SURFACE TO SUBSURFACE STRUCTURAL ANALYSIS, NORTHWEST ARBUCKLE MOUNTAINS, SOUTHERN OKLAHOMA

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By

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ABSTRACT

The Arbuckle Mountains have long been an area of considerable debate among structural geologists. Despite outcrop exposure and extensive subsurface data, there has been little consensus as to the structural style, geometry, and plate tectonic setting. This study attempts to combine surface studies with extensive subsurface data in order to determine the geometry and structural style of the buried northwestern plunge of the Arbuckle Mountains.

The Arbuckle Mountains are the surface expression of the Arbuckle Uplift whose major feature is the Arbuckle Anticline. The Arbuckle Uplift plunges northwestward beneath Permian rocks and continues to the northwest. At its northwest outcrop limit, the Arbuckle Uplift is a northeast-vergent, basement-cored fault-bend fold. Imbrications of the controlling (buried) Arbuckle Thrust form the Garrison Creek Anticline and SE Hoover Field. To the northwest, in the subsurface, these imbrications die out. Structural style of the uplift changes progressively from a fault-bend fold to a "snakehead" anticline as a function of loss of displacement and rise in stratigraphic position of the Arbuckle Thrust.

Structural style of the Arbuckle Uplift changes to a fault-propagation fold in the Robberson-Eola area. This is coincident with the development of severe footwall deformation (Eola Anticline) which uplifted and folded the Arbuckle Thrust. The increased

elevation allowed for erosion of large thicknesses of synorogenic conglomerates in this area.

Structural style of the Arbuckle Uplift is complicated by late stage normal faulting. A normal fault (Washburn Ranch Fault) merges with basement thrust ramps, leaving behind a "beheaded" basement structure similar to those seen in the Wyoming foreland. The extension post-dates the uplift and pre-dates the overlying Permian sediments.

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Seismic lines were generously provided by PGI through Texaco. Mr. Bob Allen of the Ardmore Electric Log Library was kind enough to allow me access to logs which were otherwise unavailable. Base maps used were provided by Petroleum Information Corporation. Dr. Nowell Donovan of Texas Christian University and Mr. Jerry Kendall of Mobil provided me with references and insights into transpressive deformation. Dr. Roger "Tim" Dennison of The University of Texas, Dallas, provided stimulating discussions and infectious enthusiasm for the project. Calvin Cooper of Ashland and Steve Naruk of Shell provided helpful information regarding regional style of deformation and also provided strong encouragement. Dr. Raymond Brown of the Oklahoma Geological Survey provided helpful discussions and strong encouragement.

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INTRODUCTION

Purpose

Despite great interest as an area of hydrocarbon exploration, the Arbuckle Mountains of southern Oklahoma remain a poorly understood area in the terms of structural geology. Debate has raged regarding the structural geometry of the Arbuckle and associated uplifts and numerous contrasting models of deformation have been applied to explain the observed deformation.

The purpose of this investigation is to observe the structural style of the Arbuckle Mountains displayed in the outcrop, to carefully map geologic features as they plunge northwest under the onlapping Permian sediments, to follow the uplift in the subsurface to its plunge termination and to study the geometry of the mountain front along plunge.

Location

The study area extends from T. 1 N., R. 1 W. to T. 1 N., R. 4 W. and T. 1 S., R. 1 W. to T. 1 S., R. 2 W. in Carter, Garvin, Stephens, and Murray Counties, in southern Oklahoma (fig. 1). This area includes the northwesternmost surface exposure of the Arbuckle Anticline (Arbuckle Uplift) as it plunges to the northwest under Permian sediments. Surface mapping within the study area include

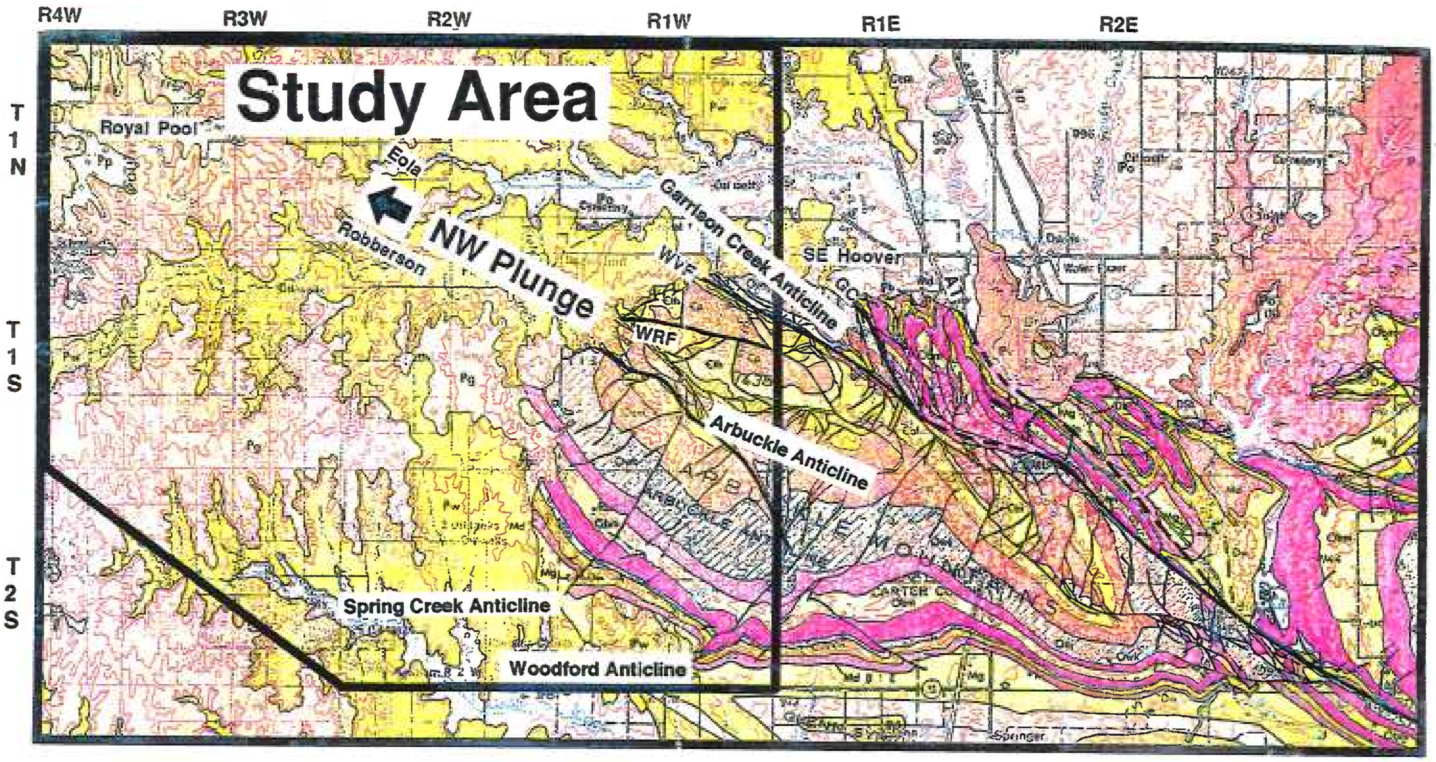


Figure 1. General geologic map of the Arbuckle Mountains showing the exposed Arbuckle Uplift as it plunges to the northwest beneath younger, Permian rocks (modified from Hart, 1974).

exposures south of the Washita Valley Fault. Subsurface analysis begins at the Permian overlap, and continues to the termination of the Arbuckle Mountain front in the northeast corner of T. 1 N., R. 4 W.

Methods

The initial aspects of the study consisted of a detailed literature review. Field work included surface mapping of the western portion of the Arbuckle Anticline utilizing aerial photographs of 1:20,000 scale, with extensive field checking to verify indentification and mapping of observed small-scale structures and obtain strike-and-dip measurements. Well log and seismic data were used in subsurface analysis. Seismic coverage was available from the outcrop to approximately the western edge of Eola Field in T. 1 N., R. 3 W.

Interpretations regarding structural style and mechanical behavior of various horizons in the subsurface were based on observation of outcrop examples. Subsurface interpretations were based primarily on cross-sections constructed parallel to the direction of tectonic transport. Seismic lines were interpreted in light of the geologic cross sections and were used as a general guide, rather than a source of primary information.

In order to extend the map view of the Arbuckle Uplift, a subcrop map at the pre-Pontotoc surface was constructed. The subcrop map was integrated with a surface map of the western portion of the exposed Arbuckle Uplift.

Well log "picks" of the Arbuckle Thrust were mapped on a fault-contour map of the fault plane. In order to illustrate the spatial relationships with other faults and structural elements, a fault-relationship map was created by projecting the interpreted foot-wall cut-off of the Arbuckle Thrust and the surface trace of the Washburn Ranch Fault on the structure contour map of the Arbuckle Thrust. A complete listing of well logs used in this thesis is presented in Appendix 1.

This thesis was written according to guidelines put forth in the United States Geological Survey manual Suggestions to Authors.

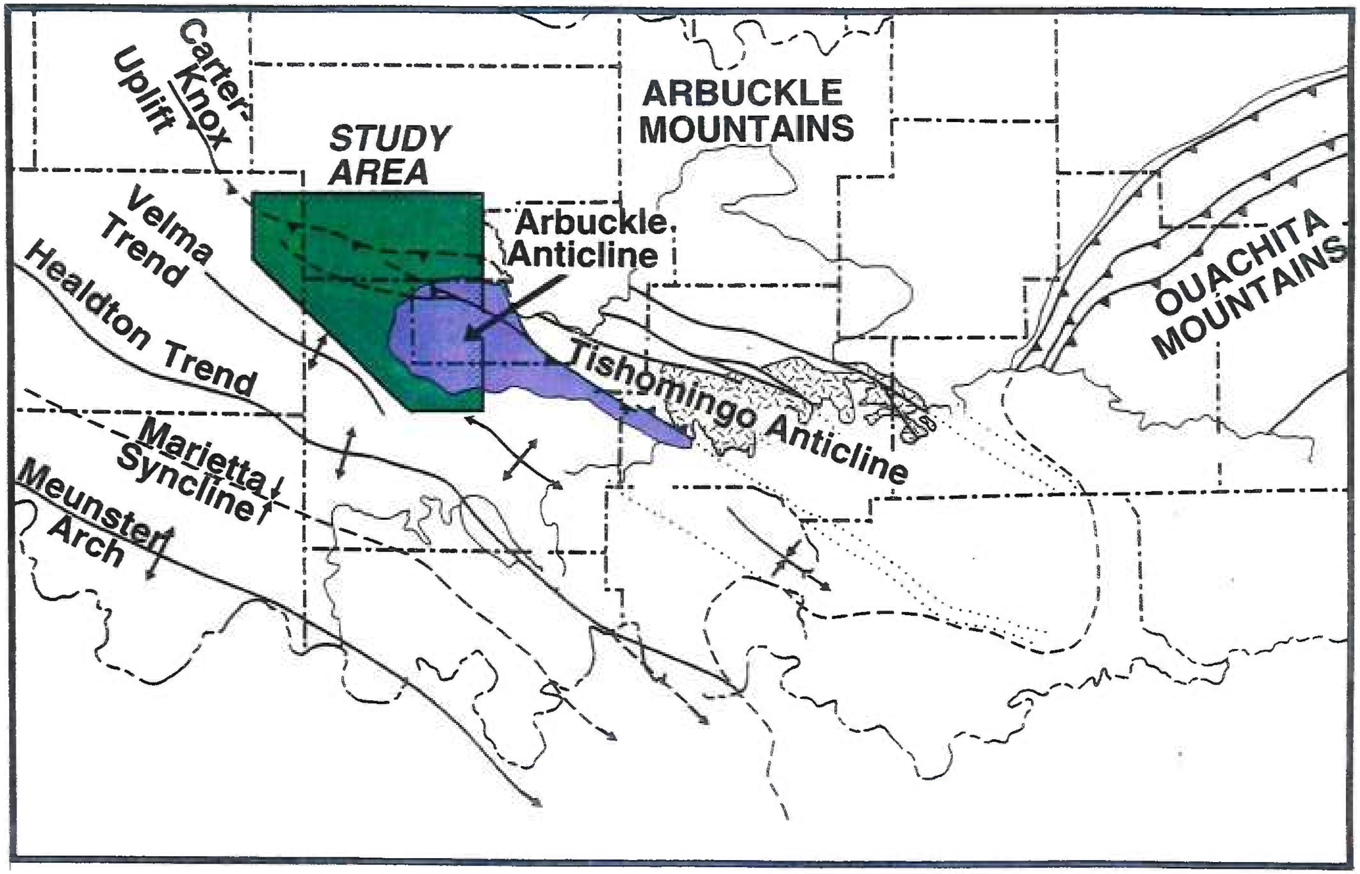
Previous Works

Historically, deformational models of the Arbuckle Mountains (fig. 2) can be classified in the following categories: 1) block uplift along high-angle normal faults, 2) local gravity-slide fault system, 3) right-lateral strike-slip system, 4) left-lateral strike-slip system, 5) low-angle reverse fault system, 6) "transpressive" fault system.

The work of Taff (1904) is the earliest structural interpretation of the Arbuckle Uplift. He interpreted the area to be a series of internally deformed blocks divided by high-angle normal faults.

Although there have been numerous articles concerning the geology of the Arbuckle Uplift, the vast majority have focused on either the exposed Arbuckle Anticline or the exposed portion of the

Figure 2. Tectonic map of the southern Oklahoma foreland. Compression related to the Arbuckle orogeny uplifted and folded the Ouachita Thrust system, creating an erosional re-entrant in the trace of the frontal Ouachita Thrust. Uplifts and basins of the foreland are linear and parallel, generally asymmetric to the northeast and follow a general orientation of N60°W (modified from Hardie, 1990).



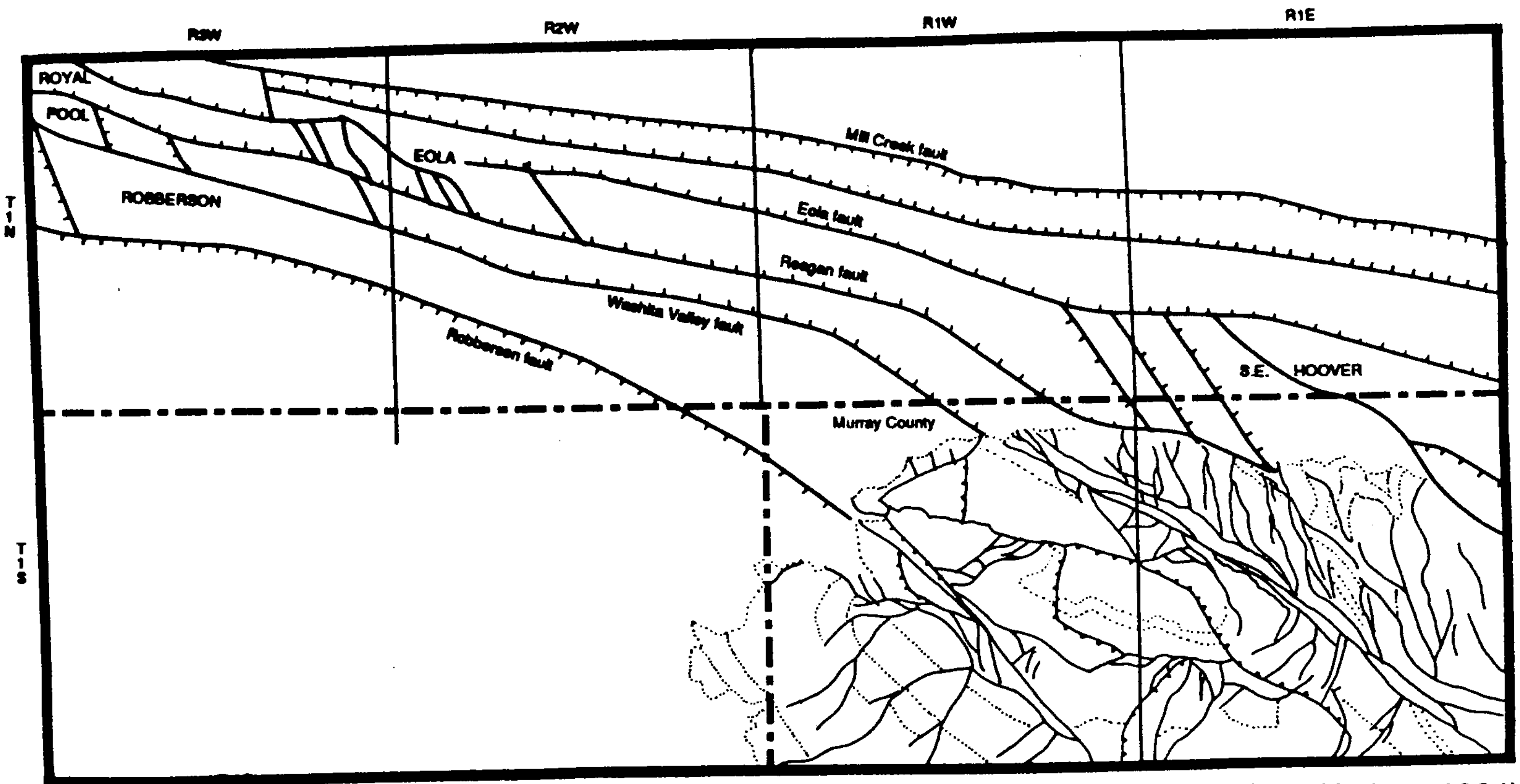
(modified from Hardie, 1990)

Washita Valley Fault. Harlton (1964) presented a detailed study of the geometry and relationships of the faults along the buried Arbuckle Mountain front (fig. 3). He characterized the region as a series of basement blocks, up-thrown along nearly vertical faults. Problems with Harlton's interpretation include inconsistencies of bed-length cutoff on opposite sides of the same fault and inconsistencies in the vertical change in the sense of throw along the same fault (fig. 4), and linking faults with markedly differing styles. These problems may have arisen from his failure to draw cross sections perpendicular to the B-axis of the structure. Cross sections oblique to the B-axis artificially decrease dip and increase vertical separation by obscuring plunge relationships.

