All the vent areas produced dark, andesite lava flows, some of which extend to the base of the mountain. The subsidiary cones (Qbsc–Pine Marten and Tot Mountain) are made of rock chemically similar to that of the main cone. Basaltic andesite flows crop out extensively along the northern base of Mt. Bachelor. The mountain has one glacier, located just below the summit on the north face. Erosion and deposition by the glacier has created a large terminal moraine (Qg) just above the timberline, and exposed three plugs in its cirque.

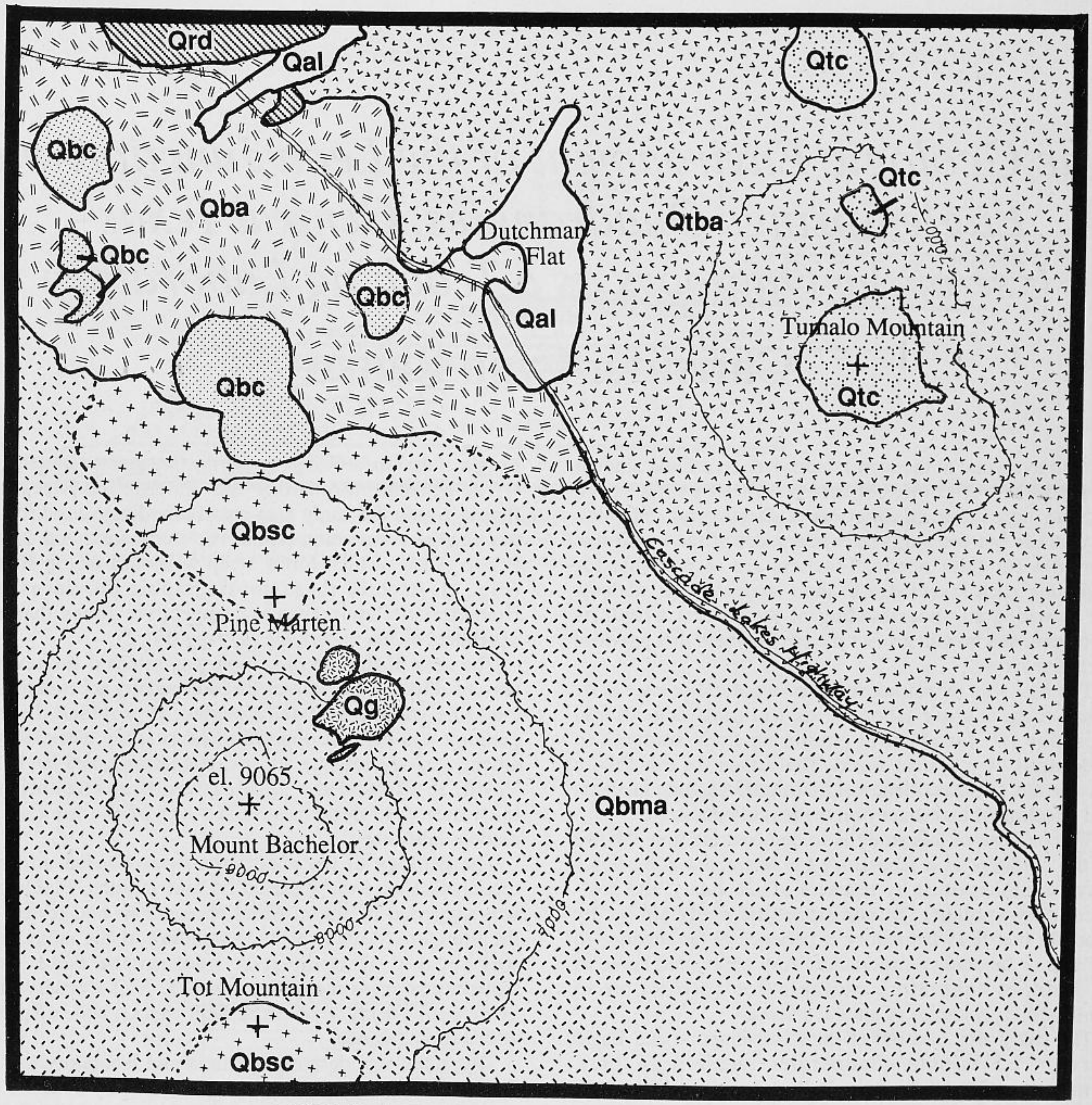
Cinder cones of basalt occur on the north side, at the base of Mt. Bachelor. Three of these are aligned on the same north-south trend as the main and subsidiary cones; three others appear along a separate north-south trend about a kilometer to the west. All cinder cones are composed of aphyric basaltic scoria, lapilli, and ash and thin lava flows (Qbc). They resulted from the youngest eruptive activity at Mt. Bachelor, approximately 30 to 60 Ka.

All of the lava flows seen at Mr. Bachelor are similar, with minor variations in texture and color. Most are thin (3-10 m), and not extensive. They are heavily vesicated and have blocky flow tops and brecciated flow bottoms. Most exhibit irregular cooling joints.

Mt. Bachelor basalts show little variation in mineralogy. They are aphyric and have groundmasses dominated by plagioclase. Olivine, clinopyroxene, and magnetite are present in smaller amounts. Andesite samples are porphyritic, with a substantial amount of plagioclase phenocrysts. Other phenocrysts include clinopyroxene and orthopyroxene. Groundmasses are dominated by small laths of plagioclase, with clinopyroxene crystals.

Mt. Bachelor is less evolved than other Cascade stratocones, particularly in comparison to the South Sister, located 7 km to the west. It probably represents either a short-lived magmatic system, or a system with frequent basaltic recharge. Cinder cone basalts are low in silica and potash, indicating the presence of unevolved magma late in the volcano's eruptive history.