Most workers (Ham, 1951; Dunham, 1955; McKinley, 1954; Tanner, 1967; Walper, 1977) have classified the Washita Valley Fault as a wrench fault; some interpreting right-lateral motion, most assigning it left-lateral motion. The wrench fault interpretations have been made, based on the following assumptions:

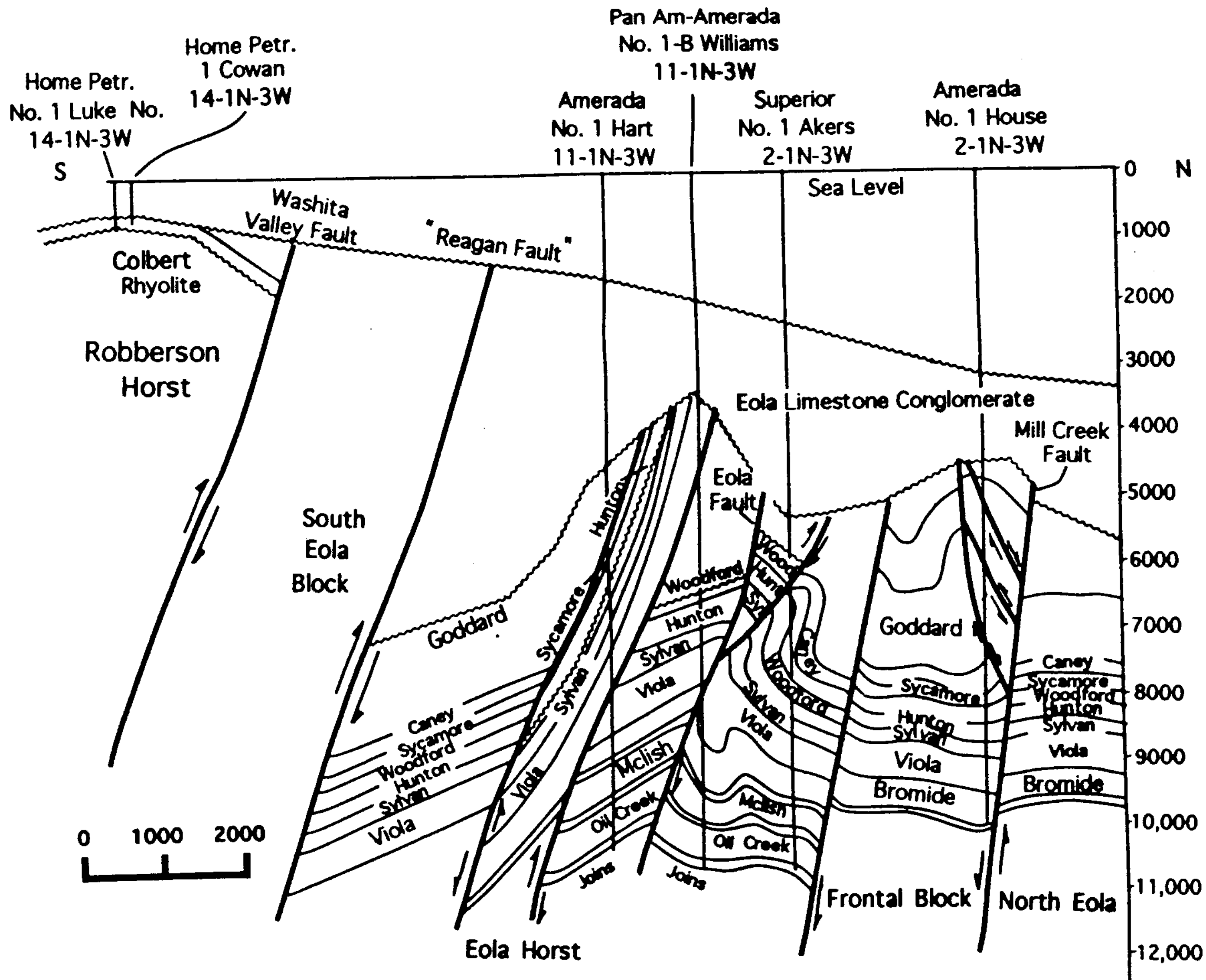
1) The surface trace of the Washita Valley Fault is relatively linear.
2) Outcrop patterns appear to be offset across the Washita Valley Fault in a manner consistent with left-lateral offset.
3) Isopach maps of certain formations exhibit left-lateral separation, if the Washita Valley Fault is assumed to be vertical.
4) The Reagan Fault projects into the area of Eola Field.

Figure 3. Surface and subsurface structural map of the northwest Arbuckle Mountains (from Harlton, 1964). This interpretation is inconsistent in linking surface and subsurface offsets (Robberson Fault). The Reagan Fault is projected across the study area in the subsurface even though Harlton shows it connected to the Garrison Creek Fault in the surface outcrop. It is not shown to join with its last definite surface exposure over 15 miles to the east, bounding the Tishomingo Uplift (modified from Harlton, 1964).



(modified from Harlton, 1964)

Figure 4. South-north cross section across the Arbuckle mountain front and Eola Field (from Harlton, 1964). Faulting is interpreted to have occurred along high-angle faults reactivated from older normal faults. This interpretation contains numerous inconsistencies in fault cut-off angles and lengths and fails to offer an interpretation of the structure of the area labeled "South Eola Block." The labeled "Reagan Fault" is not encountered by well control nor can it's existence be inferred from geometric or balancing constraints. (modified from Harlton, 1964).



(Modified from Harlton, 1964)

These assumptions have been reinforced by the following factors:

1) Seismic lines through the area generally have poor resolution due to steep dips and stratigraphic units with nearly similar velocities (for example the Arbuckle Group and the Carlton Rhyolite).

2) Lack of geometry-based structural studies of the area and properly oriented cross sections based on subsurface data.

3) The belief that, due to large amounts of lateral motion, cross section balancing is not applicable to the area.

Models involving regional left-lateral strike-slip motion have been used as a general explanation of the Arbuckle Mountain region. A proposal of deformation resulting from left-lateral motion was made by Tanner (1963) as part of a regional model involving the deformational history of the Amarillo-Wichita-Arbuckle trend and the Nemaha Ridge. The patterns were thought to fit the geometry predicted by the Moody-Hill (1956) strain ellipsoid for a left-lateral stress system.

Walper (1979) argued that convergence between the North and South American plates during the formation of Pangaea produced a series of northwest-trending megashears across Oklahoma and Texas. Reactivation of bounding faults of a Precambrian rift by the northwest-southeast Pennsylvanian compression produced the series of basins and uplifts of this region. A component of second-order right-lateral slip was thought to occur on the Washita Valley Fault which was assumed to be the primary crustal fault in the Arbuckle Uplift.

Based on detailed surface mapping, Ham (1951); McKinley (1954) and Dunham (1955) each proposed a left-lateral strike-slip system to explain deformation of the Arbuckle region. The Washita Valley Fault was interpreted as the primary fault of the proposed wrench system. Ham (1951) argued for three miles of left-lateral offset. Dunham called for one mile of offset along smaller imbricates of the Washita Valley Fault. These studies represent the conservative end-members of the subsequent left-lateral interpretations.

Outcrop evidence for lateral motion cited has been primarily based upon "apparent" offset of surface structures, the presence of horizontal slickensides along various faults and fractures, and angular relationships between major folds and faults. Subsurface evidence for lateral motion has been based primarily upon offsets of isopachs of the Oil Creek Formation and Hunton Group. It should be noted that in these studies the Washita Valley Fault was assumed to be nearly vertical and through-going, although no direct evidence of fault geometry was offered in support of these assumptions.

Assuming a vertical Washita Valley Fault to be the major uplift-bounding fault, Tanner (1967) used the zero isopach line of the basal Oil Creek sand, to suggest 40 miles of left-slip along the Washita Valley Fault. Although he supported a left-slip interpretation, Wickham (1978) warned of the ambiguity of stratigraphic evidence because "displacement on the fault may have controlled the location of the [basal Oil Creek] sand."

Offsets in the Hunton Group isopach, as well as apparent surface offsets were used as evidence for 20 miles of left-slip displacement by Carter (1979). Contour interpretations of local "thins" within the Hunton were used as piercing points. Again the assumption was made that the Washita Valley Fault was the controlling fault and that it is vertical. The Hunton Group is extremely variable and contains numerous (at least five) unconformities. Carter showed that the Hunton may double in thickness and change lithology in as little as one-quarter mile on a non-faulted block. This leads me to question the validity of interpretive isopachs of the Hunton as valid offset indicators. Though his interpretation was based on offset of fold patterns, Carter failed to address the ratio of the shortening component to the assumed slip. Furthermore, he used "separation" as equivalent to slip (two dimensions vs. three dimensions), failing to take into account the effect of plunge and erosion on apparent separation.

Brownlee (1982), investigated strata of the Simpson Group occurring above the Eola Anticline, immediately beneath the limestone Eola Conglomerates. Her conclusion was that the Simpson interval represented gravity slide features from the Robberson Horst. Brownlee states that the deformation within the gravity slide blocks was most likely due to wrenching deformation prior to gravity sliding, though how this conclusion is reached is not clearly stated. Furthermore, she stated that she disregarded dipmeter data when the data "seemed most in error or created impossible geologic situations." No explanation was given as to how raw data could be inherently in error, or what constituted an "impossible" geologic situation. As with Harlton's (1964) work, her cross sections are constructed along north-south lines, oblique to the trend (B-axis) of the major folds and faults, yet she states that "no oblique sections were made". Although she firmly concluded that the regional deformation of the Eola area was the result of left lateral wrenching, her arguments were based on the conclusions of previous workers and she did not offer any new evidence in support of this conclusion.

Haas, 1979, studied the Reagan Fault, east of the Arbuckle Anticline, which he viewed as part of a left-lateral wrench system that extends westward into the Eola region. Haas interpreted the Reagan Fault as a near-vertical wrench fault, yet offered no evidence from well control or seismic data to support his interpretation of the fault geometry. Haas states that the Reagan Fault displays 10,000 feet of vertical uplift, but does not state whether this amount is continuous along the strike of the fault or represents a local maximum figure, nor does he address the amount of shortening in the area.

Based upon interpreted plate motions, Kluth and Coney (1981) suggested that Late Pennsylvanian suturing of North and South America caused compression and wrenching along the aulacogen boundaries, which were inherent crustal zones of weakness.

Arguments for so-called "transpressive" deformation involving a left-lateral component have been made by several recent workers. Based on work in the Wichita Mountains of western Oklahoma, Donovan (1986) has called on a transpressive system to explain Pennsylvanian deformation across the Southern Oklahoma Aulacogen.

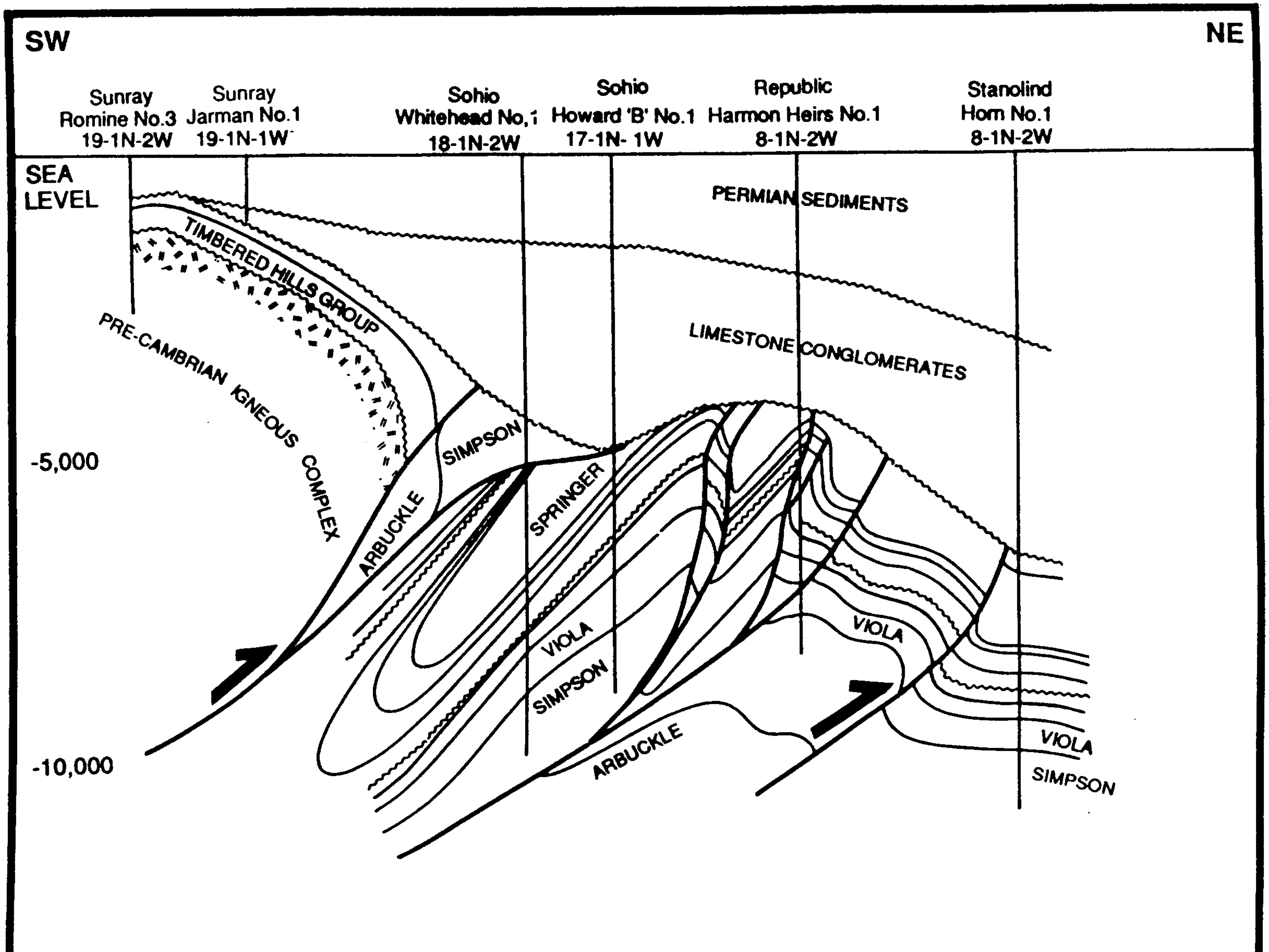
Kendall (1991) called for transpression in his study of Eola Field. Little agreement seems to exist however, as to which end member of transpression (dominantly wrench or dominantly thrust) occurred and what the resulting structural style would be by those who employ the term "transpression".

Dott (1934) called for thrusting and compression to explain the Arbuckle Anticline. Swesnick and Green (1950), working with initial data from the then newly discovered Eola Field, persuasively and logically argued that overthrusting, along a single regional fault, brought up the Arbuckle Anticline (fig. 5). Regional work by Tomlinson (1952) in the Ardmore Basin/Arbuckle Mountain region led him to conclude deformation resulted from regional horizontal compression. An apparent change in the direction of offset and dip of the Washita Valley Fault led him to conclude the fault was "propeller shaped" and indicated differential displacement and rotation.

Consortium for Continental Reflecting Profiling (COCORP) deep seismic-reflection profiles in the early 1980s revealed that drilled basement overhangs were carried along low-angle reverse faults in the Wichita Mountains northeast of the study area. The mountain front was thrust significantly over the southern end of the Anadarko Basin. Brewer (1982) documented these reflections and showed through palinspastic restoration that shortening of up to 10 to 15 km had occurred on the reverse faults.

Using subsurface well data, structurally balanced, properly oriented structural cross sections, and published maps, Brown (1984) showed that the Washita Valley Fault is a back-limb

Figure 5. Southwest-northeast cross section across Eola Field (modified from from Swesnick and Green, 1950). Deformation of the hanging wall was interpreted to have occurred along a single thrust which also uplifted the Arbuckle Anticline exposed to the southwest. "Precambrian" igneous complex has since been dated to be the Cambrian Carlton Rhyolite (modified from Swesnick and Green, 1950).



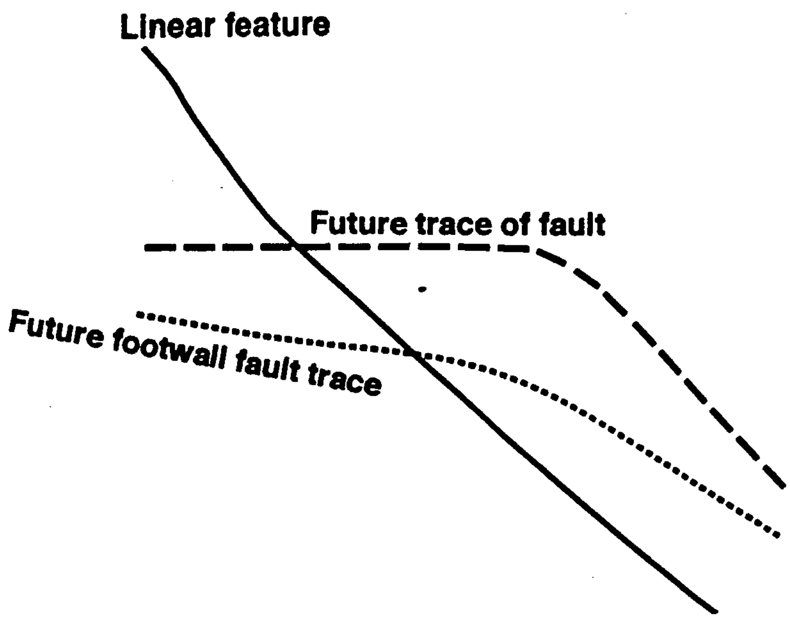
(modified from Swesnick and Green, 1950) imbricate to the blind major fault, which he termed the "Arbuckle Thrust". This claim was supported with a general contour map of the fault plane based upon well control. Brown demonstrated that apparent left-lateral offsets of the basal Oil Creek sand zero isopach line could be accounted for by extending contours to match cut-offs on the hanging-wall and footwall of the thrust plane (fig. 6) rather than a vertical fault plane, as previously proposed by Tanner (1967). Brown's palinspastic restoration of the zero sand isopach line across overturned folds and reverse faults, showed little or no lateral movement.

Working along the southeastern plunge of the Arbuckle Anticline, Palladino (1986), demonstrated that the southern portion of what is commonly called the Washita Valley Fault Zone is comprised of two oppositely verging thrusts, which have been eroded to the point at which they impinge upon one another (fig. 7). Using outcrop and well data, Palladino showed that the southwest-dipping Arbuckle Thrust, post-dated the slightly older Ravia Thrust. Palladino's cross sections portrayed the plunging Arbuckle Anticline with a geometry similar to a fold and thrust belt.

Workers such as Juilliard (Dougherty Anticline, 1982); Powers (southwest Davis Field, 1984); Ostroff (Colbert Creek Anticline, 1985); Fletcher (Caddo Anticline, 1986); and Cooper (Criner Hills, 1992) have all demonstrated that structures in the Arbuckle Mountain region formed as a consequence of a dominantly northeast-southwest oriented horizontal compressive system.

Beck (1987) showed a portion of the Arbuckle Thrust in detail and documented that SE Hoover Field was a hanging wall feature on

Figure 6. Diagram showing how left-lateral separation may be the product of reverse dip-slip motion. If the final fault trace is assumed to be that of a vertical fault, lateral off-set may be misinterpreted as the product of left-lateral slip (modified from Brown, 1984).