Harker diagrams and trace element plots for twelve analyzed samples exhibit linear trends, indicating possible genetic relationships between the magmas represented by the analyses. It is likely that open-system processes such as fractional crystallization, magma mixing, and crustal assimilation were responsible for the variation in the suite, but the lack of mineral data currently precludes a detailed analysis.



EXPLANATION

- **Qal** Lake and Stream Deposits
- **Qba** Basaltic andesite lava flows of the north slope of Mt. Bachelor
- **Qbma** Dark gray and gray andesite of the main cone of Mt. Bachelor
- **Qtc** Basaltic cinder cones of Tumalo Mountain
- **Qtba** Basaltic andesite lava flows and ash-flow tuffs of Tumalo Mountain
- **Qg** Glacial deposits
- **Qbc** Basaltic cinder cones of Mt. Bachelor composed of crudely-bedded, oxidized lapilli, bombs, blocks and thin lava flows
- **Qbsc** Andesite subsidiary cones of Tot Mountain and Pine Marten
- **Qrd** Rhyodacite lavas of Todd Lake
- + Location of topographic peak

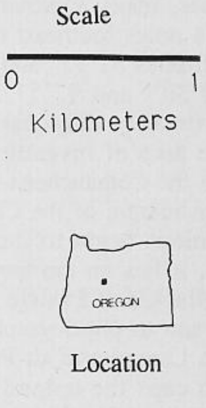


Fig. 1. Geologic map of the Mt. Bachelor area, central Oregon. The geology is dominated by basalt and andesite erupted by Mt. Bachelor and its subsidiary cinder cones, and Tumalo Mountain and its cinder cones.

The Geologic Environment of the Leon Junction and Eagle Springs Quadrangles, Central Texas– Use of the Outdoors as a Teaching Laboratory

Christifer Lynn Rainer

With everyone in the world dependent on a fintie amount of resources, it is critical that people of every nation become more informed about issues affecting not only their way of life but the physical environment of the world that provides for their needs. Teachers are responsible for imparting such knowledge to their students. The students are provided an understanding of the natural world, its resources, and how to protect the environment that provides such resources.

The best way to instruct students of natural science is by conducting outdoor laboratories, yet most educational facilities fall far short in equipping their students to understand the physical world. The reason for this failure may be due to the resiliency of traditional teaching methods and a feeling of inadequacy on the part of educators.

The purpose of this study is to demonstrate how the use of the outdoors as a laboratory for instructional purposes may be implemented by teachers of secondary and post-secondary students. In addition, this study shows by example that field laboratory experience is far superior to the indoor laboratory experience. Any area could serve as an outdoor laboratory suitable for instruction to demonstrate principles of natural science.

The study area consists of the Leon Junction and Eagle Springs 7.5 minute quadrangles (scale 1:24,000), southeastern Coryell, northern Bell, and western McLennan counties, Texas, approximately 20 miles southwest of Waco and 14 miles southeast of Gatesville. The area is bounded by latitudes 31°15' and 31°22'30" north and longitudes 97°22'30" and 97°37'30" west and covers an area of approximately 128 square miles.

The area of investigation includes formations found within the Comanchean-Gulfian outcrop belt. It lies on the eastern margin of the Central Texas Platform where these formations begin to increase in dip into the East Texas Basin. It lies on the transition between the Grand Prairie and Blackland Prairie. Three geologic formations are important to physiographic expression in the development of the Lampasas Cut Plain: 1) the Edwards Limestone, which caps the upland divides; 2) the Comanche Peak Limestone, which forms the steep slopes beneath the Edwards Limestone; and 3) the Walnut Clay, which forms broad valleys within the Cut Plain.

The two geologic formations that are reflected in the physiography of the Washita Prairie are: 1) the Del Rio Shale, which forms the broad soil-mantled flats along the eastern margin of the Grand Prairie; and 2) the Georgetown Limestone.

The geologic formations that underlie the Blackland Prairie within the study area are: 1) the Eagle Ford Shale, the youngest formation within the study area; and 2) the Pepper Shale, which forms steep westward-facing slopes (Fig. 1). Each of these physiographic provinces has characteristic landscapes and vegetative zones that are dependent on the underlying geology (Fig 2).

The area of this investigation was selected for several reasons. First, it was an area that was readily accessible and could be studied in detail. Second, it provided diverse geology and offered opportunities to study associations among geology, topography, soils, vegetation, and land use. Third, it allowed the application of environmental information to demonstrate the use of the area as an outdoor laboratory.

The geology of the area was mapped based on field reconnaissance over a period of four months. Fieldwork was supported by use of aerial photographs and review of the literature. A general understanding of the study area was secured after the first week in the field. Soil associations were mapped using U.S. Soil Conservation Service soils maps, verified by field checks, and correlated with a geologic map.

This study was designed for field and laboratory use by students in secondary and post-secondary schools. It provides a foundation for experiences students receive in the field that may be transferred to a laboratory setting. It is clear that by joining observations from the field with those of the laboratory, students will better understand how the natural sciences of the world are interrelated.

The demand for space and resources is rising at an ever-increasing pace and the environmental impact of those demands makes it necessary for students to have a better understanding of the world's physical environment and the roles they play as consumers and stewards of those resources. Students need to be made aware of the relationships of the natural world and how these relationships interact and affect the communities where they live and even the entire world.

This awareness is best conveyed in the outdoor laboratory, a far superior approach to the indoor laboratory characteristic of modern education. The outdoor laboratory offers the best opening for instructing students of natural science in concepts and interrelationships among the different branches of science.

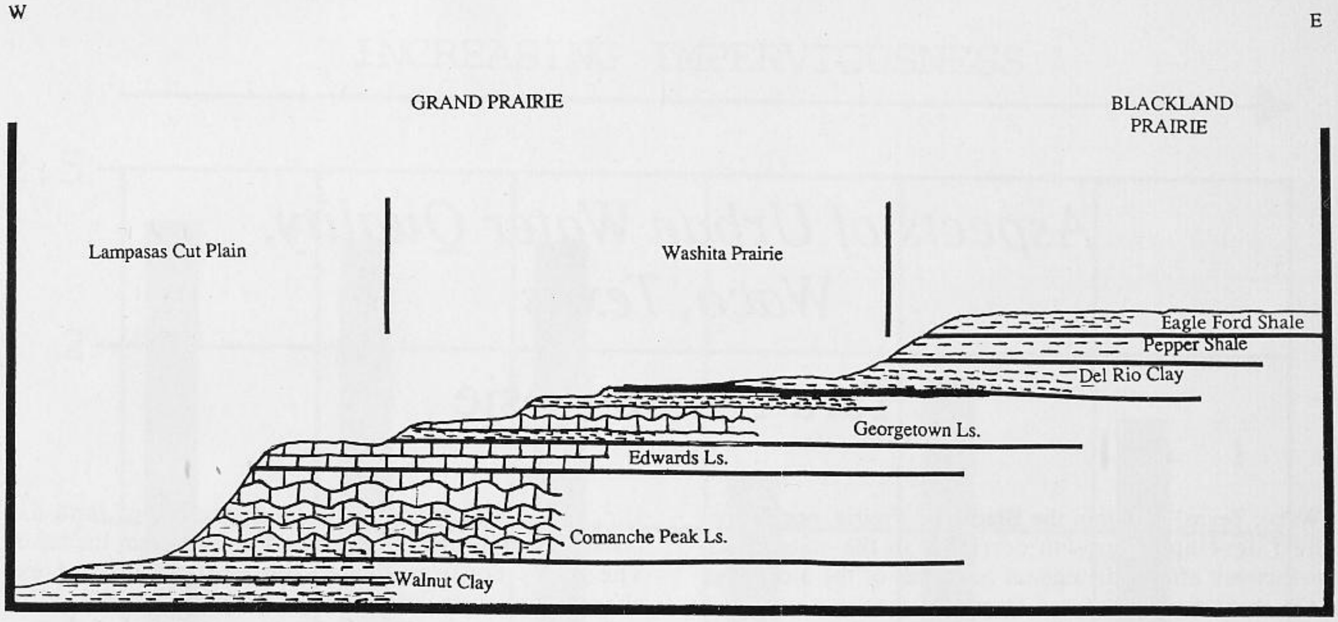


Fig. 1. Diagrammatic west-to-east profile and section of the Leon Junction and Eagle Springs quadrangles. The figure shows relationships among physiography, stratigraphy, and structure within the study area. While the Grand Prairie is subdivided into three distinct physiographic subregions, only two are exposed in the study area: 1) the Lampasas Cut Plain; and 2) the Washita Prairie.

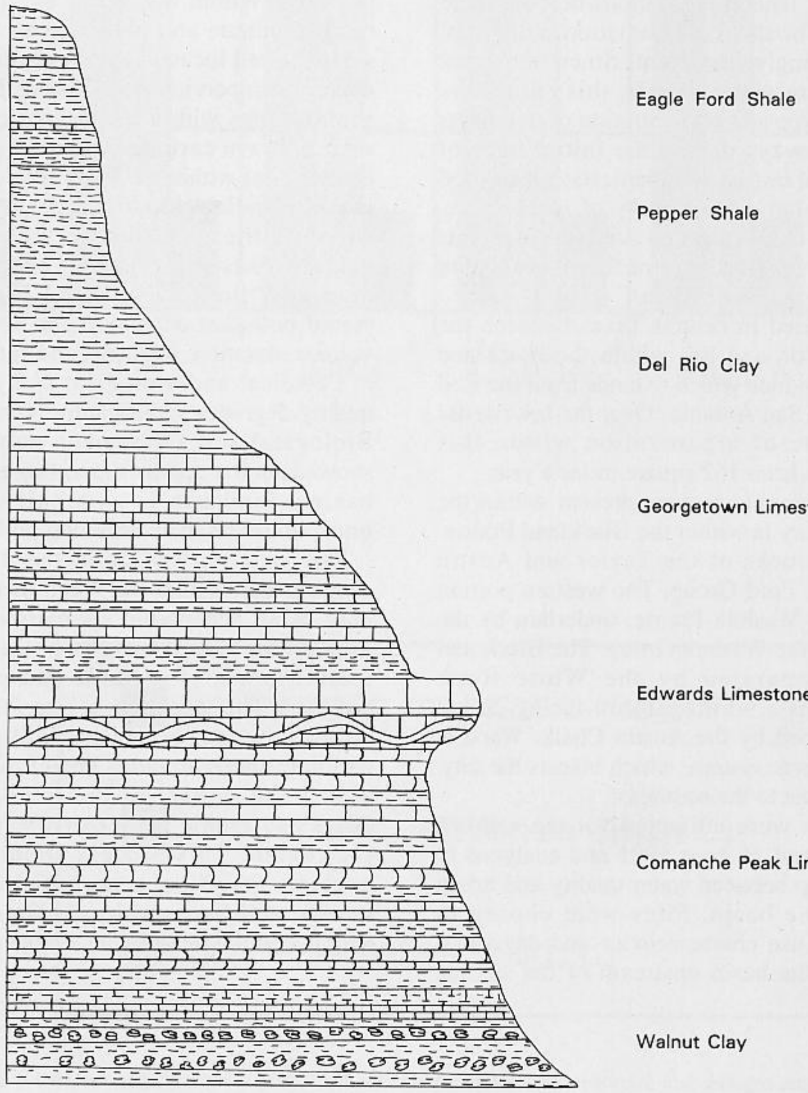


Fig. 2. Diagrammatic stratigraphic section of the formations exposed in the Leon Junction and Eagel Springs quadrangles. Formations from the Walnut Clay through the Del Rio Clay belong to the Comanchean section. Pepper Shale and Eagle Shale are the lowermost units of the Gulfian section. The Edwards Limestone is the dominant physiographic control in the Lampasas Cut Plain. The basal Eagle Ford with its thin flaggy limestone forms escarpments exposed only on the far eastern margin of the Eagle Springs quadrangle.