Linear feature
Future trace of fault
Future footwall fault trace

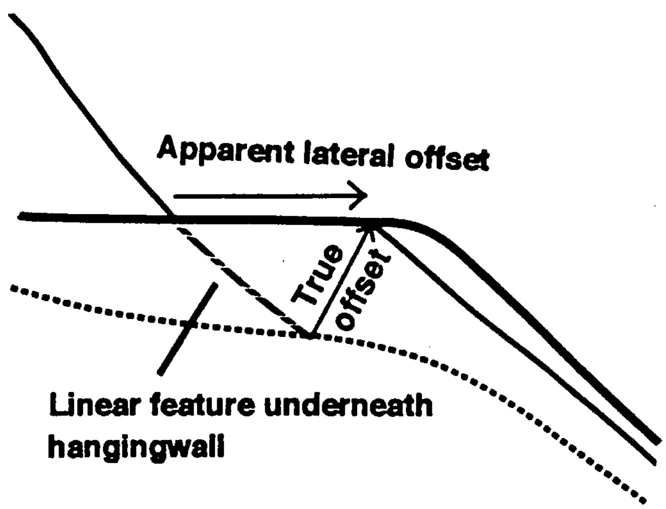
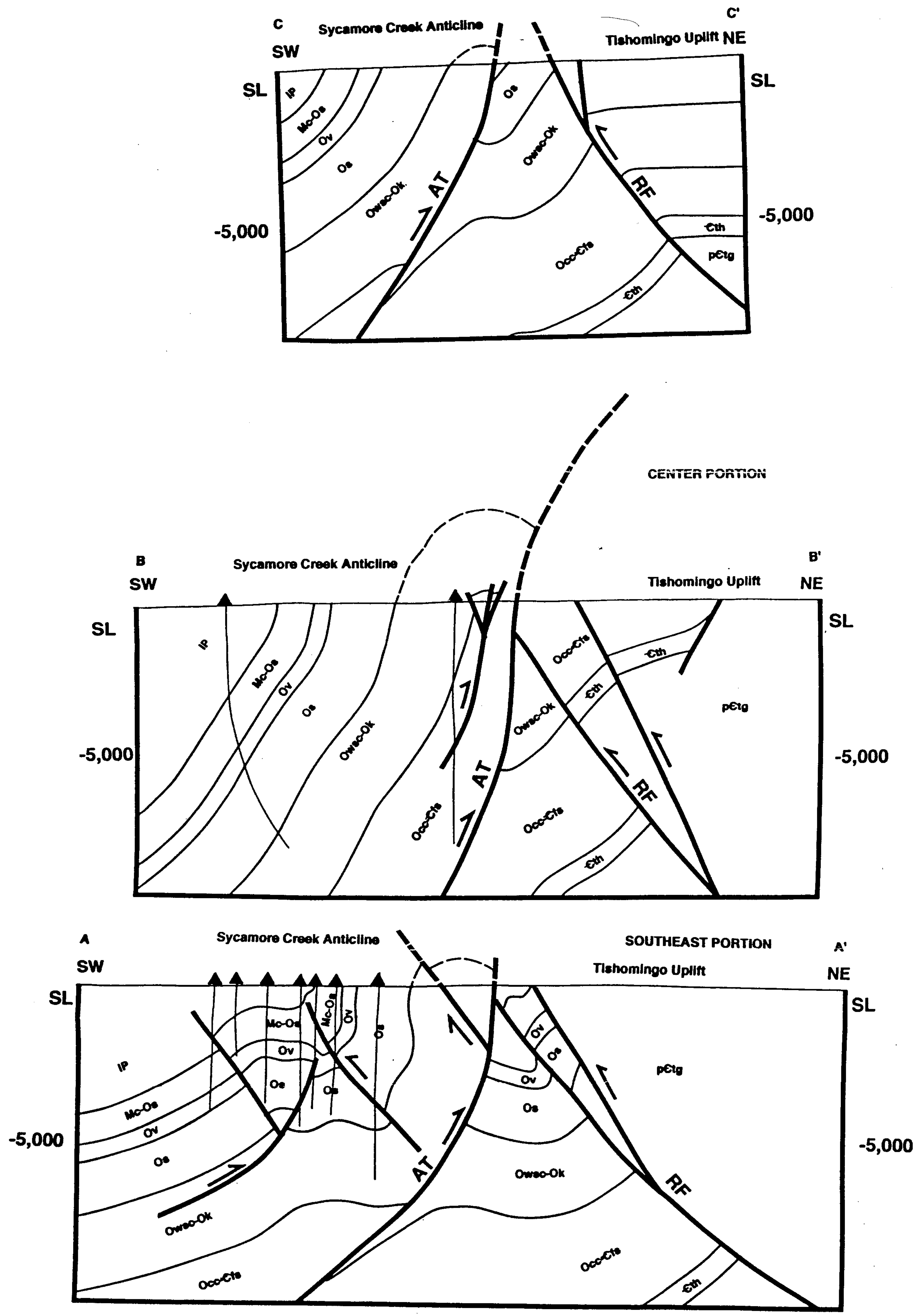

Apparent lateral offset
True
offset
Linear feature underneath
hangingwall

Figure 7. Series of cross sections along the Arbuckle Thrust and Ravia Fault . The Arbuckle Thrust forms long bedding-parallel detachments within the Arbuckle Group (modified from Palladino, 1986).



(modified from Palladino, 1986)

the buried Arbuckle Thrust (fig. 8). Based on well control, he showed the Washita Valley Fault to have a southwest dip of 60 degrees.

Hardie (1990) studied the relationship of the Arbuckle-Tishomingo trend, to the buried Ouachita System. Thrusts of the Ouachita System were folded in the Isom Springs Field by northeast-southwest oriented compression related to the Arbuckle orogeny. Uplift of the Tishomingo block, raised the overlying thrust sheets, and subsequent erosion resulted in their present day "reentrant" pattern. Although folded, the Ouachita thrust sheets are not offset by lateral faulting. These relationships are strong evidence that the compressive event (Arbuckle orogeny) was not a function of, nor accompanied by, regional strike-slip motion.

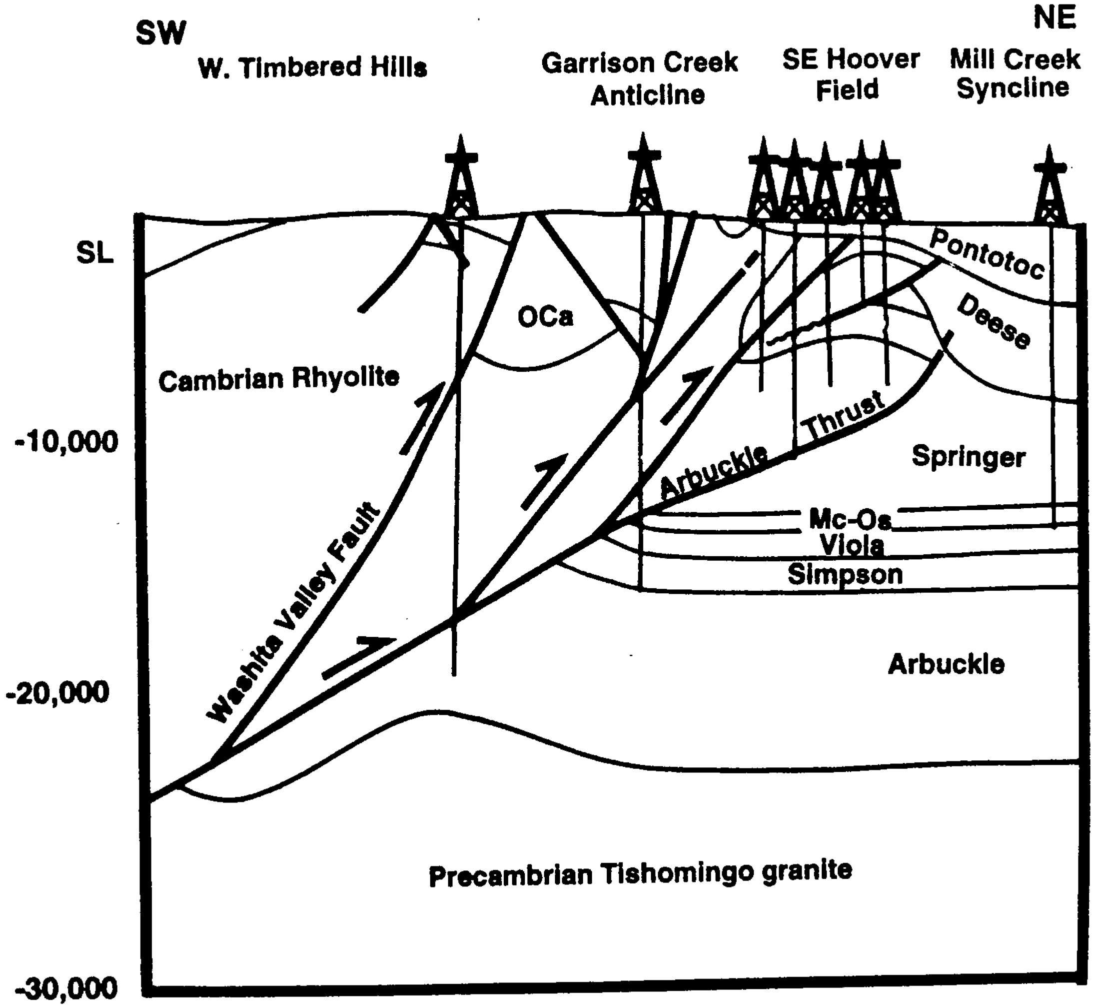


Figure 8. Northeast-southwest cross section through SE Hoover Field. The Arbuckle Uplift has been deformed by a series of imbricate thrusts which sole into the buried Arbuckle Thrust. Note that the dip of the Arbuckle Thrust is known from wells on either side of the surface exposure of the Washita Valley Fault (modified from Beck, 1987).

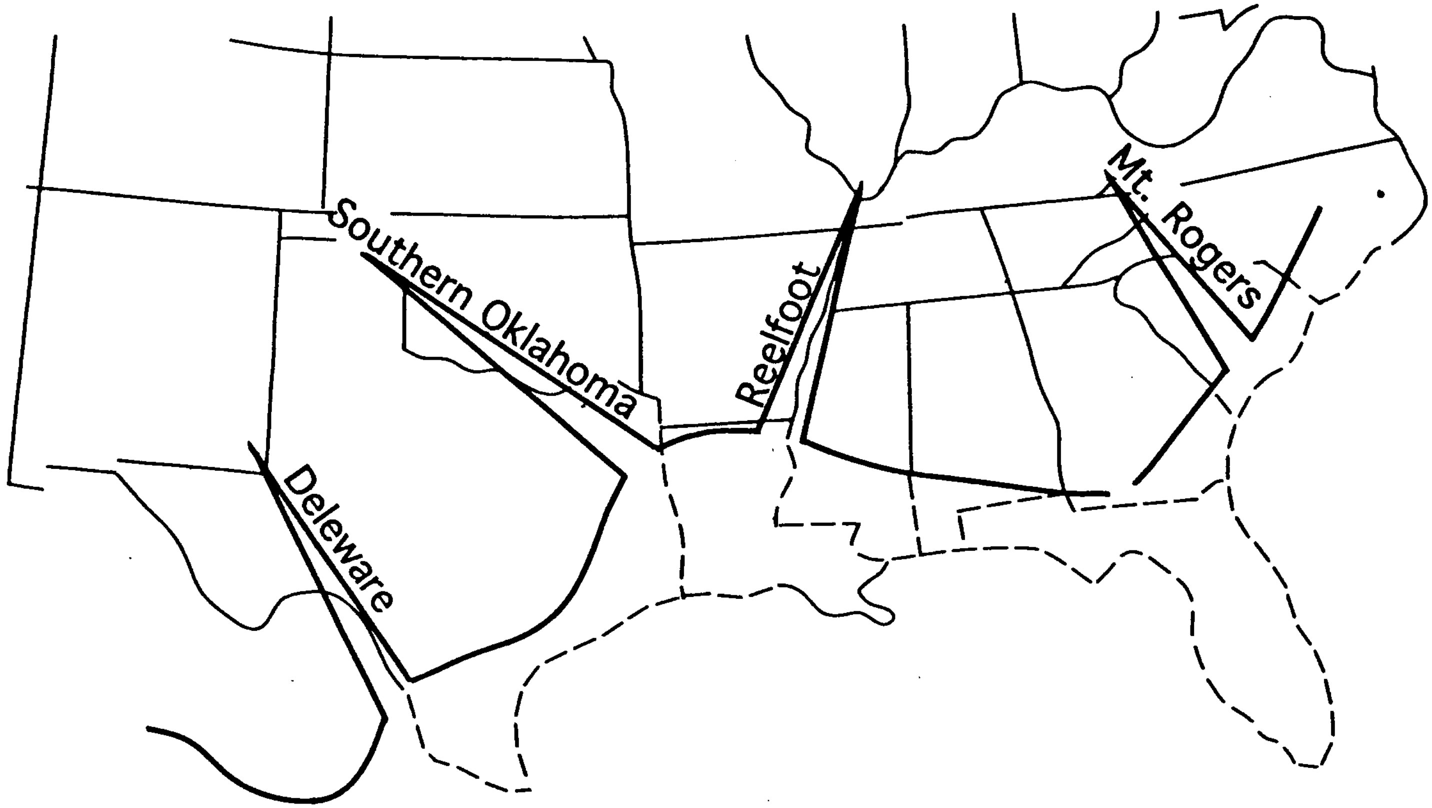
TECTONIC SETTING

The tectonic history of the southern margin of North America is both fascinating and complex. Many details remain poorly understood, nonetheless, a general picture exists. Events relating to the stratigraphy and structural fabric of the Arbuckle region will be discussed in this segment.

Late in the Precambrian, southern North America was sutured to a proto-Afro-South American plate (Walper, 1977). Later rifting along what is now the present-day southern margin of North America occurred in the latest Proterozoic. The rifting separated North America from the proto-Afro-South American plate (Walper, 1977; Wickham, 1978). Some disagreement arises as to the morphology and generation of this rift, with two schools of thought dominating.

The first is that a series of plume-generated triple junctions (Dewey and Burke, 1973), swelled and thinned the crust. The crust then broke in response to the "least work" principle along a series of three armed rifts; each rift 120 degrees apart (fig. 9). Two of the arms experienced the majority of the extension and linked with other triple junctions to form the continental boundary. The third arm "failed", creating a rift which extended into the continental interior. Interior basinal patterns suggest that at least four such rifts were formed along the Early Paleozoic margin of North America

Figure 9. Location of continental rifting of southern North America in early Paleozoic (modified from Beck, 1987).



(After Beck, 1987)

(fig. 9). The southern Oklahoma area is a type area for aulacogens and was recognized as such by Schatski (1946).

The second explanation is that the rifting was created by the landward continuation of a transform fault (fig. 10) formed by the opening of a proto-Gulf of Mexico (Thomas, 1989; Arbenz, 1989).

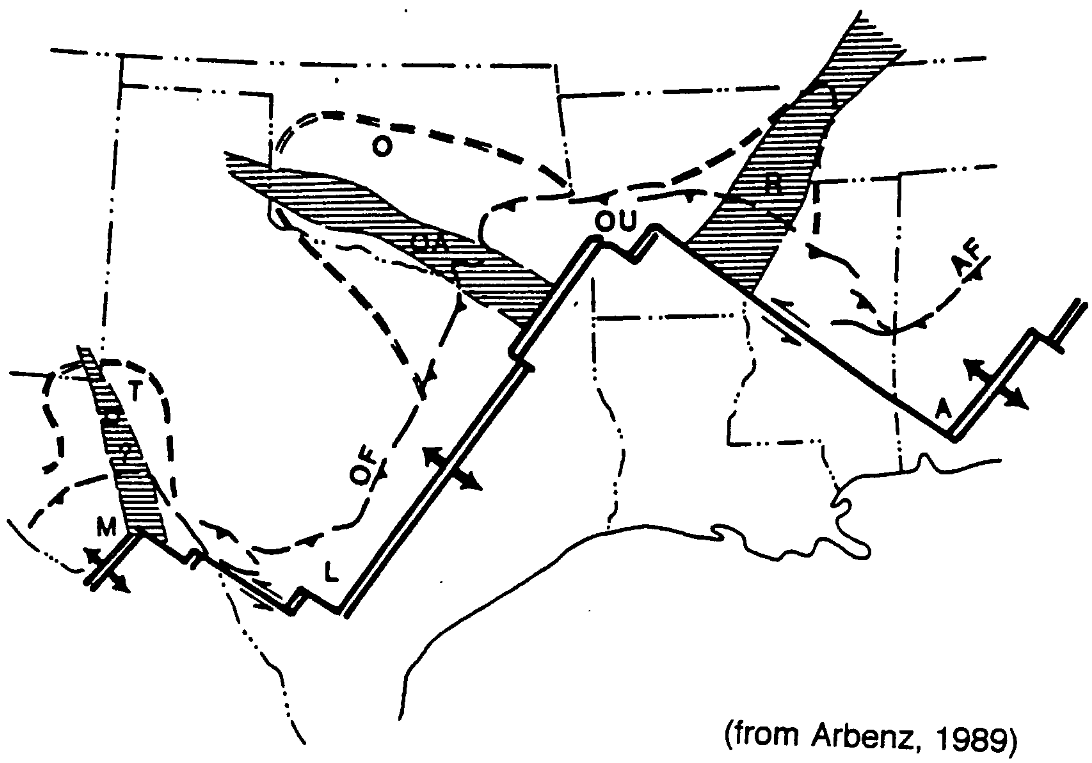
Wickham (1978) characterized the Southern Oklahoma Aulacogen development as three major stages: 1) rifting, 2) subsidence, and 3) deformation (fig. 11).

Rifting was initiated in the Late Precambrian along the previously mentioned triple junctions. Significant igneous activity accompanied normal faulting. Both intrusive and extrusive rocks are believed to have been generated. Encroaching seas from the newly created proto-Gulf of Mexico then transgressed the aulacogen, depositing shallow-marine sediments over the volcanic fill.

The rift then cooled and began to subside. Sediments accumulated in greater thickness within the rift than on the surrounding craton due to the rate of subsidence (fig. 12). The Cambrian-to-Mississippian strata reflects this history, recording fewer unconformities within the rift setting. Enormous amounts of sediments were preserved within the rift, at least twice that of the surrounding craton.