Aspects of Urban Water Quality, Waco, Texas

Tara Lynne Rosie

Waco, Texas, is within the Blackland Prairie, one of the fastest developing growth corridors in the state. This development affects the natural resources of the area. One of the most significant and fragile of these resources is water. Groundwater sources have already been significantly decreased or contaminated by urbanization. Surface water, therefore, becomes an increasingly significant source. Unfortunately, development has many negative impacts on surface water quality. As federal legislations become more strict on point sources for this contamination, non-point sources become increasingly important. Since non-point pollution involves storm water runoff, this study was designed to analyze the type and concentration of pollutants supplied to local waterways during the initial hour of runoff. Evaluating the full impact of urbanization is beyond the scope of this study, but a pilot study of local water-quality parameters, and their variation with storm events and land use, is a necessary first step for future evaluation of the total water supply system of Waco.

The study area is located in central Texas between the cities of Dallas and Austin and lies within the Blackland Prairie physiographic province which extends from the Red River southward through San Antonio. Over the last twenty years, the average rate of urbanization within this development corridor has been 162 square miles a year.

There are two physiographic regions present within the Waco area. Most of the city is within the Blackland Prairie, which is underlain by rocks of the Taylor and Austin formations and the Eagle Ford Group. The western portion of the area is within the Washita Prairie, underlain by the shales and limestones of the Washita Group. The Black and Grand Prairies are separated by the White Rock Escarpment, which forms a northwestward-facing cuesta and fault line scarp capped by the Austin Chalk. Waco is drained by the Brazos River system, which bisects the city, flowing from the northwest to the southeast.

Storm water samples were collected for ten rainfall events between 1 April and 16 June 1991 and analyzed to determine the relationship between water quality and urban development within the basin. Sites were chosen to represent different land-use characteristics and degree of imperviousness within the basin upstream of the sample site. Pollutants appeared to be reflective of land-use practices and degree of impervious cover within the basin. The study confirmed the significance of land-use characteristics in influencing the quality and kind of pollutants available. Chemical analyses showed that when comparing urban land uses, residential sectors often are more detrimental to water quality than industrial or commercial zones, due to lawn care and fertilization practices. Within this study, the highest concentrations of nitrogen-nitrate and phosphorous were not recorded from sample sites located within drainage basins with a high degree of imperviousness. Rather, high concentrations were noted at sites with a low degree of imperviousness but in which lawn care techniques supplied more of the contaminant within the basin (Fig. 1). The greater variation in concentrations recorded from these less-impervious sites supports the idea that pervious areas are collecting contaminants and releasing them either slowly or in a dramatic "flush" or "shock" load. The behavior of the stored pollutant depends upon several variables: rainfall volume, duration, intensity, and antecedent conditions.

Chemical and biological analyses suggest that water quality degrades significantly with increased development. Biological site assessment using the Fort Worth Plan showed similar results supporting the idea that within urban basins, land use is as significant as the degree of imperviousness in determining pollutant concentrations.

The proximity of collected data to modeled results suggests that within the Waco metropolitan area modeling may be an acceptable alternative to field collection for preliminary assessment of pollutant loads to aid in the establishment of a viable and cost-effective sampling program. This does not negate the need for field analysis entirely but suggests that field data should be used to calibrate these models. Therefore, it may be possible to assess the impact of continued development on the Blackland Prairie and predict water quality trends within the region. This process should allow developers to evaluate the effect a proposed development or zoning change will have on the quality of surface water in this fragile environment before further damage occurs.