Deformation marked the final stage of development for the Southern Oklahoma Aulacogen. From Late Mississippian to Early Permian the area underwent crustal shortening along basement involved faults. Major orogenic events include the formation of the

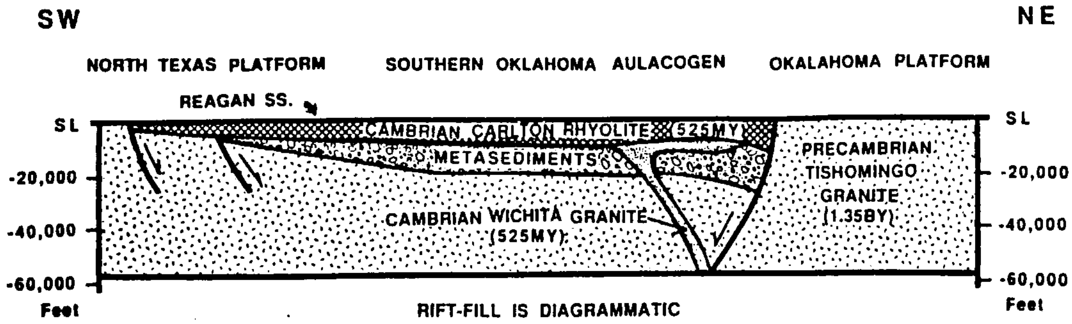
Figure 10. Location of transform boundaries and area of continental extension during the Early Paleozoic extension of North America (from Arbnez, 1990).



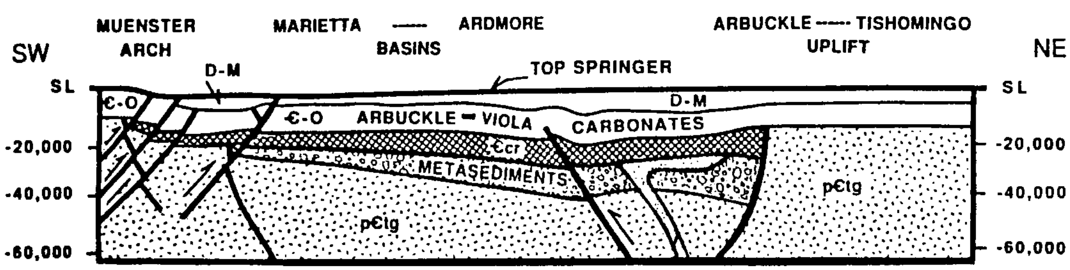
(from Arbenz, 1989)

Figure 11. Sequential evolution of the Southern Oklahoma Aulacogen (from Brown,1991).

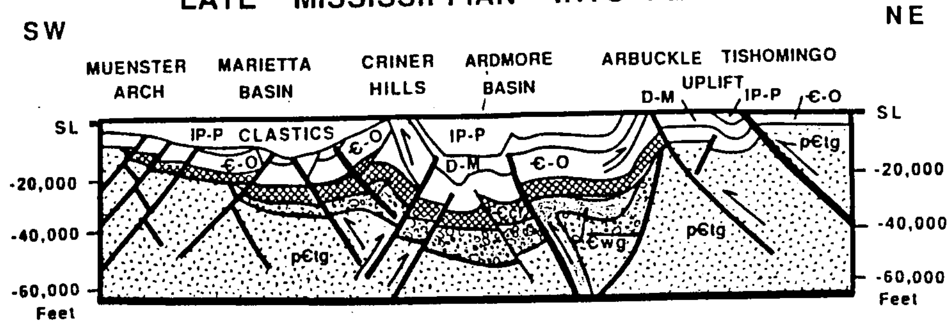
LATE PROTEROZOIC to MIDDLE CAMBRIAN



LATE CAMBRIAN to LATE MISSISSIPPIAN

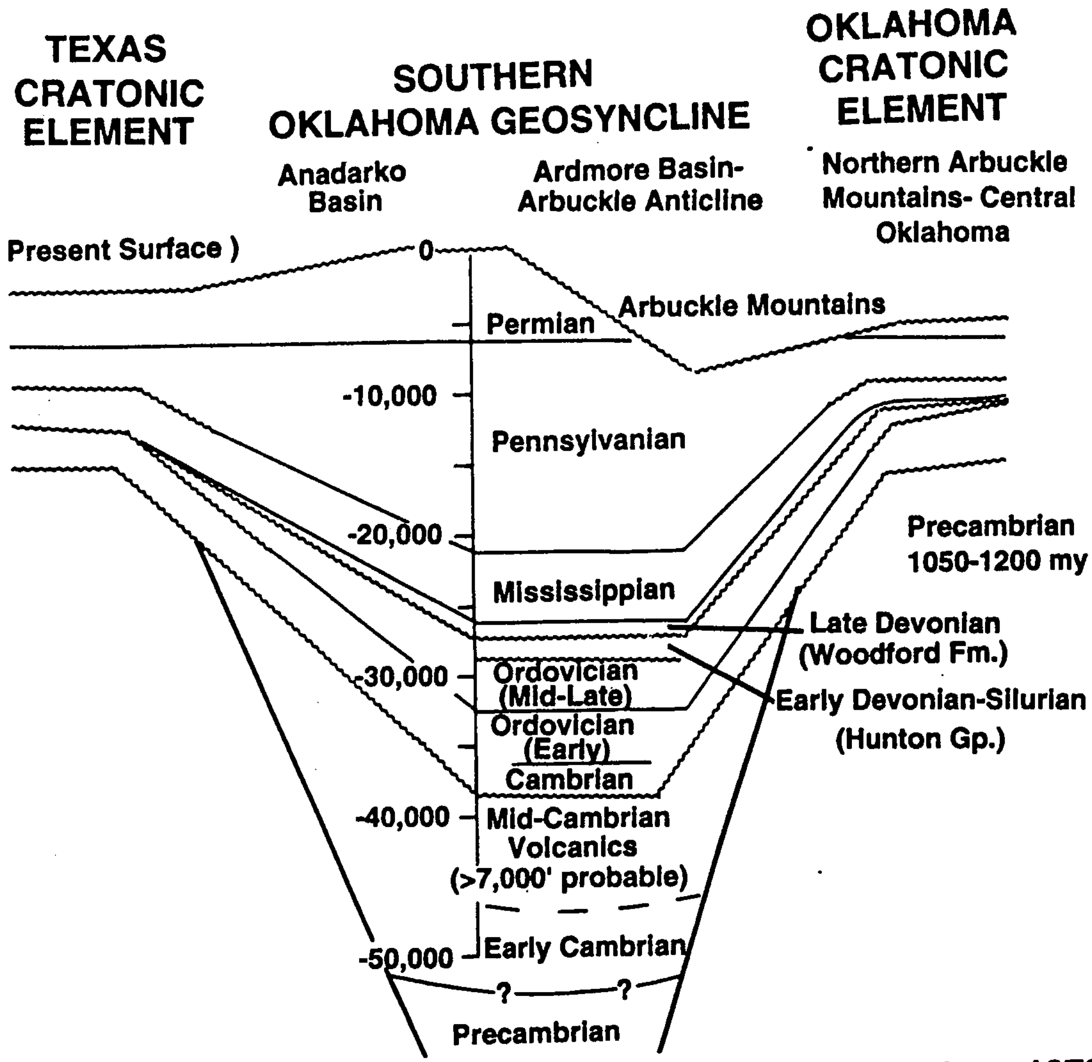


LATE MISSISSIPPIAN INTO PERMIAN



(from Brown, 1991)

Figure 12. Stratigraphic-structural relationships of the in-filling of the Southern Oklahoma Aulacogen (modified from Ham, 1978). The Paleozoic section is much thicker (approximately 45,000 feet) in the aulacogen than on the stable cratonic platform (10,000 feet).



(modified from Ham, 1978)

Wichita and Arbuckle Mountains. Enormous volumes of synorogenic sediments were generated and filled intermontaine basins.

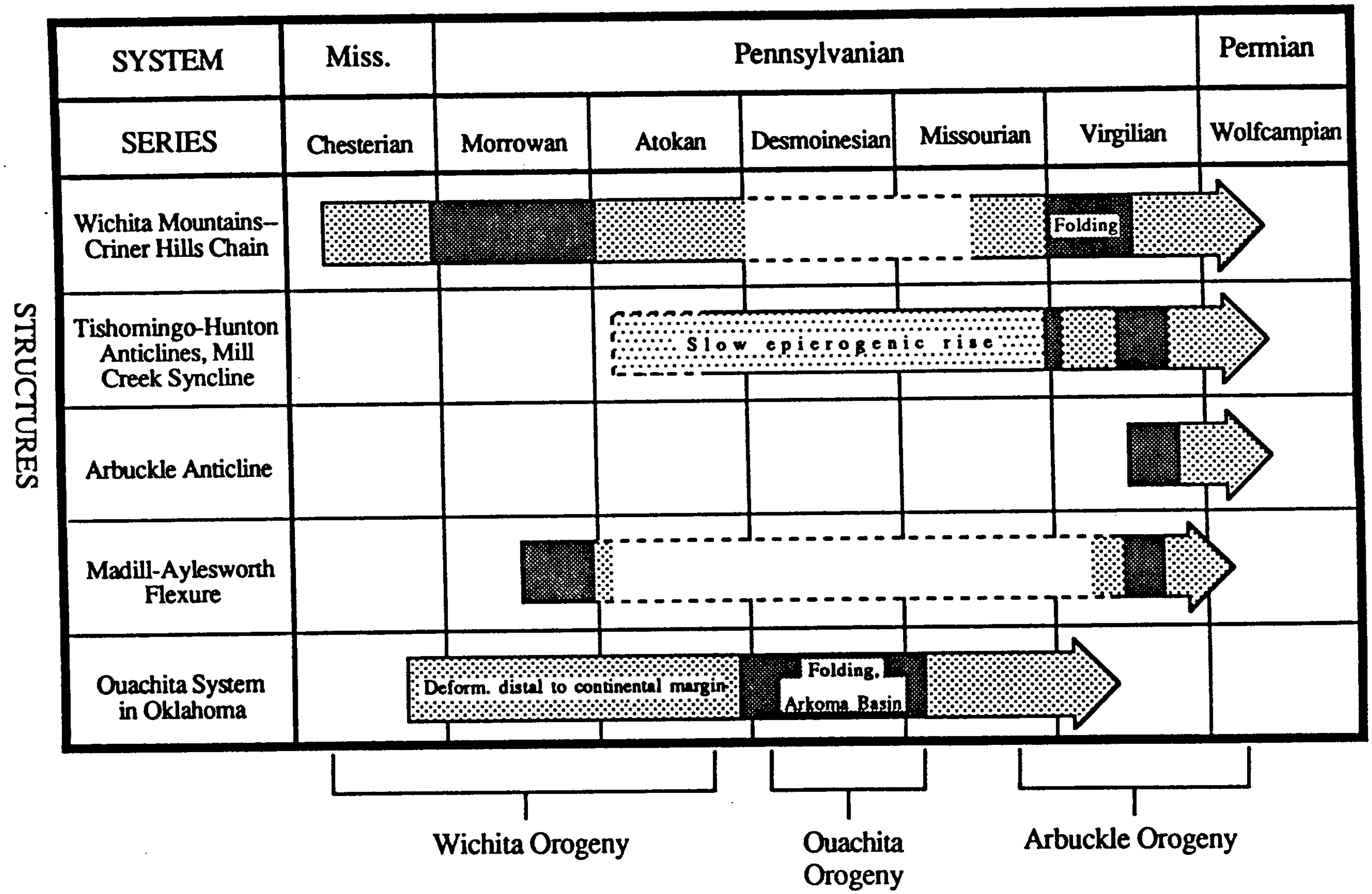
The Wichita Orogeny preceded the Arbuckle Orogeny, with deformation beginning in Late Mississippian and ending in Early Atokan. The southeastern continuation of this trend is expressed as the Criner Hills, which lie to the south of the Arbuckle Anticline. The Wichita Uplift formed an associated foreland basin, the Anadarko, which filled with the synorogenic clastics of the Dornick Hills Group. Contemporaneous with this deformation was the onset of the uplift of the Tishomingo Uplift and Hunton Arch.

The Arbuckle Orogeny (fig. 13) represents a later pulse of deformation taking place from the Desmoinesian to Early Virgilian. In addition to the formation of the Arbuckle Anticline, rejuvenation occurred on both the Hunton Arch and Tishomingo Uplift and parts of the Criner Hills. Compression of the area between the Criner Hills and the Tishomingo-Hunton system resulted in the formation of the Ardmore Basin and the Arbuckle Anticline. Shortly after maximum uplift was attained, a relaxation of tectonic forces allowed the formation of a series of normal faults parallel to, and reactivating at depth, major thrusts that cut many of the structures. This extensional phase is one of the least recognized in the literature. The displacement on many of these normal faults is of considerable magnitude. Relaxation in the Wichitas is associated with normal movement on the Meers Fault. Normal faults also cut the Criner Hills and the Arbuckle Uplift.

Causes of Pennsylvanian deformation are hotly debated. Closing of the proto-Gulf of Mexico and Iapetus Ocean, associated

Figure 13. Chart of sequential orogenic deformation of Southern Oklahoma showing the temporal relationships of the Wichita, Ouachita, and Arbuckle orogenies (from, Hardie, 1990).

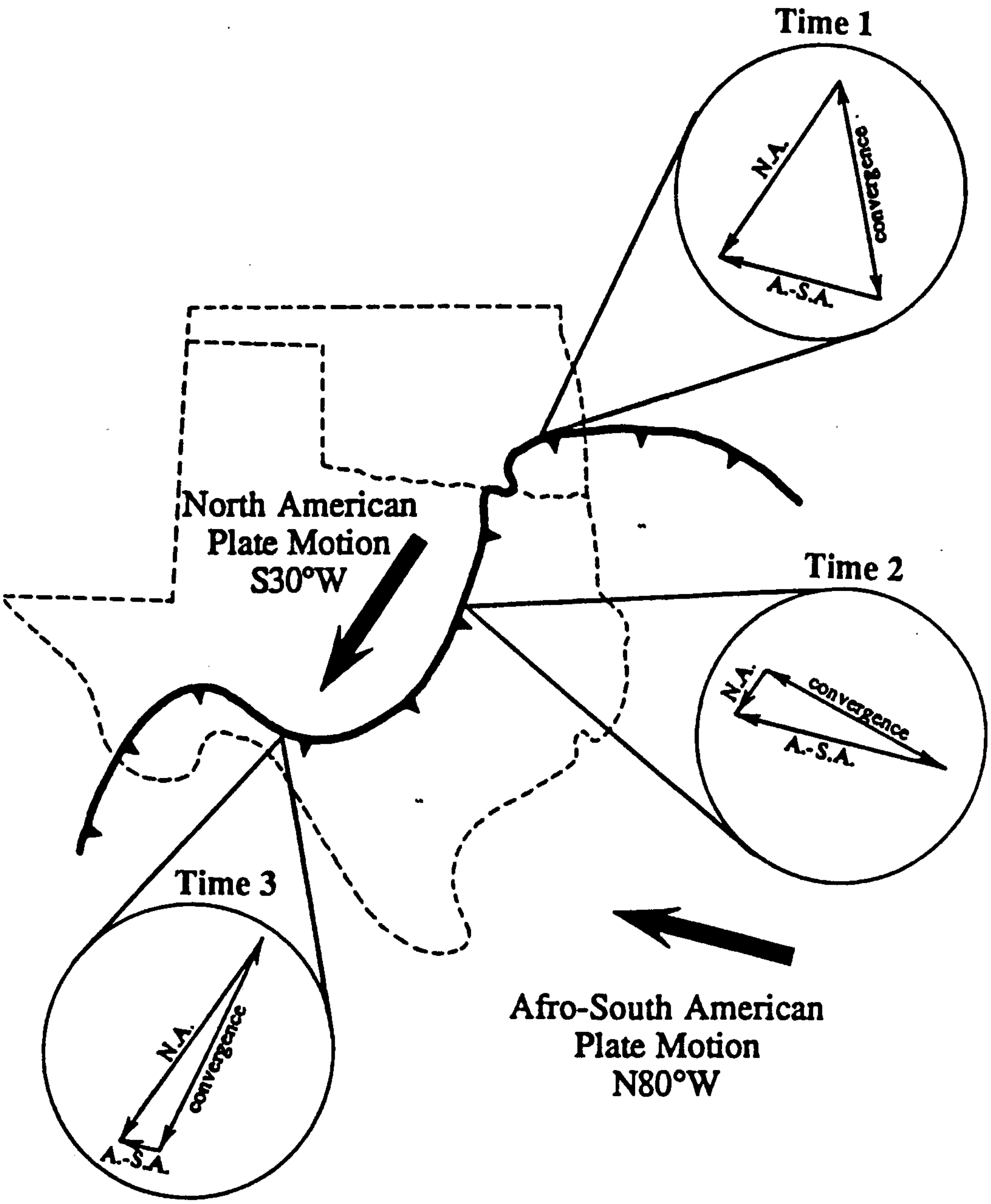
TIME OF DEFORMATION



(from Hardie, 1990)

with the suturing of South America to North America and the formation of Pangaea are thought responsible by many. Kluth and Coney (1981) demonstrated that continental suturing moved progressively southwestward along the southern margin of North America (fig. 14). Additionally, thin-skinned deformation of the Ouachita-Marathon orogen also progressed southwestward along the southern North American margin (Graham and others, 1975).

Figure 14. Possible convergence vectors between North and South America during the Late Paleozoic. Time three corresponds to Late Pennsylvanian (Arbuckle) deformation. The direction of convergence implies a compressive stress on the Southern Oklahoma Aulacogen oriented nearly north-south during the Arbuckle orogeny (modified from Hardie, 1990)



(modified from Hardie, 1990)

REGIONAL STRATIGRAPHY

Introduction

The Arbuckle Mountain region offers the best exposure of Paleozoic strata in the southern Mid-continent. Prolific exploration for hydrocarbons has extended the available data in the form of numerous subsurface well logs. The complex stratigraphic history of the area is due, in part, to the Paleozoic tectonic activity.

The purpose of this section is to provide a concise lithologic framework of the stratigraphic units recognized in the area and involved in the structural history of the study area (fig. 15).

Pre-Pennsylvanian Stratigraphy

Basement

Basement rock was observed in outcrop and interpreted by electric-log responses in several wells located within the study area. In outcrop the basement is represented by the Cambrian Carlton Rhyolite (500-550 Ma). Other basement rock cropping out within the general Arbuckle Mountain region is the Precambrian Tishomingo Granite (1.35 Ga).

The differences in outcrop distribution of these two units reflects a major boundary in the composition of the basement. The Carlton Rhyolite is confined to the aulacogen and is believed to be related to the rifting event which formed the aulacogen. This unit is believed to be contemporaneous with early normal faulting and to have been extruded along, and offset by, these normal faults (Wickham, 1978).

Several wells within the study area penetrate Cambrian basement. In these wells the basement has been uplifted and thrust northeastward. The basement is believed to consist of varying layers of rhyolite, mafic dikes, and granite. Due to the complexity of igneous intrusive and extrusive rocks, one would not expect to be able to easily correlate this basement with electric logs. The author noted that both spontaneous potential and resistivity log signatures within the basement sequence were extremely erratic (fig. 16).

Timbered Hills Group

The Timbered Hills Group accumulated during a craton-wide transgressive Sauk sequence. Late Cambrian sedimentation began with the deposition of a basal sand, the Reagan. Within the aulacogen the Reagan ranges from 50 to 500 feet thick. The Reagan is an immature sand with high feldspar and glauconite content. Facies are variable and may be locally conglomeratic. Donovan (1986) proposed that the Reagan landscape consisted of a series of local highs of rhyolite, some above sea-level, within a shallow sea, thereby accounting for variability in both facies and thickness of the Reagan Sandstone.

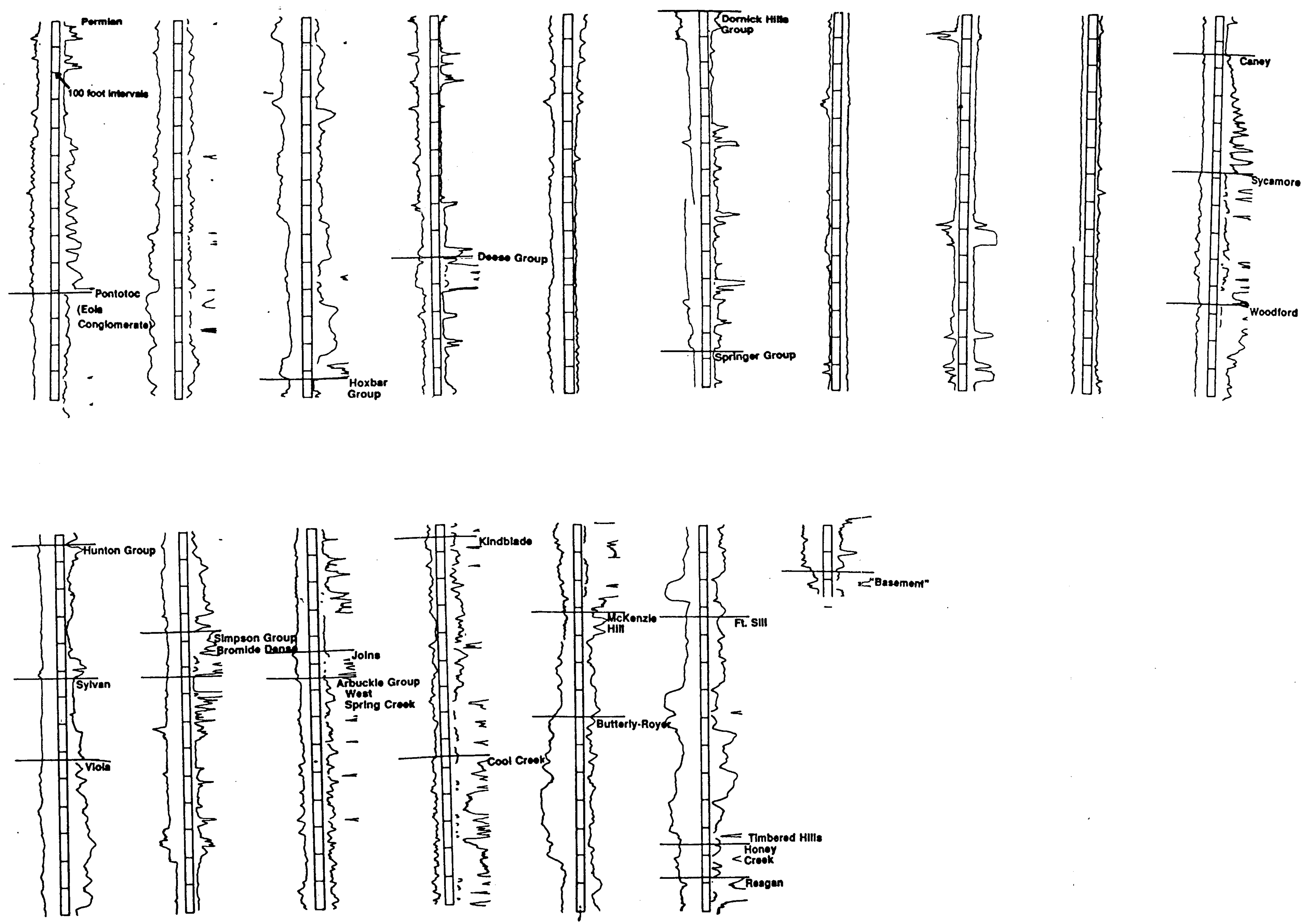
This variability, along with its position above the unconformity, results in difficult well log correlations. The overlying Honey Creek Limestone also shows great variability.

Figure 15. General stratigraphic column (modified from Beck, 1987).

SYSTEM	SERIES	GROUP	FORMATION
PERMIAN	Wolfcampian	Pontotoc	
PENN.	Virgilian	Cisco	
	Missourian	Hoxbar	
	Desmoinesian	Deese	
	Atokan	Dornick Hills	
	Morrowan	Springer	Goddard
MISS.	Chesterian		
	Meramecian		Caney
	Osagian		Sycamore
	Kinderhookian		
DEV./ SIL.	Late		Woodford
	Early	Hunton	
ORDOVICIAN	Late	Viola	Sylvan
			Viola
	Middle	Simpson	Bromide
			Tulip Creek
			McLish
			Oil Creek
			Joins
	Early	Arbuckle	Kindblade
			West Spring Creek
			McKenzie Hill
			Cool Creek
			Signal Mountain
			Butterly
CAMBRIAN	Late		Royer
			Fort Sill
		Timbered Hills	Honey Creek
			Reagan
	Middle	"Basement"	Carlton Rhyolite / p€tg
	Early		
PRE-CAMBRIAN			Tishomingo Granite

(Modified from Beck, 1987)

Figure 16. Montage of electric logs showing typical signatures of rocks units. Variations of signatures may be quite pronounced within drilled conglomeratic and igneous rocks.



Permian
100 foot intervals
Pontotoc
(Eola
Conglomerate)
Hoxbar
Group
Deese Group
Dornick Hills
Group
Springer Group
Caney
Sycamore
Woodford
Hunton Group
Sylvan
Viola
Simpson Group
Bromide Dense
Joins
Arbuckle Group
West
Spring Creek
Kindblade
Cool Creek
McKenzie
Hill
Butterly-Royer
Ft. Sill
Timbered Hills
Honey
Creek
Reagan
"Basement"

Difficulty in picking the Honey Creek is enhanced by similar log signatures with the overlying Arbuckle Group (fig. 16).

Arbuckle Group

The Arbuckle Group represents an unusually thick sequence of similar carbonate facies. These rocks are primarily interbedded thin carbonate mudstones, oolitic and intraclastic calcarenites, and laminated dolomite. They range in age from Late Cambrian to Early Ordovician. The depositional environment included supratidal to shallow subtidal conditions. The vast thickness and relative vertical consistency of facies suggests that the rate of deposition was equal to that of subsidence in the aulacogen. Maximum thickness of the Arbuckle Group attained within the Arbuckle Mountains was 6,700 feet (Ham, 1973).

The Arbuckle Group consists of seven formations in descending order: West Spring Creek, Kindblade, Cool Creek, McKenzie Hill, Signal Mountain, Royer Dolomite, and Fort Sill. Variable electric-log response and similarities between individual formations made log picks of individual formations difficult (fig. 16). There was also some difficulty in distinguishing the Arbuckle Group from synorogenic conglomerates derived from the Arbuckle Group.

In outcrop, the Arbuckle is internally deformed through small-scale folding on bedding-plane slip. Folds may be tight and there is often a ramp-flat geometry of small faults. Penetrative deformation on this scale probably exists in the subsurface but it is of too small a scale to interpret in electric logs.

Simpson Group

The Simpson Group represents Middle Ordovician deposition and marks a distinctive break from the carbonate-dominated deposition of the Arbuckle, to a more clastic-dominated (though highly variable) lithology. From oldest to youngest, the Simpson Group is composed of the Joins, Oil Creek, McLish, Tulip Creek, and Bromide formations. Shale and sandstone lithologies provide the mechanical means for numerous zones of detachment (shale) and ramps (sandstone). The sandstones are extremely mature quartz arenities, typical of mid-continent sandstones of this time.

Joins Formation

The Joins Formation is a skeletal limestone approximately 200 feet thick. Its high resistivity and low spontaneous potential (SP) response on an electric log enable an easy pick to be made from the overlying basal Oil Creek sandstone where present (fig . 16). As a mechanical package the Joins tended to behave structurally like the underlying Arbuckle Group.

Oil Creek Formation

The Oil Creek Formation consists of 700 to 1,000 feet of shales, grainstones, and sandstones. The sand occurs at the base of the formation and is composed of supermature, clean sandstone that forms a distinctive "squared-off" pattern on the SP curve (fig. 16). This basal sand, as well as the entire Oil Creek Formation, thins to the northwest.

Offsets in isopach thicknesses of the basal sand have been used to interpret left-lateral offset along the Washita Valley Fault (Tanner, 1967).

McLish Formation

The McLish Formation consists of approximately 500 feet of sands and shales that are similar to the underlying Oil Creek, in both electric-log pattern and lithology. The McLish also contains numerous interbedded thin limestone beds. The "Birdseye" Limestone is a prominent algal limestone that ranges in thickness from 400 feet to absent.

Tulip Creek Formation

The Tulip Creek Formation consists of about 400 feet of predominantly shale with interbedded sands and limestone.

Bromide Formation

The Bromide Formation consists of up to 500 feet of interbedded sand, shales, and limestones, similar to the underlying Tulip Creek. The upper Bromide is identified by a thick-bedded limestone known as the Bromide "Dense" Member.

Viola Group

Easily recognized in the field by its distinctive double hogback topography, the Ordovician Viola shows the same expression in electric-log signature, forming a prominent double hump on the resistivity curve. The depression in both topography and electric log signature is caused by a shaly zone between the two thick limestone units (fig. 16).

Average thickness of the Viola is about 500 feet. Pollard and Williams (1985) divided the Viola into three distinct units. The basal unit is a siliceous, graptolitic, laminated, deeper-water limestone. The middle unit is composed of a shallow-shelf sequence of thin, bioturbated, micritic carbonates, interbedded with very thin layers of silt and shale. The upper unit is composed of thick-bedded, high-energy, fossiliferous, shallow-water grainstone facies.

Due to the characteristic high average resistivity electric log signature, the Viola is one of the easiest unit to recognize on electric-logs.

Sylvan Formation

The Ordovician Sylvan Formation is a readily identifiable shale characterized by low resistivity. Thickness of the Sylvan varies from 200 to 300 feet. In outcrop, the shale is not well exposed and is commonly expressed as a topographic valley. Where visible, the shale is dark greenish-gray in color. Fauna include graptolites and chitinozoans, reflective of deeper-water conditions. This relatively deep-water environment may indicate an increase in subsidence rate of the aulacogen during the Ordovician.

Hunton Group

The Hunton Group is reflective of sedimentation during the Late Ordovician, Silurian, and Early Devonian. Composed primarily of carbonates, this interval contains numerous unconformities and is extremely variable in thickness and content within the study area. Thickness ranges from approximately 400 feet to absent by erosion. Ham (1973) attributed variations in the Hunton to the position of isolated cratonic basins and to the effectiveness of the several unconformities rather than to localization within a through-going trough.

Woodford Formation

The boundary between the Hunton and the Woodford is marked by a widespread unconformity. The appearance of the Woodford shales and chert in the Devonian marks the end of carbonate-dominated deposition (Ham, 1978). In the outcrop, the shales are apple green to grey to black in color. In the Arbuckle Mountains, the Woodford is 350 to 400 feet in thickness. Both the shales and the cherts are siliceous and fissile. Silicified tree fragments have been found in the Woodford. Nodules of calcium phosphate may be found in the upper part of the sequence. The electric log signature of the Woodford is prominent and easy to recognize (fig. 16).

Mechanically, the beds are easily folded and contain many structures generated by bedding-plane slip. However, good exposures are not readily found.

Sycamore Formation

The Mississippian Sycamore Formation is a variable assemblage of fine-grained silty, massive limestones, interbedded with thin layers of dark shale (Ham, 1978). The contact with the underlying Woodford Formation is gradational as is its upper contact with the overlying Caney Shale.

Thicknesses range from 230 to 350 feet at the surface, to as little as 100 feet in the subsurface. The Sycamore is the uppermost formation in the section that forms a prominent topographic ridge in the Arbuckle Mountains.

Caney Formation

The Mississippian Caney Formation is a dark-gray, fissile shale that is poorly exposed in the Arbuckle Mountain region. Despite outcrop similarities to the overlying Springer shales, a prominent subsurface break in log signature does exist (fig. 16). The boundary between the two formations occurs as an abrupt widening of the "railroad track" pattern of spontaneous potential and resistivity of the Springer.

In southern Oklahoma the thickness of the Caney varies from 250 to 650 feet, though it seldom exceeds 300 feet in the study area.

Springer Group

The Springer Group is a thick (350 to 4,500 feet) accumulation of shales, which mark the advent of local basin subsidence. Lower sections are marked by the thick shales of the Goddard Formation of Late Mississsippian (Chesterian) age. The exact location of the Mississippian-Pennsylvanian boundary is, however, still a matter of debate. Upper sections of the Springer contain sand beds, which are often reservoirs for hydrocarbon accumulation (Ham, 1978).

Pennsylvanian Rocks

The Pennsylvanian section of southern Oklahoma is dominated by thick sequences of clastic material, which was shed into asymmetric basins separated by isolated uplifts. Deformation occurred in pulses, which folded and faulted the sediments during deposition. Four major groups, the Dornick Hills, Deese, Hoxbar, and Pontotoc were deposited, of these, the Pontotoc represents the major pulse of Arbuckle deformation. Because many of these sediments were sourced from isolated uplifts, their areal extent, composition, and geometry are quite varied.

Dornick Hills Group

Sediments from the upper Springer Group and Dornick Hills Group mark the onset of aulacogen deformation. Greater thicknesses of Dornick Hills were deposited on the northeast flank of the Criner Hills, with grain size decreasing away from the source. Dornick Hills sedimentation encompasses Morrowan, Atokan, and Lower Desmoinesian time during which shales, punctuated by locally thick conglomerates, sands, and limestones, were deposited into rapidly subsiding asymmetric basins (Tomlinson and McBee, 1959). Maximum thickness attained was approximately 3,000 feet near basin centers and sediment sources, however, thickness decreases rapidly towards structural highs.

Within the study area the typical log signature of the Dornick Hills Group showed variable sands and shales interbedded amongst thick shale sequences.

Deese Group

The Deese Group was sourced from uplifts generated during a Late Desmoinesian pulse of the Wichita orogeny. Comprised of thick shales with interbedded limestones, sands, and conglomerates, the Deese is restricted to basins and thins near uplifts. Maximum thickness attained is 6,000 feet, though it is generally less than 2,000 feet (Tomlinson and McBee, 1959). Due to the conglomeratic nature of Deese sedimentation, electric log response is highly variable.

Hoxbar Group

Sediments of the Hoxbar Group are Missourian in age and represent the early stages of the Arbuckle orogeny. The base of the Hoxbar is marked by the Confederate Limestone, though the formation is comprised primarily of shale with interbedded limestones and sand. The top of the Hoxbar is marked by an angular unconformity, produced by the major pulse of the Arbuckle orogeny. Maximum thickness is approximately 4,000 feet. In the study area, the Hoxbar is relatively thin and is not present over much of the study area (Tomlinson and McBee, 1959).

Pontotoc Group

The Pontotoc Group records Latest Pennsylvanian and Early Permian sedimentation, when thick conglomerates accumulated during the main pulse of the Arbuckle orogeny. The lower portion of the Pontotoc is represented by the Vanoss and Collings Ranch Conglomerates of Virgilian age. These formations outcrop along the north flank of the Arbuckle Anticline. Subsurface equivalents are often reported by the local driller's term "Eola conglomerate". Near the uplift, these conglomerates are composed of clasts of Arbuckle limestone. Electric-log response is very similar to that of the Arbuckle Group and it is often very difficult to distinguish between the two (fig. 16). Sandy and shaly facies have been encountered, and granite wash may be locally present. The upper portion of the Pontotoc is dominated by red beds. Thickness of the Pontotoc is much greater north of the Arbuckle Mountains, reflecting the vergence of motion of the Arbuckle Uplift.

In outcrop, the Collings Ranch Conglomerate is folded and faulted due to contemporaneous deposition and structural activity.

Permian Sediments

Permian redbeds constitute the surface exposures that cover the northwestern portion of the Arbuckle Uplift. Thickness is generally less than 3,000 feet. These sediments post-date regional deformation, burying, or partially covering, the major uplifts from which they were derived.

STRUCTURAL ANALYSIS

Introduction

The Arbuckle Uplift is a series of northeast-vergent fault-bend and fault-propagation folds, formed in the Late Pennsylvanian by dip-slip movement of the hanging wall of the Arbuckle Thrust. A period of extension followed, in which normal faulting reactivated basement thrust ramps, leaving behind collapsed basement-cored blocks. Deformation mechanisms include bedding-plane slip, parallel folding, out-of-the-syncline crowding, ramping, and fault-to-fold interchanges. These features are best explained by northeast-southwest directed regional horizontal compression.

This section begins with a description of structural style observed in outcrop and then proceeds to describe a series of true-scale northeast-southwest cross sections and accompanying seismic lines. Explanation of geometrical constraints and important features is given. Discussion of a subcrop map and a structural contour map of the Arbuckle Thrust then follows. A synthesis of structural interpretation is presented, and lastly, regional significance is addressed.

Surface Structural Analysis

The purpose of this section is to first describe the style(s) of deformation observed in outcrop and then to describe individual faults and structures, with emphasis on their relationships and geometries.

Structural Style

Structural style is scale independent; observations of a pervasive structural style or styles and timing of deformation at the outcrop level can and must be extrapolated to oil-field and regional scale interpretations.