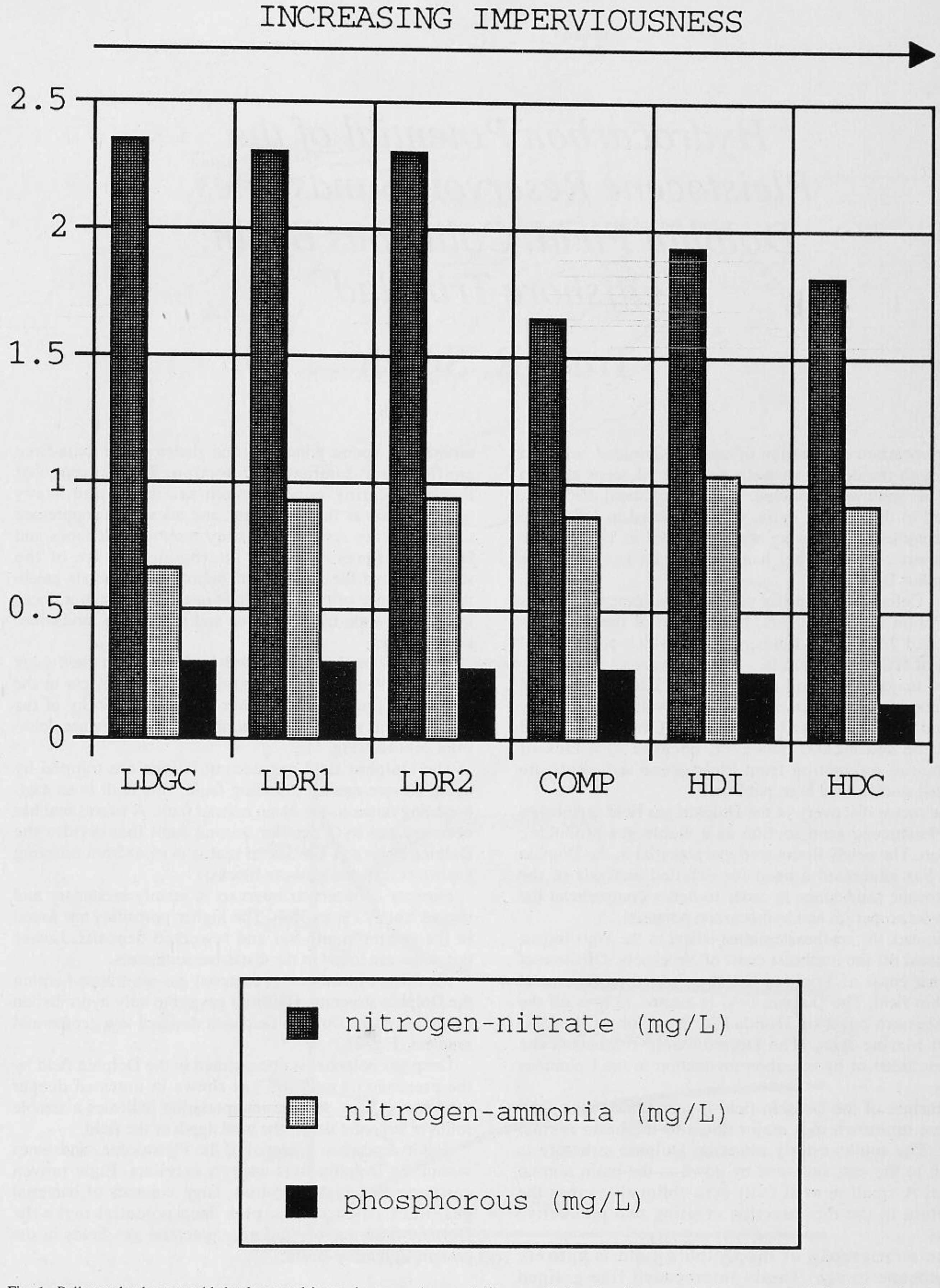


Fig. 1. Pollutant loads vary with land use and imperviousness. Averaged nitrogen-nitrate, phosphorous, and nitrogen-ammonia loads have been plotted against land-use classification in order of increasing imperviousness. Phosphorous loads are greatest at low-density residential sites, and LDGC, a recreational golf course site. Nitrogen-nitrate concentrations are also highest for these sites, suggesting the influence of lawn-care practices. Nitrogen-ammonia concentrations generally do appear to increase with increasing imperviousness. Highest nitrogen-ammonia concentrations were recorded at the HDI site, suggesting the influence of industrial waste. Therefore, within this study, pollutant loads appeared to be more significantly associated with specific land uses than degree of imperviousness.

Hydrocarbon Potential of the Pleistocene Reservoir Sandstones, Dolphin Field, Columbus Basin, Offshore Trinidad

Truitt R. Smith

Hydrocarbon exploration of onshore Trinidad began in 1866 with the drilling of wells near the oil seeps at Pitch Lake in southwest Trinidad. The first offshore discovery, located in the Gulf of Paria, was completed in 1954. The first commercial discovery was completed in 1963 off the southeast coast in what has come to be known as the Columbus Basin.

The Columbus Basin has yielded significant oil and gas production for many years. Exploration of the basin has produced 23 separate fields, three of which are giant oil fields of 100 million barrels.

The major producing reservoirs are late Miocene and Pliocene in age. Several interpretative works have largely defined the structure and stratigraphy of the Miocene and Pliocene sediments. However, because of a lack of substantial production from Pleistocene sediments, no detailed studies have been published.

The recent discovery of the Dolphin gas field establishes the Pleistocene sand section as a viable gas-producing horizon. The newly discovered gas potential in the Dolphin field has generated a need for detailed analysis of the Pleistocene sandstones in order to better comprehend the reservoir properties and hydrocarbon potential.

Trinidad, the southeasternmost island in the West Indies, is located off the northeast coast of Venezuela. Offshore of the east coast of Trinidad lies the Columbus Basin and Dolphin field. The Dolphin field is located 73 kms off the southeastern coast of Trinidad in Block 6b of the East Coast Marine Area. The Dolphin field represents the eastern limits of hydrocarbon production in the Columbus Basin.

Structure of the Dolphin field is represented by a fault closure upthrown to a major down-to-the-basin normal fault. The southwesterly plunging Dolphin structure is bound to the east and west by down-to-the-basin normal faults. A small normal fault cuts obliquely across the structure in the dip direction creating two productive blocks.

The stratigraphy of the Dolphin field is entirely Pleistocene in age. Thinly interbedded fine-grained sandstones, coarse siltstones, and shales of the delta-front environment dominate the section. The presence of thorium-bearing minerals such as zircon, and heavy minerals such as siderite, pyrite, and micas, has suppressed the gamma-ray response of many reservoir siltstones and fine sandstones. The thin interbedded nature of the sediments and the presence of radioactive minerals create the appearance of tight and shaly intervals. However, these intervals contain highly porous and productive sandstones and siltstones.

The Orinoco delta prograded to the Atlantic shelf edge during the Pleistocene, depositing deltaic sediments in the area of the present-day Dolphin field. The majority of the Dolphin field reservoir sandstones and siltstones are delta-front deposits (Fig. 1).

The Dolphin field gas accumulations are trapped by updip closure against a sealing fault. This fault is an east-bounding down-to-the-basin normal fault. A lateral seal has been created by a smaller normal fault that divides the Dolphin structure. The lateral seal is evident from differing gas/water contacts between blocks.

Porosity of reservoir intervals is mainly secondary and ranges from 21% to 36%. The higher porosities are found in the stream-mouth-bar and reworked deposits. Lower porosities are found in the distal-bar sediments.

Significant quantities of bacterial gas are trapped within the Dolphin structure. Bacterial gas is the only hydrocarbon generated in the Dolphin field area due to a low geothermal gradient (Fig. 2).

Deep gas potential is documented in the Dolphin field by the presence of mud-log gas shows in untested deeper sandstones. Also, seismic interpretation indicates a sizable rollover structure below the total depth of the field.

The hydrocarbon potential of the Pleistocene sandstones within the Dolphin field appears excellent. Eight proven gas reservoirs, high porosities, large volumes of bacterial gas, thick pay sections, plus deep potential make the Dolphin field one of the larger potential gas fields in the eastern Columbus Basin.

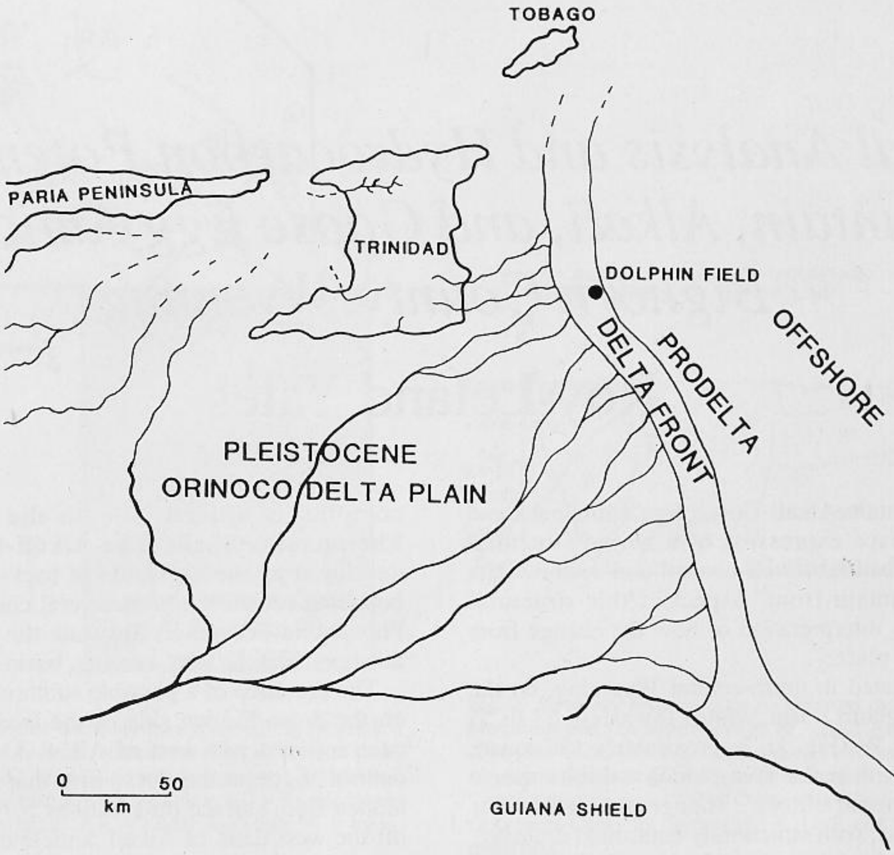


Fig. 1. Generalized depositional model for the Columbus Basin and the Dolphin field during the Pleistocene.