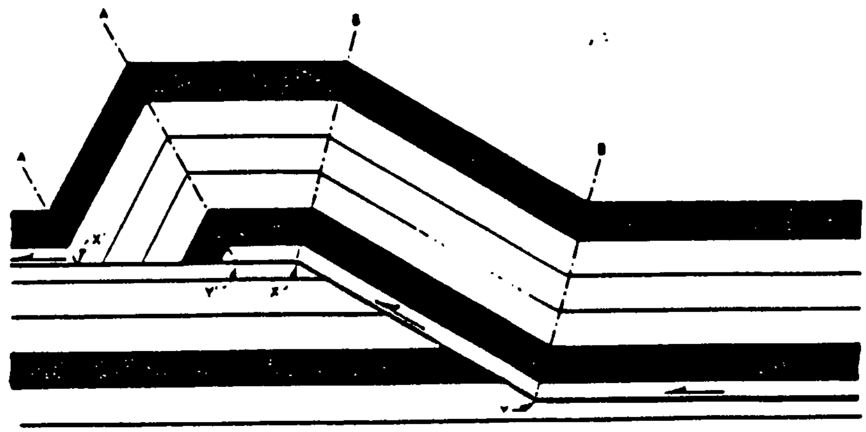
Interstate-35 provides a continuous roadcut across the Arbuckle Uplift. Here it is possible to correlate outcrop patterns with direct cross-sectional profiles. The added third dimension is useful as a starting point in determining outcrop relationships, as they are, at times, obscured by planar erosion, highly-weathered outcrop, low-angle faulting, great thicknesses of similar facies, and overprinting of structural styles. The third dimension is especially helpful when mapping sections of similar facies (Arbuckle Group) which have been complexly deformed.

The deformational style consists of dominant parallel folding by bedding-planer slip along layer parallel shear with layer-parallel shortening. Most small-scale and large-scale structures are the result of northeast-vergent thrusting, with back-thrusts also present. Features observed include low-angle thrusting, parallel folding, fault-bend folds, fault-propagation folding (fig. 17), out-of-the-syncline thrusting, cross-crestal structures, back-limb structures, and rabbit-ear structures (fig. 18). These structures are dominantly northeast-vergent, asymmetrical, with local overturning of the steep flank. The intense compressional style is overprinted by a much less severe extensional normal faulting.

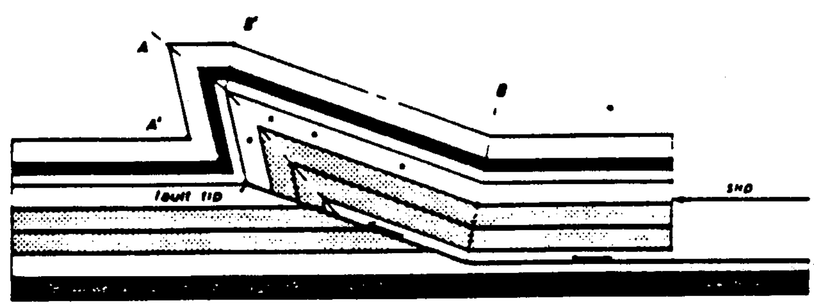
Style of folding and internal deformation are also partially dependent upon stratigraphy. Thick carbonates of the Arbuckle Group and older formations form broad folds, with significant pervasive small-scale folding and faulting not readily seen on large-scale maps (fig. 19). Features of internal shortening include fault-bend and fault-propagation folds (some of which are tight), detachments, tectonic stylolites, and pervasive fractures. Many of these features are overprinted by numerous small-scale normal faults.

Above the Arbuckle Group, the lithology becomes more varied, with a notable increase in shales. At this stratigraphic level, detachments commonly sole out in shales. Subsidiary structures, such as the Spring Creek and Woodford Anticlines, form from low-angle thrusts and detachments (fig. 20).

Several lineations, that were mapped by Ham (1954) as faults display little or no offset, and are actually fractures which form prominent lineations on aerial photographs where solution has taken place. Several of Ham's "fault" lines were drawn to link various separate lineations and faults. Thus some of the "faults" on Ham's map show little and often contradictory displacement. This is



(A)



(B)

Figure 17. Anticlines formed by A) fault-bend and B) fault propagation folding. A) Thrust sheet is translated over a stair-step bend (ramp) in a fault onto the upper bedding-plane thrust (flat). B) fault terminates at tip and slip decreases progressively forward along fault with shortening accomodated by folding (modified from Namson and Davis, 1988).

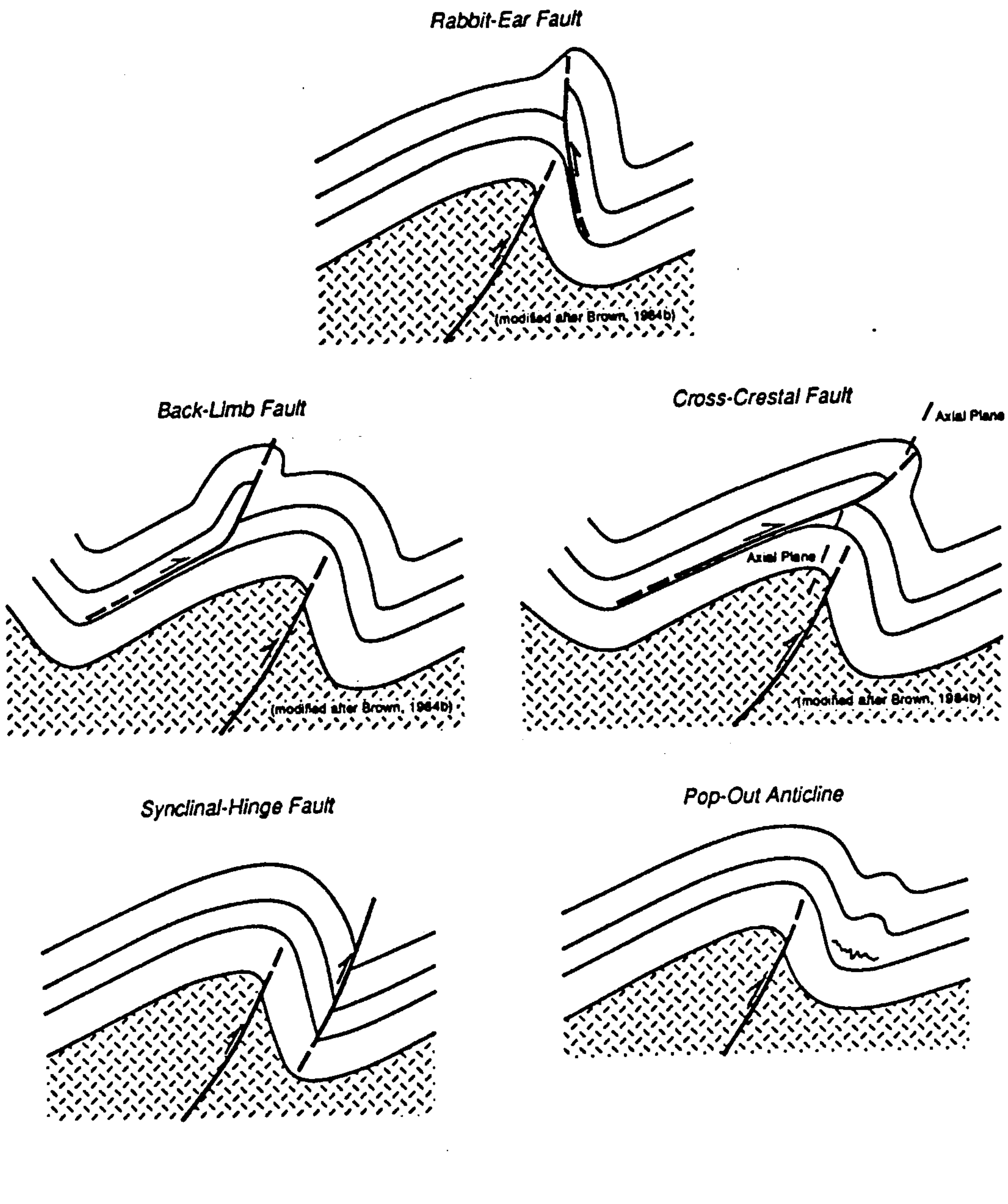


Figure 18. Diagramatic representation of subsidiary structures formed within the study area and other areas of compressional deformation (from Willis, 1993).

Figure 19. Panorama photograph of typical outcrop exposure within the Arbuckle Group displaying internal shortening along low-angle, northeast-vergent thrusts, and parallel folding. These photos were taken along one of the rare gullies. Where the vertical dimension due to topography is lacking it is difficult to see how pervasive is the internal deformation.

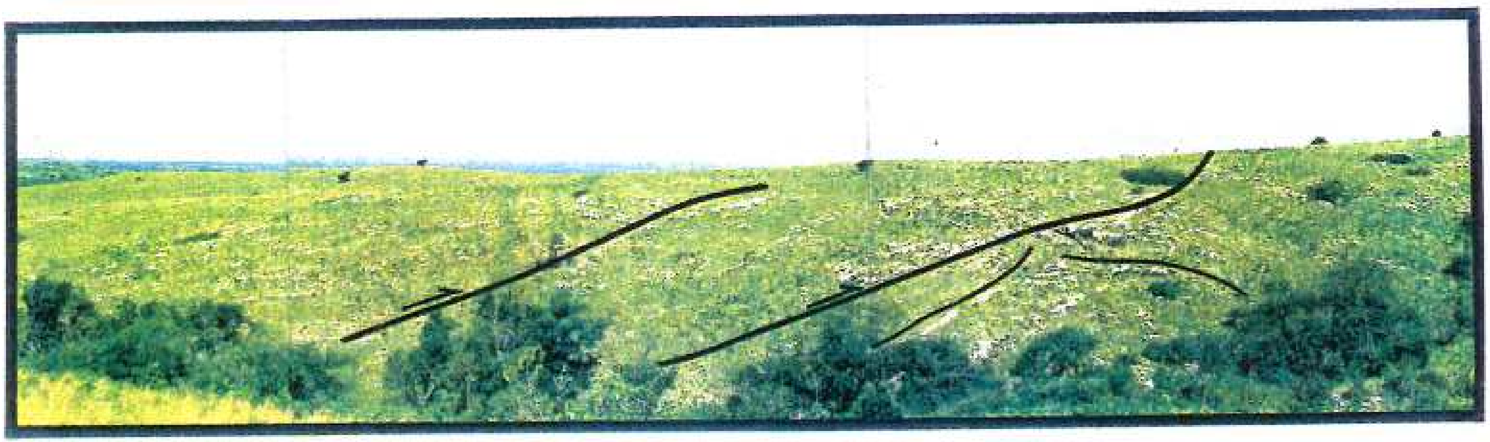


Figure 20. Photograph of a quarry exposure of the Woodford Formation on the Woodford Anticline. Incipient triangle zone is consistent with parallel folding and layer-parallel shear of the sedimentary cover.

especially true of northeast-trending "faults" that run adjacent to the Woodford and Spring Creek Anticlines. These "faults" show alternate reverse and normal sense of offset along the same trace. These apparent relationships may have influenced some workers to interpret these "faults" as evidence for strike-slip deformation. However, field-checking shows no fault continuity along these lineations.

Down-plunge viewing (fig. 21) reveals that these local anticlines were formed by back-limb thrusts (fig. 18) on the Arbuckle Anticline. The Woodford Anticline displays ramp-and flat geometry with detachments in the shales of the upper Simpson. Parallel deformation, bedding-plane slip, low-angle faulting, triangle zones and other compressional features consistent with low-angle thrusting were found in the Woodford Formation on the Spring Creek Anticline.

Elsewhere on the Arbuckle Anticline, several small-scale unnamed faults mapped by Ham have been found to be nonexistent, but coincide with axial surfaces indicating a change in dip panels (dip domain boundaries). Structural style is further addressed in the discussion of individual structures of the exposed Arbuckle Uplift.

Surface Geology of the Arbuckle Uplift

The northwestern exposure of the Arbuckle Uplift is comprised of three imbricate thrust sheets carried on the upper plate of the Arbuckle Thrust. Though previously recognized as formed by reverse

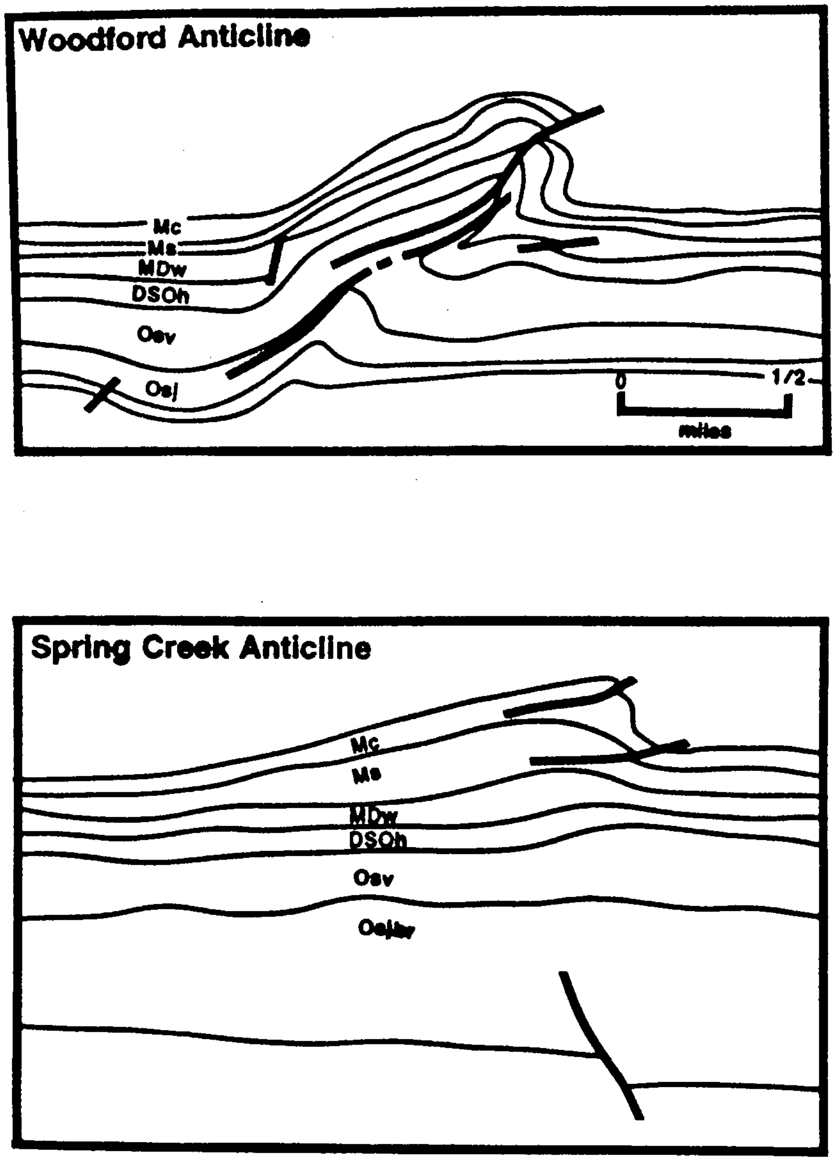


Figure 21. Down-plunge (south) views of the Woodford and Spring Creek Anticlines. These anticlines are formed from back-limb thrusting on the Arbuckle Anticline and display fault-bend and fault-propagation fold geometries.

faults, several of these sheets have not been formally named. Here they are referred to as the SE Hoover sheet, Garrison Creek sheet, and the previously named Arbuckle Anticline. Imbricate fault splays separate the individual sheets, each of which differs in exposed stratigraphy and style of deformation (fig. 1 and fig. 22).

The northeasternmost sheet is the SE Hoover sheet which includes the tightly folded area of Pickens, Lick Creek, and Colbert Creek Anticlines. This thrust sheet is located on the hanging wall of the Arbuckle Thrust near its leading edge. Structural style is characterized by tight folds, pervasive thrusts, and detachments. This style of deformation, in combination with excellent reservoir rocks, has led to the trapping of hydrocarbons that have been exploited at SE Hoover Field.

The Garrison Creek Thrust separates the SE Hoover sheet from the Garrison Creek Anticline. Surface stratigraphy of the Garrison Creek Anticline consists of Arbuckle Group carbonates. The anticline plunges N60°W at 12°, forming the surface expression of the second thrust sheet. Abundant well control shows that the Garrison Creek sheet is distinguished from the SE Hoover sheet by its broad folding and basement involvement. Beck (1987) interpreted the Garrison Creek Anticline as a rabbit-ear structure subsidiary to a broader fold in the subsurface (fig. 8).

The third thrust sheet is comprised of the Arbuckle Anticline and subsidiary structures. It is bounded to the northeast by the Washita Valley Fault and to the south and west by onlapping post orogenic sediments. The Arbuckle Anticline is a northeast-vergent basement-cored uplift displaying predominantly parallel folding and low-angle thrusting.

The Arbuckle Anticline contains prominent sets of fractures and several faults (Washburn Ranch Fault, Chapman Ranch Thrust, Joins Ranch Thrust, and other unnamed faults), most of which are northeast-vergent thrusts. Mapping in this study has arrived at a different interpretation regarding the number of, location, and sense of offset for many fractures and faults on the Arbuckle Anticline presented by previous workers (Ham, 1954). The significance of these interpretations are discussed later.

The Washburn Ranch Fault is the largest normal fault of the area. It has a surface trace oriented approximately N80°E. To the west, the fault is covered by onlapping conglomerate. The Washburn Ranch Fault truncates northwest-trending faults and folds, indicating that movement along it occurred subsequent to regional compression. Map patterns suggest left-separation of three miles. This sense of offset may be explained by oblique, down-to-the-south normal dip slip of the plunging fold.