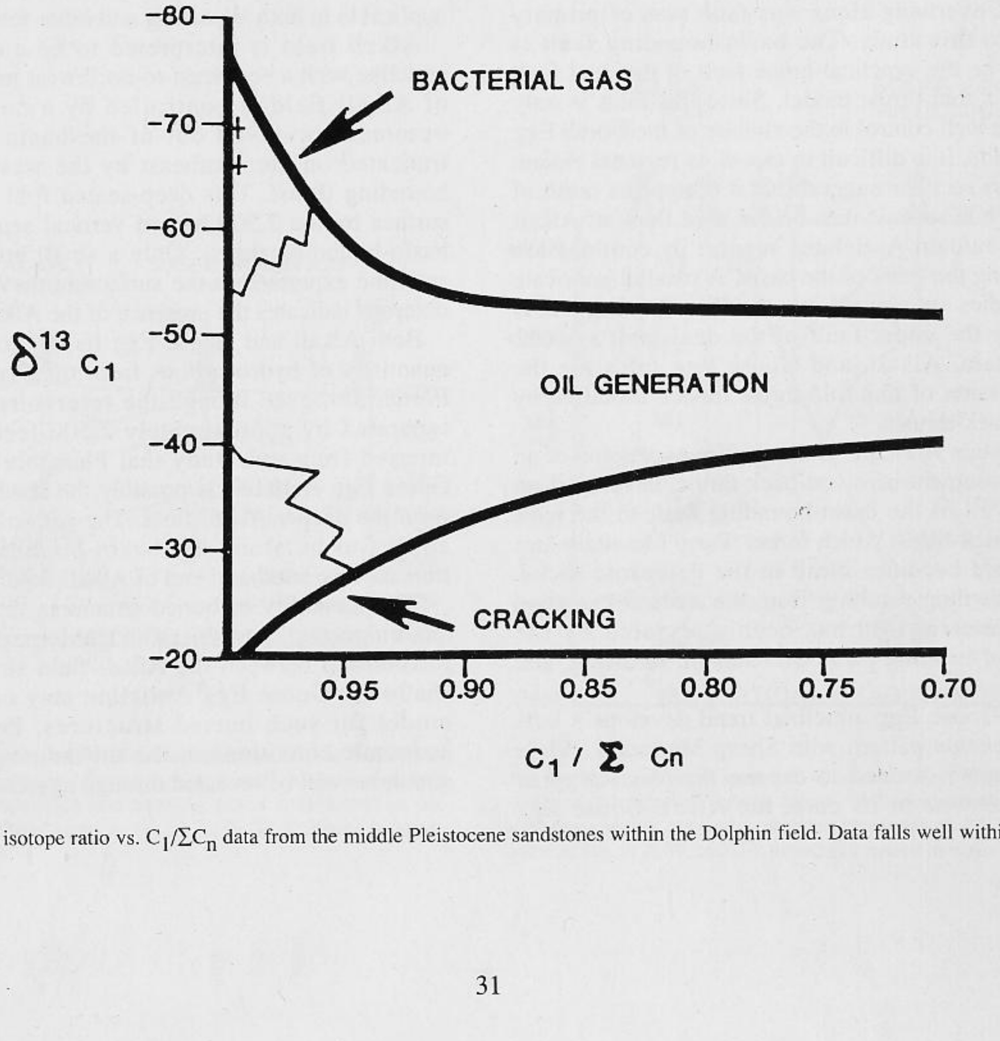


Fig. 2. Plot of carbon isotope ratio vs. $C_1/\Sigma C_n$ data from the middle Pleistocene sandstones within the Dolphin field. Data falls well within the bacterial gas realm.

Structural Analysis and Hydrocarbon Potential of the Sheep Mountain, Alkali, and Goose Egg Anticlinal Trend, Bighorn County, Wyoming

Roy Leland Yates

The Sheep Mountain-Alkali-Goose Egg anticlinal trend represents the surface expression of a buried structural mountain front. Subsurface well control and seismic data confirm the "mountain-front" aspect of this structural complex, and allow interpretation of how the change from uplift to basin takes place.

This study is located in north-central Wyoming, on the east flank of the Bighorn Basin, within Townships 53 to 55 N., Ranges 94 to 96 W. (Fig. 1). Approximately 150 square miles is encompassed in the area, which exhibits sparse vegetation in a semiarid climate. Topography consists of cuestas and hogbacks, with structurally controlled drainage. Lovell, Wyoming, is approximately eight miles to the north.

The structural pattern is that of anticlines localized by back-thrusts on the hanging wall of a west-verging, basin-bounding reverse fault which controls the western margin of the Bighorn Mountain uplift. Determination of the magnitude of overhang along this fault was of primary importance to this study. The basin-bounding fault is interpreted to be the synclinal-hinge fault of the dual fault zone of Berg's fold-thrust model. Since this fault is only encountered in well control in the vicinity of the Goose Egg and Alkali fields, it is difficult to assess its regional extent. However, cross sections suggest that it disappears north of Goose Egg, while seismic data on the west flank of Alkali and Sheep Mountain Anticlines suggest its continuation southward along the flank of the basin. A parallel imbricate thrust, which dies out upward into the Paleozoic section, is inferred to be the upper fault of the dual fault system. Sheep Mountain, Alkali, and Goose Egg folds are the shallow expression of this fold-thrust model, modified by east-verging back-thrusts.

Sheep Mountain Anticline is the surface expression of an east-verging basement-involved back-thrust, developed on the hanging wall of the basin-bounding fault to the west (Fig. 2). The back-thrust which forms Sheep Mountain dies out upward and becomes blind in the Paleozoic rocks. Volumetric crowding resulting from the eastward rotation of this asymmetric fold has been alleviated by the development of bedding-plane detachment, thrusting, and folding.

The Alkali-Goose Egg anticlinal trend develops a left-stepping *en echelon* pattern with Sheep Mountain. While Sheep Mountain is eroded to expose the Mississippian Madison Limestone in its core, the Alkali-Goose Egg complex is eroded only to the Lower Cretaceous Thermopolis Shale. The Alkali-Goose Egg trend is developed by the interacton of back-thrusts and the basin-bounding reverse fault. Structural contours on the Permian Phosphoria Formation illustrate the relationship between this trend and the west-verging, basin-bounding fault.

The presence of a possible subthrust anticline developed on the down-thrown side of the basin-bounding fault has been inferred just west of Alkali Anticline (Fig. 3). Well control suggests the possibility that such a fold could be hidden from surface observations by the steep panel of dip off the west flank of Alkali Anticline. In a similar position northwest of Goose Egg Anticline, Alkali field is developed on the down-thrown side of the basin-bounding fault (Fig. 4). Determination of the mode of separation of the shallow surface anticline from the structurally lower and more deeply buried Alkali field is the focus of a structural model for buried mountain fronts, which is applicable to both Wyoming and other foreland areas.

Alkali field is interpreted to be a doubly plunging anticline with a southeast-to-northwest trend. The structure of Alkali field is controlled by a northeast-verging, basement-involved out-of-the-basin thrust which is truncated on the southeast by the west-verging, basin-bounding thrust. This deep-seated fold is masked at the surface by the 2,500 feet of vertical separation along the basin-bounding thrust. Only a small northwest-plunging anticline expressed at the surface in the Upper Cretaceous outcrops indicates the presence of the Alkali field structure.

Both Alkali and Goose Egg fields produce commercial quantities of hydrocarbons from the Permian Phosphoria Formation, even though the reservoirs are structurally separated by approximately 2,500 feet vertically. It is inferred from this study that Phosphoria production on Goose Egg Anticline is possibly the result of oil migration from the deeper Alkali field. The path of migration would appear to be along the basin-bounding fault, which truncates the southeast end of Alkali field.

The possibility of buried structures such as Alkali field has encouraged exploration geologists for years. The relationship between the Alkali field structure and much shallower Goose Egg Anticline may now be used as a model for such buried structures. Perhaps in better economic conditions in the oil industry, more of these structures will be revealed through aggressive exploration.