Relationship of the Reagan Fault to the Arbuckle Anticline

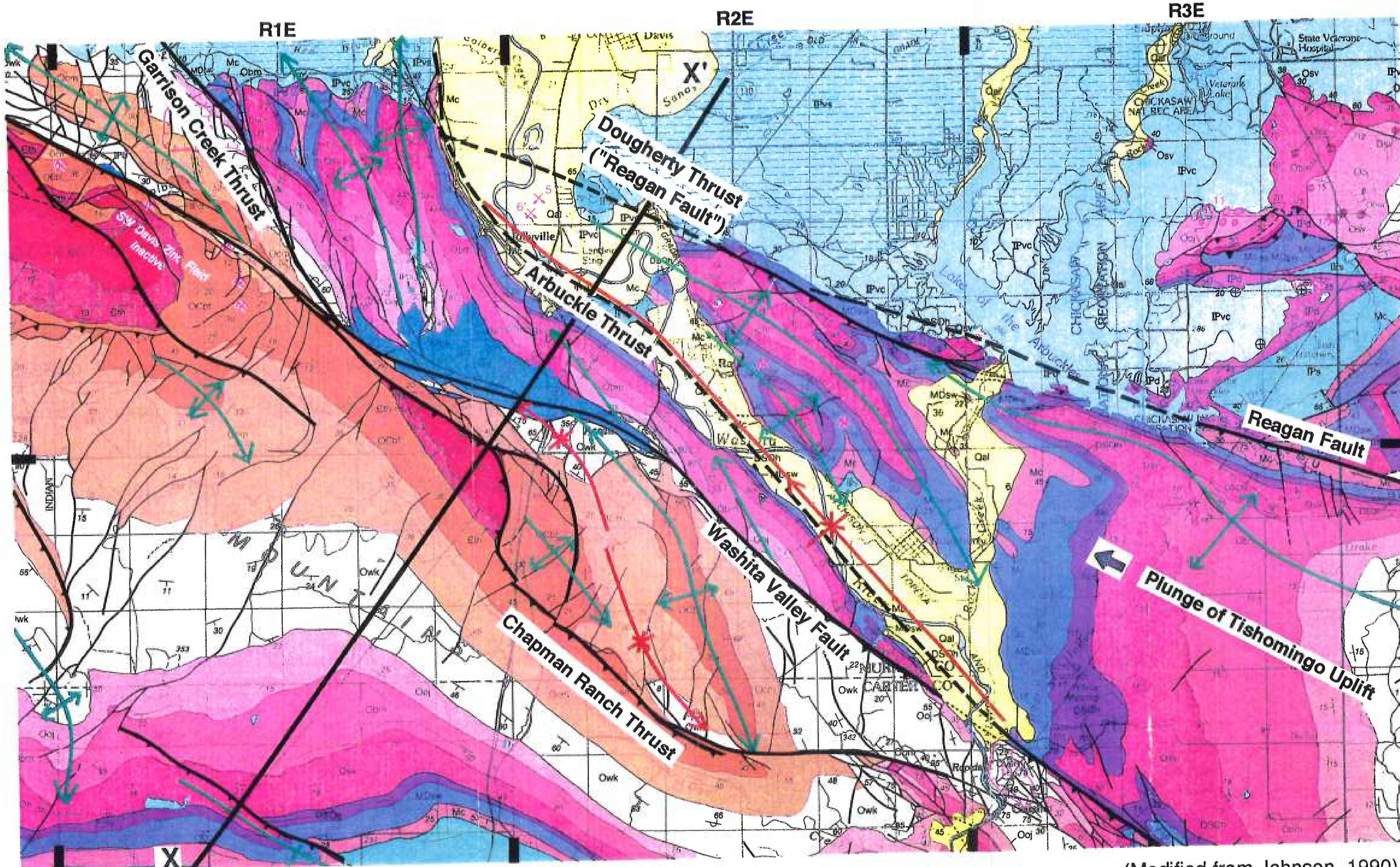
Though not in the main study area, this subject is addressed here because of the historical tendency of some workers to project the Reagan Fault across the study area into the Anadarko Basin (Harlton, 1964; Haas, 1979; Brownlee, 1979; McCaskill, 1993).

The Reagan Fault is a north-vergent reverse fault that defines the northern boundary of the basement-cored Tishomingo Uplift (fig. 22). The Reagan Fault is well exposed on the eastern portion of the Tishomingo Uplift, which is a broad open fold for most of its exposure. As the Tishomingo Uplift plunges to the west, structural style changes and a series of tight folds develop from detachments in the Simpson and higher stratigraphic section.

To the west, near the area of Dougherty Anticline, the Reagan Fault is covered by synorogenic sediments and river alluvium. Harlton (1964) shows the Reagan Fault as continuing westward underneath the Washita River supposedly forming the blind leading edge of the SE Hoover Field. This interpretation is called into question by analysis of well data, outcrop patterns, and down-plunge viewing which show that the Reagan Fault loses displacement as the Tishomingo Uplift plunges to the west, with both the Tishomingo Uplift and the Reagan Fault passing underneath the Arbuckle Anticline (fig. 22 and fig. 23) and possibly dying out in the footwall to the Arbuckle Thrust. East of Dougherty Anticline, the Reagan Fault disappears underneath younger sediments. West of Dougherty Anticline, a fault along the same general strike as the Reagan Fault is exposed at the surface. This fault, traditionally mapped as the Reagan Fault, may in fact be a separate fault, here named the "Dougherty Thrust." The Dougherty Thrust is a NE vergent out-of-the-syncline fault which occurs in the hanging wall above the true, burried Reagan Fault.

Regardless of whether the fault in question is the Reagan Fault (Harlton, 1964) or the Dougherty Thrust, as interpreted by this

Figure 22. Geologic map showing the northwest plunge of the Tishomingo Uplift. The Arbuckle Thrust cuts across the northwest-plunging Tishomingo Uplift at an acute angle with plunge allowing the Tishomingo Uplift to plunge beneath the Arbuckle Thrust and Arbuckle Anticline. Although previously interpreted as the same fault, the Reagan Fault and Dougherty Thrust are different faults. A prominent rabbit-ear is formed along with a general increase in detached subsidiary structures as the Tishimingo Uplift plunges west. On the Arbuckle Anticline note the lateral ramp and long flat within the Chapman Ranch Thrust when viewed NE to SW along cross section line (modified from Johnson, 1990).



(Modified from Johnson, 1990)

author, it is clear from well control that immediately east of the Washita River, the fault in question displays little offset (less than 1,000 feet) and dips at nearly 45 degrees to the southwest. Immediately west of the Washita River, wells in the Southeast Hoover Field penetrate a thrust (Arbuckle Thrust) which dips 30 to 35 degrees to the southwest and shows several *miles* of offset (fig. 8). Figure 24 compares differences in the amount of overhang of Caney and older rocks over Springer and younger rocks between the Dougherty Thrust (east of Washita River) and the Arbuckle Thrust (west of the Washita River). Blue dots represent wells which have definitely encountered a reverse fault and overhang. Green dots represent an apparent "normal" section. Because some of the wells encountering "normal" section may be encountering the Dougherty Thrust where Springer shales are duplicated (nearly impossible to identify the fault zone), the offset of pre-Springer rocks was used to delineate the trace of the Dougherty Thrust in the subsurface. Note that the well control and surface hanging wall anticline show the Dougherty Thrust to continue westward under the alluvium of the Washita River (fig. 22) rather than turning northward to become the northern boundary of the Southeast Hoover area as interpreted by previous workers (Harlton, 1964; Haas, 1979; and McCaskill, 1993). The extreme differences in overhang, shortening, structural style, fault dip, and plunge of hanging wall structures between the Dougherty Thrust and the Arbuckle Thrust clearly indicate that these are *not* the same fault. Interpretations which show the Reagan Fault as extending into the Eola region are incompatible with both surface and subsurface data.

Figure 23. Southwest-northeast cross section (X-X') illustrating the relationship of the Arbuckle Uplift to the plunging Tishomingo Uplift. Numbered vertical lines are well control.

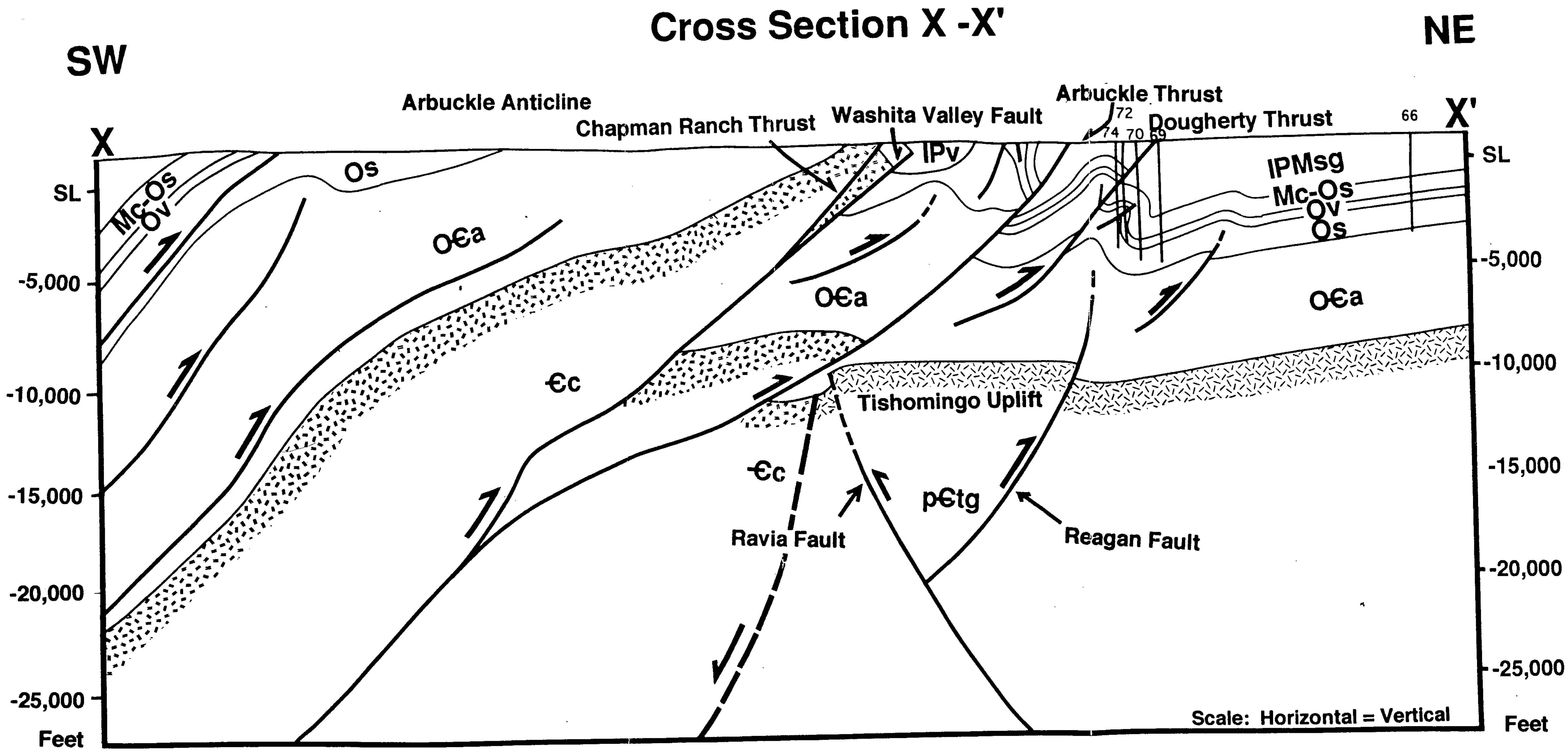
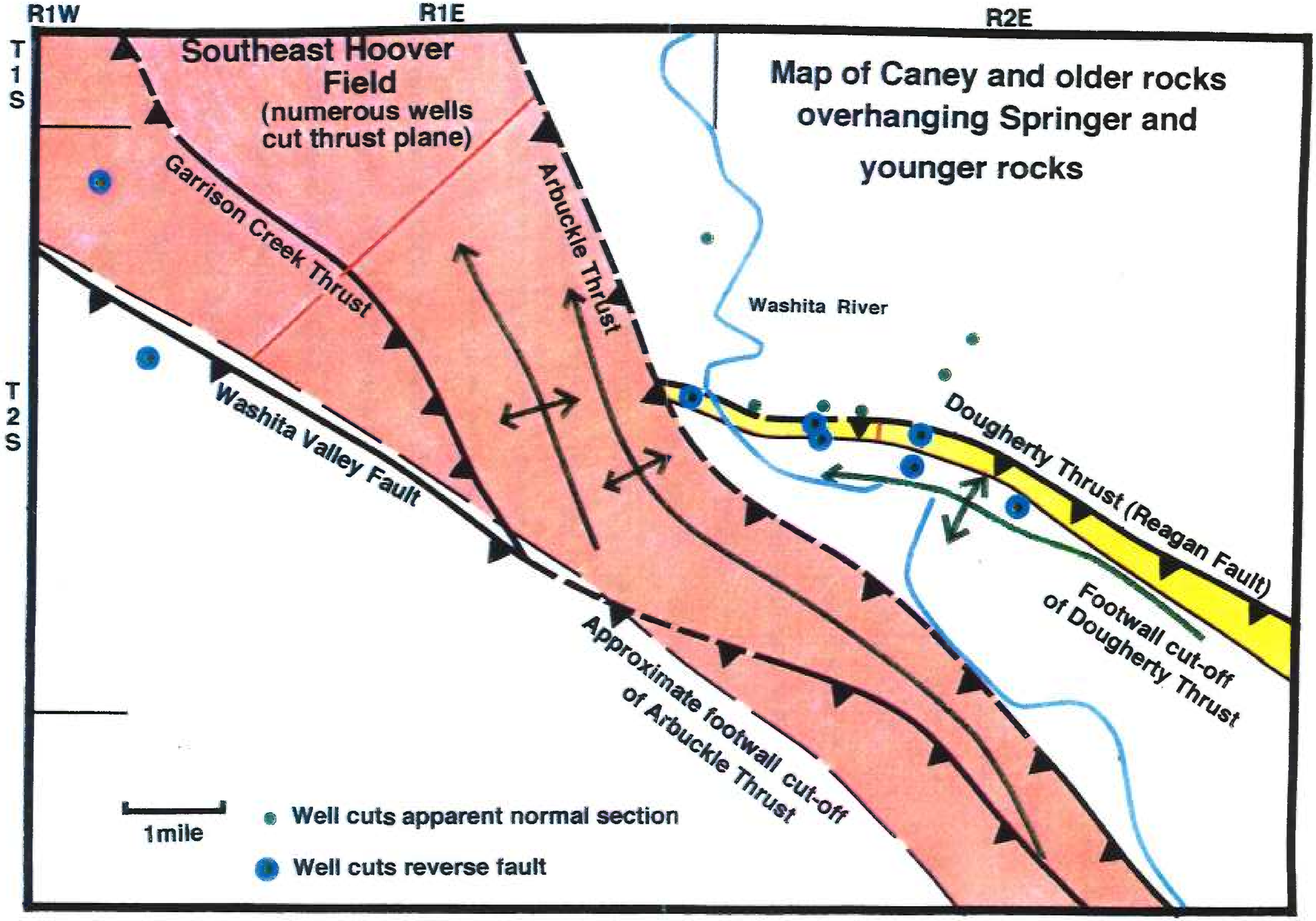

Cross Section X -X'
SW
NE
X
X'
Arbuckle Anticline
Chapman Ranch Thrust
Washita Valley Fault
Arbuckle Thrust
Dougherty Thrust
72
74
70
69
66
SL
-5,000
-10,000
-15,000
-20,000
-25,000
Feet
Mc-Os
Ov
Os
O€a
€c
IPv
IPMsg
Tishomingo Uplift
p€tg
Ravia Fault
Reagan Fault
Scale: Horizontal = Vertical

Figure 24. Map illustrating the difference in overhang between the Arbuckle Thrust and the Dougherty Thrust. Overhang of pre-Springer rocks over Springer rocks is shown on the Dougherty Thrust (shaded tan). Blue dots indicate wells which have definitely cut a reverse fault. Green wells encounter an apparent normal section, though some may also encounter a reverse fault which duplicates Springer shales. For this reason, overhang of pre-Springer rocks was used to constrain the Dougherty Thrust.


R1W
R1E
R2E
T 1 S
T 2 S
Southeast Hoover Field
(numerous wells cut thrust plane)
Map of Caney and older rocks overhanging Springer and younger rocks
Garrison Creek Thrust
Arbuckle Thrust
Washita River
Washita Valley Fault
Dougherty Thrust (Reagan Fault)
Footwall cut-off of Dougherty Thrust
Approximate footwall cut-off of Arbuckle Thrust
1mile
Well cuts apparent normal section
Well cuts reverse fault

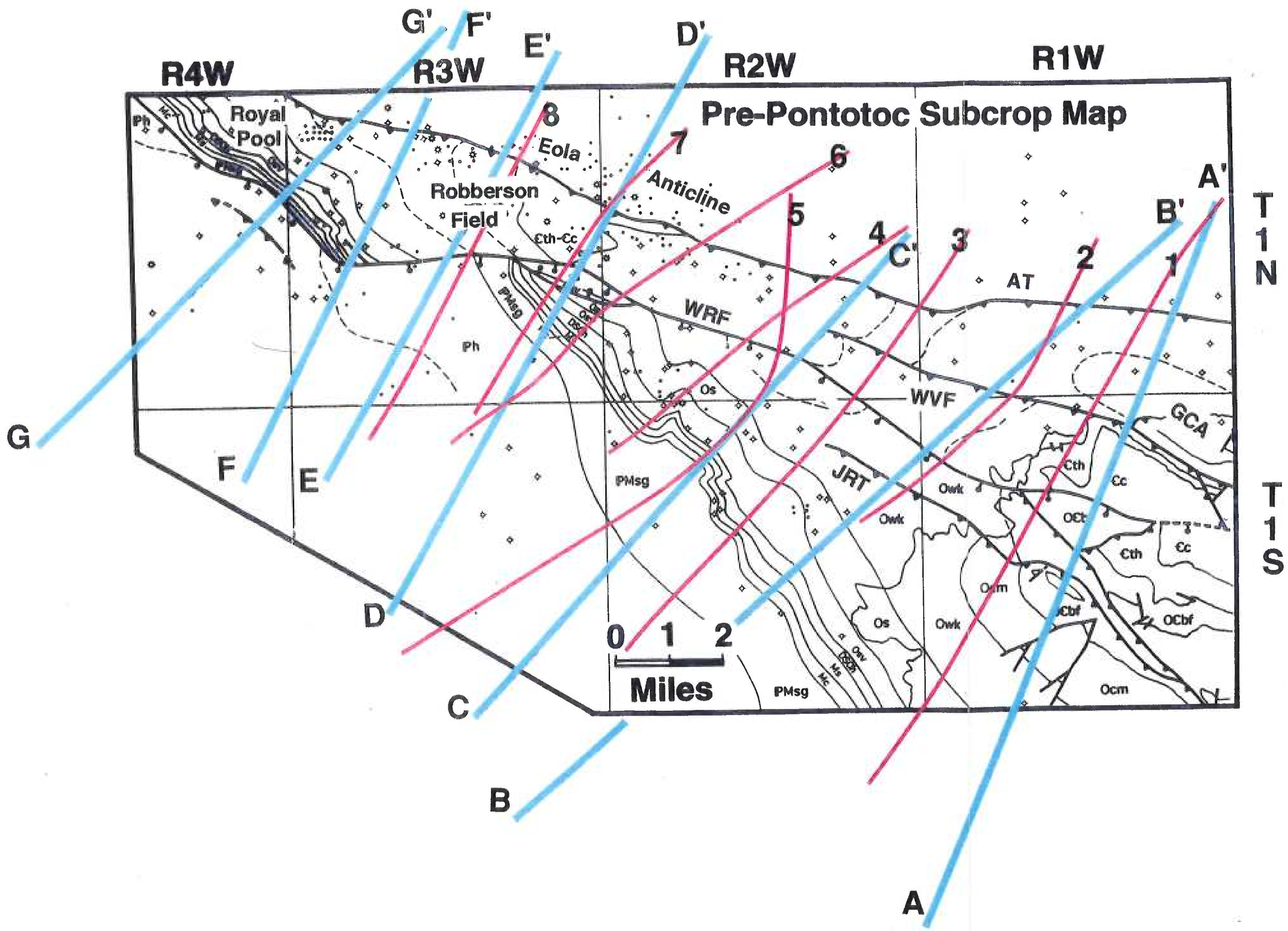
Subsurface Structural Analysis

Across most of the study area, the Arbuckle Uplift continues as a subsurface feature. Many economically important oil fields, including Eola, Robberson, and Royal Pool, produce from the uplift or from structures or sediments associated with the uplift. As a result of prolific hydrocarbon exploration, numerous well logs and seismic lines were available to assist in the subsurface analysis.