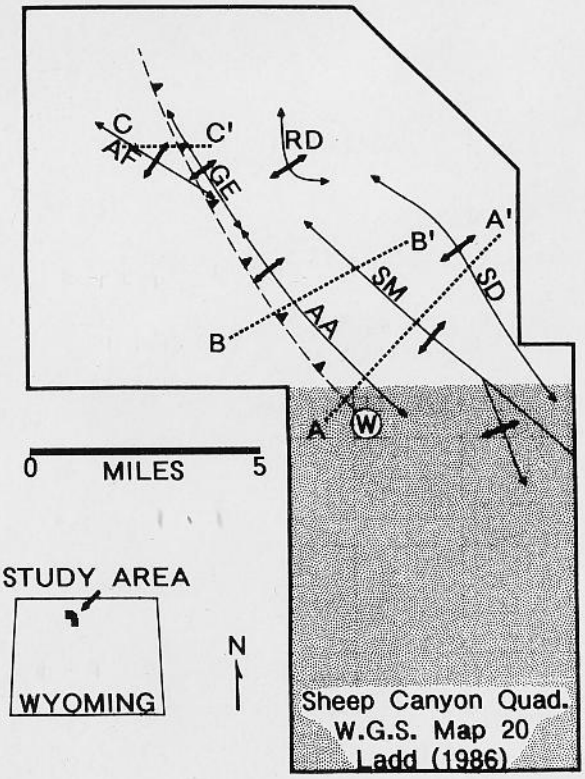


Fig. 1. General tectonic map of the study area showing the *en echelon* pattern developed by the Laramide structures. Also shown are cross sections A-A', B-B', and C-C' (Figs. 2, 3, and 4). Symbols: AF = Alkali Field; GE = Goose Egg Anticline; RD = Rose Dome; SD = Spence Dome; SM = Sheep Mountain Anticline; AA = Alkali Anticline; W = basin-bounding thrust.

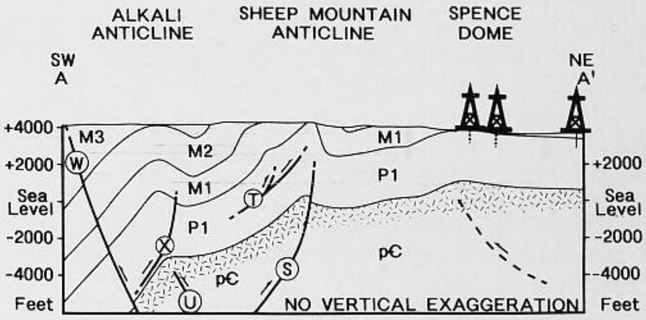


Fig. 2. Structural cross section A-A' across the north plunge of Sheep Mountain and the south plunge of Alkali Anticline. Structures are controlled by basement-involved thrusts which have transport in opposing directions. Symbols: pC = Precambrian basement; P1 = Paleozoics; M1 = Triassic thru Jurassic; M2 = Cretaceous Cloverly thru Frontier; M3 = Cretaceous Cody thru Tertiary; W, X, U, T, and S = thrusts referenced in major text.

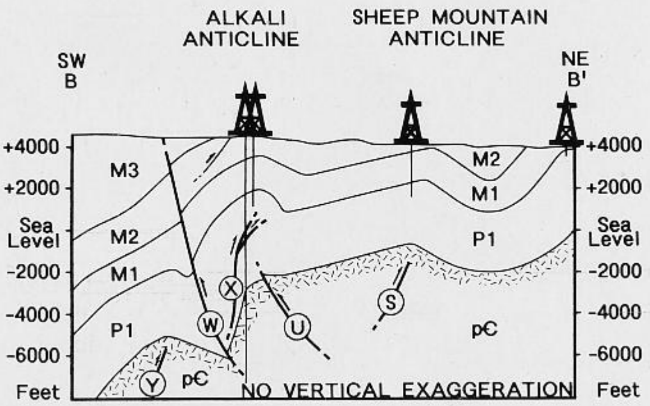


Fig. 3. Structural cross section B-B' across the center of Alkali Anticline and down-plunge of Sheep Mountain. Deep well control at Alkali Anticline indicates repetition and bedding plane detachment in the Paleozoic section. Symbols: same as Fig. 2; Y, W, X, U, and S = thrusts referenced in major text.

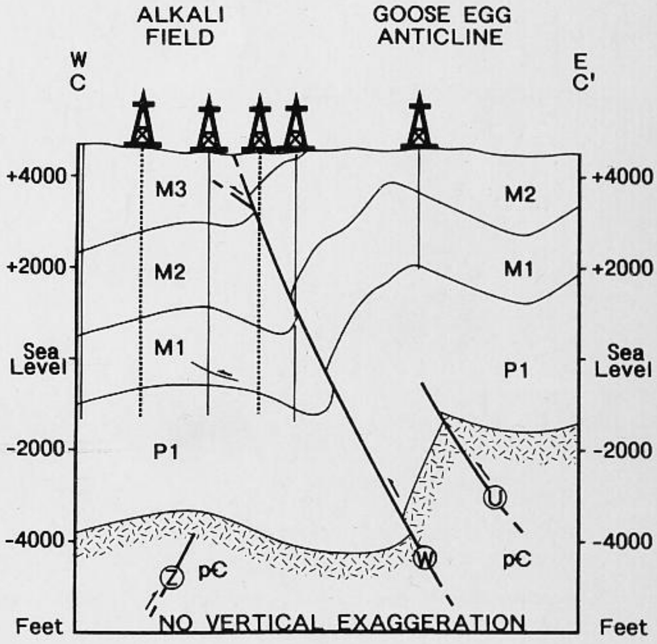


Fig. 4. Structural cross section C-C' across Alkali Field and Goose Egg Anticline. Southwest-vergent thrust "W" separates the two producing structures with a vertical separation in excess of 2,500 feet. Symbols: same as Fig. 2; Z, W, and U = thrusts referenced in major text.

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