This subsurface analysis of the Arbuckle Uplift is based upon seven true-scale cross sections drawn perpendicular to the B-axis of the plunging uplift (fig. 25). Cross sections were based on wells directly on the line of section, or projected into the section. Bed lengths, cut-off angles as well as fault-displacements were closely maintained. No bottom-hole locations were available, and as a result, all wells were represented as vertical boreholes. Due to steep dips, deep wells in the Eola area may have deviated from true vertical, however, because of lack of deviation data, no deviation from true vertical is shown. Structures deeper than the top of the "basement" (footwall level) are highly speculative due to lack of control and are depicted with dashed lines.

Eight seismic dip lines covering the eastern and middle portion of the study area were interpreted in this study (fig. 25). The seismic lines were compared with cross sections based upon well control, and used as a general guide for structural analysis. The

Figure 25. Map showing the location of cross sections (A-G) used in this study. Seismic lines (1-8) are located only approximately to honor request of company supplying seismic lines. Further explanation of the subcrop map is given in figure 39.



Pre-Pontotoc Subcrop Map
R4W
R3W
R2W
R1W
T 1 N
T 1 S
Royal Pool
Eola
Anticline
Robberson Field
WRF
WVF
JRT
GCA
AT
Miles
0 1 2
A
A'
B
B'
C
C'
D
D'
E
E'
F
F'
G
G'
1
2
3
4
5
6
7
8

lines were first computer scanned and foreshortened to approximate a 1:1 scale in order to better represent true structural geometry. The seismic lines were of better quality on the eastern side of the study area where dips were relatively shallow.

Cross sections and seismic lines were constructed and are here analyzed from east to west to enable projection of surface data into the subsurface cross sections in a systematic manner. In order to illustrate fault relationships, the cross sections were tied together with a surface and subcrop map created beneath the pre-Pontotoc unconformity.

Cross Section A - A' and Seismic Line 1

Cross section A-A' (fig. 26) is located on the western end of the exposed Arbuckle Mountains, crossing surface exposure of the Arbuckle and Garrison Creek Anticlines. This line of section is based upon surface data, well control, and seismic line 1 (fig. 27) which is located just to the west, also traversing the exposed uplift. The general structural style is a basement-cored fault-bend fold with complications due to frontal imbrications, late-stage normal faulting, and subsidiary structures. The uplift is formed within the upper plate of the Arbuckle Thrust, which remains burried beneath synorogenic Vanoss (Pontotoc) Conglomerate. The Arbuckle Thrust forms a flat (less than 10° to the southwest) deep in the Ardmore Basin and then steps up to the northeast (ramp dips 50° to the southwest) through the Cambrian-Ordovician section. In the Springer Group, the dip becomes relatively shallow (25°) to the

Figure 26. Cross section A - A'. The Arbuckle Anticline forms a broad fault-bend fold as the hanging wall translates up the steep basement ramp onto the less steeply dipping ramp in the Paleozoic section. WVF = Washita Valley Fault. AT = Arbuckle Thrust. WRF = Washburn Ranch Fault. F1 = Fault 1. SCT = Squirrel Creek Thrust.

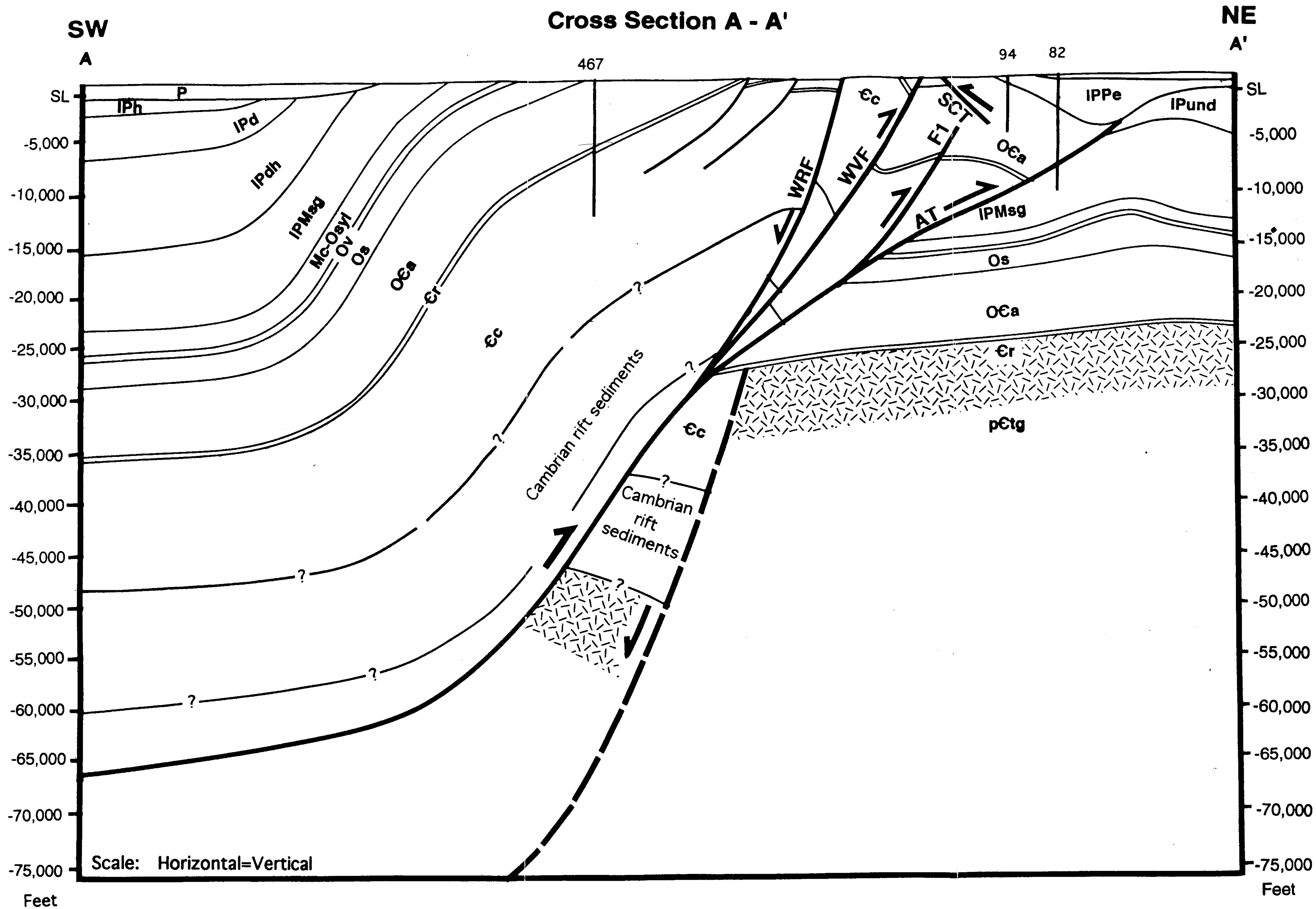
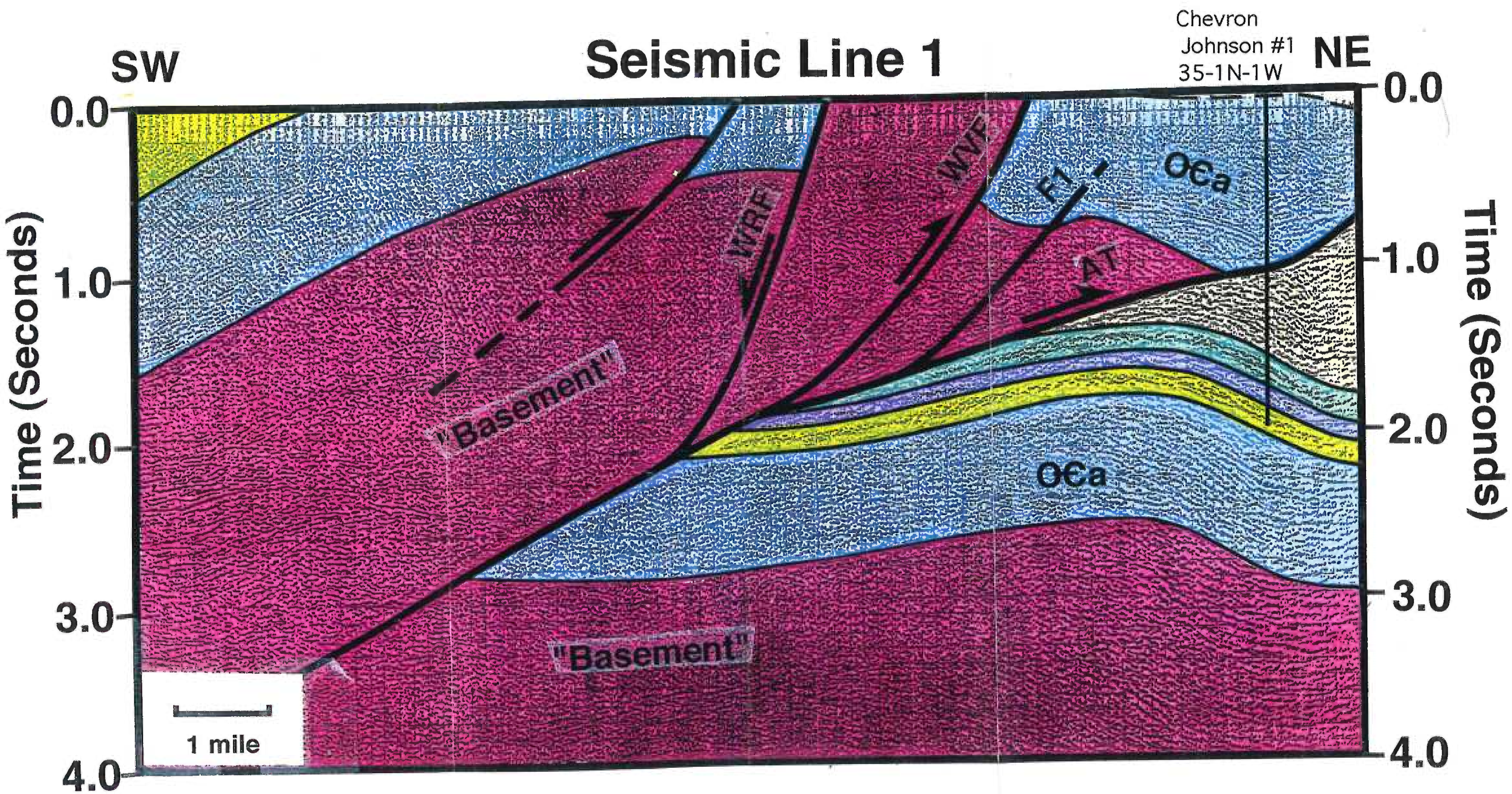

SW
A
Cross Section A - A'
NE
A'
467
94
82
SL
-5,000
-10,000
-15,000
-20,000
-25,000
-30,000
-35,000
-40,000
-45,000
-50,000
-55,000
-60,000
-65,000
-70,000
-75,000
Feet
IPh
P
IPd
IPdh
IPMsg
Mc-Osyl
Ov
Os
O€a
€r
€c
Cambrian rift sediments
€c
Cambrian rift sediments
WRF
WVF
F1
SCT
AT
IPPe
IPund
O€a
IPMsg
Os
O€a
€r
p€tg
Scale: Horizontal=Vertical

Figure 27. Interpreted seismic time profile 1 showing geometry of the Arbuckle Anticline at its western outcrop limit. The Arbuckle Thrust reflector dips beneath the surface location of the Washita Valley Fault. Data provided by PGI through Texaco; interpretation is the author's. AT = Arbuckle Thrust, WRF = Washburn Ranch Fault, WVF = Washita Valley Fault, JRT = Joins Ranch Thrust, SCT = Squirrel Creek Thrust, F1 = Fault 1.



Seismic Line 1
SW
NE
Chevron
Johnson #1
35-1N-1W
0.0
1.0
2.0
3.0
4.0
Time (Seconds)
"Basement"
WRF
WVF
F1
AT
OЄa
OЄa
"Basement"
1 mile

SW. Displacement, as measured by basement offset (dip separation), is approximately 39,000 feet.

The Washita Valley Fault is a back-limb imbricate of the Arbuckle Thrust which, in outcrop, places Lower Arbuckle Group against Lower Simpson Group. Displacement is minor compared to that of the Arbuckle Thrust. Analysis of seismic line 1 (fig. 27) precludes an interpretation that the Washita Valley Fault is a vertical, deep crustal strike-slip fault. The location of the Washita Valley Fault is constrained by outcrop exposure and is underlain by the clear, continuous, unbroken seimic reflector of the Arbuckle Thrust. Owing to its steep dip and displacement of rhyolite against rhyolite, the Washita Valley Fault generates no strong reflector. Instead, its location is delineated from changes in reflector dip panels and reflector characterization.

Footwall deformation consists of an asymmetric anticline which increases in amplitude in the Springer and Pennsylvanian sections. The anticline is formed from folds above detachments which may be an effect of the footwall anticline plunging out from the northwest. Seismic line 1 shows a broad arching of the footwall which is interpreted as a velocity pull-up.

The hanging wall is broken by late-stage normal dip slip motion of the Washburn Ranch Fault which links with the basement ramp of the Arbuckle Thrust to create a listric extensional plane. Projected displacement in this section is estimated at 2,000 feet.

Seismic Line 2

Seismic line 2 (fig. 28) is a non-migrated time section located west of seismic line 1, and is shot across Permian sediments which outcrop northwest and down plunge plunge of A-A'. Again, the Arbuckle Thrust generates a strong, well-defined reflector with low dip. Fault-bend fold geometry is well illustrated, though displacement of the Arbuckle Thrust and Washita Valley Fault has decreased westward from cross section A-A' and seismic line 1. Frontal imbricate fault F1 is no longer present, having lost displacement and died out from the east. Extensional offset of reflectors is now visible along the Washburn Ranch Fault.

Apparent highs in the footwall are due to velocity pull-ups. Though there is abundant well control along this seismic line, penetration of the footwall is not typically deep enough to determine the extent of footwall deformation. The depth of the Arbuckle Thrust is controlled by a sonic log from the Taylor Morrow #1 well in section 32 of T. 1 N., R. 1 W. The fault-bounded area along the ramp of the Arbuckle Thrust is interpreted to be a horse, possibly containing basement rock.

Cross Section B - B'

Cross section B - B' (fig. 29) is the first line constructed west of the edge of the Permian overlap along the northwest plunge of the Arbuckle Uplift. The Arbuckle Thrust forms a flat and ramp that

Figure 28. Interpreted unmigrated seismic time line 2 immediately west of the outcropping Arbuckle Anticline. Data provided by PGI through Texaco; interpretation is the author's.

Seismic Line 2

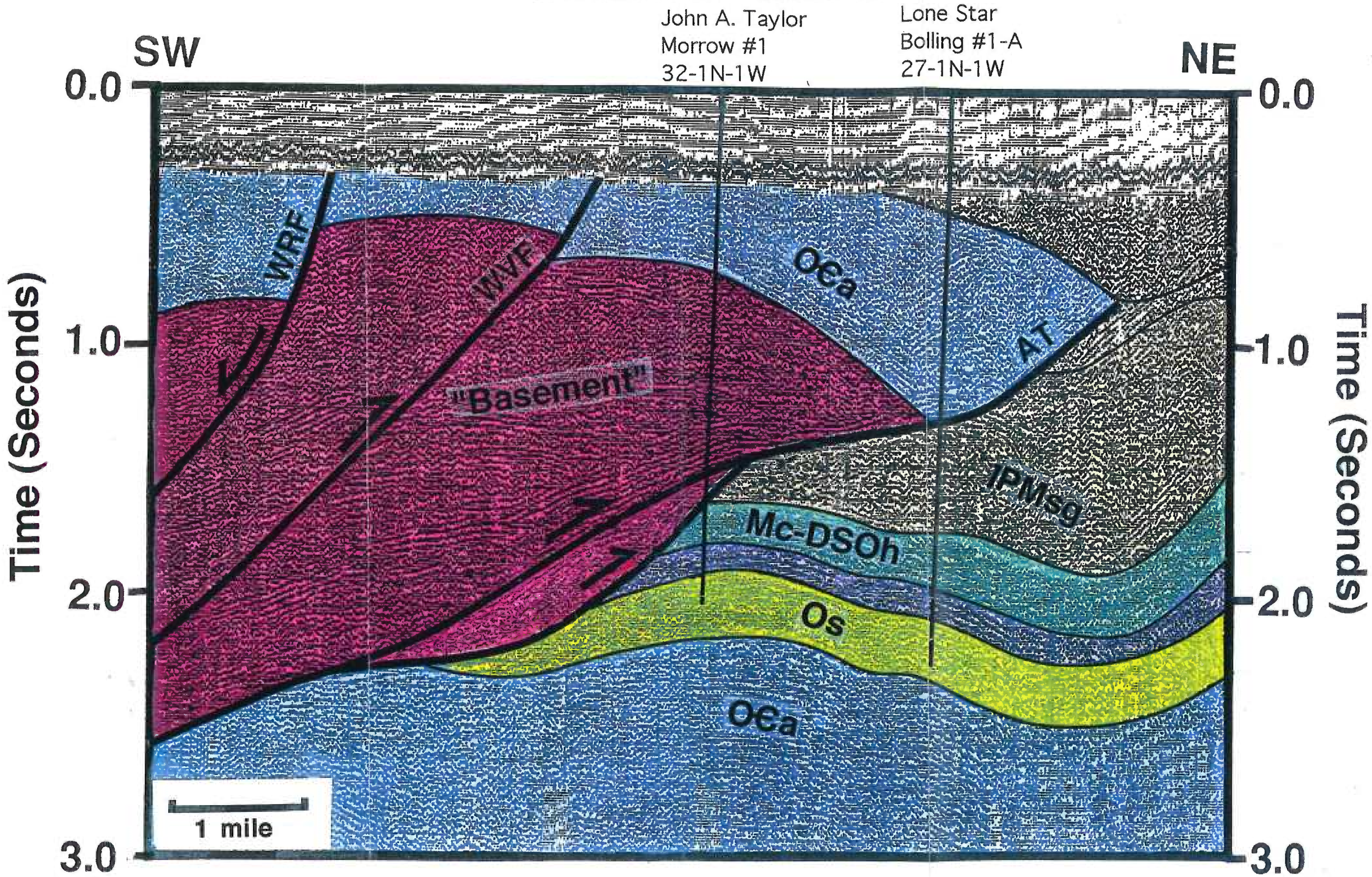
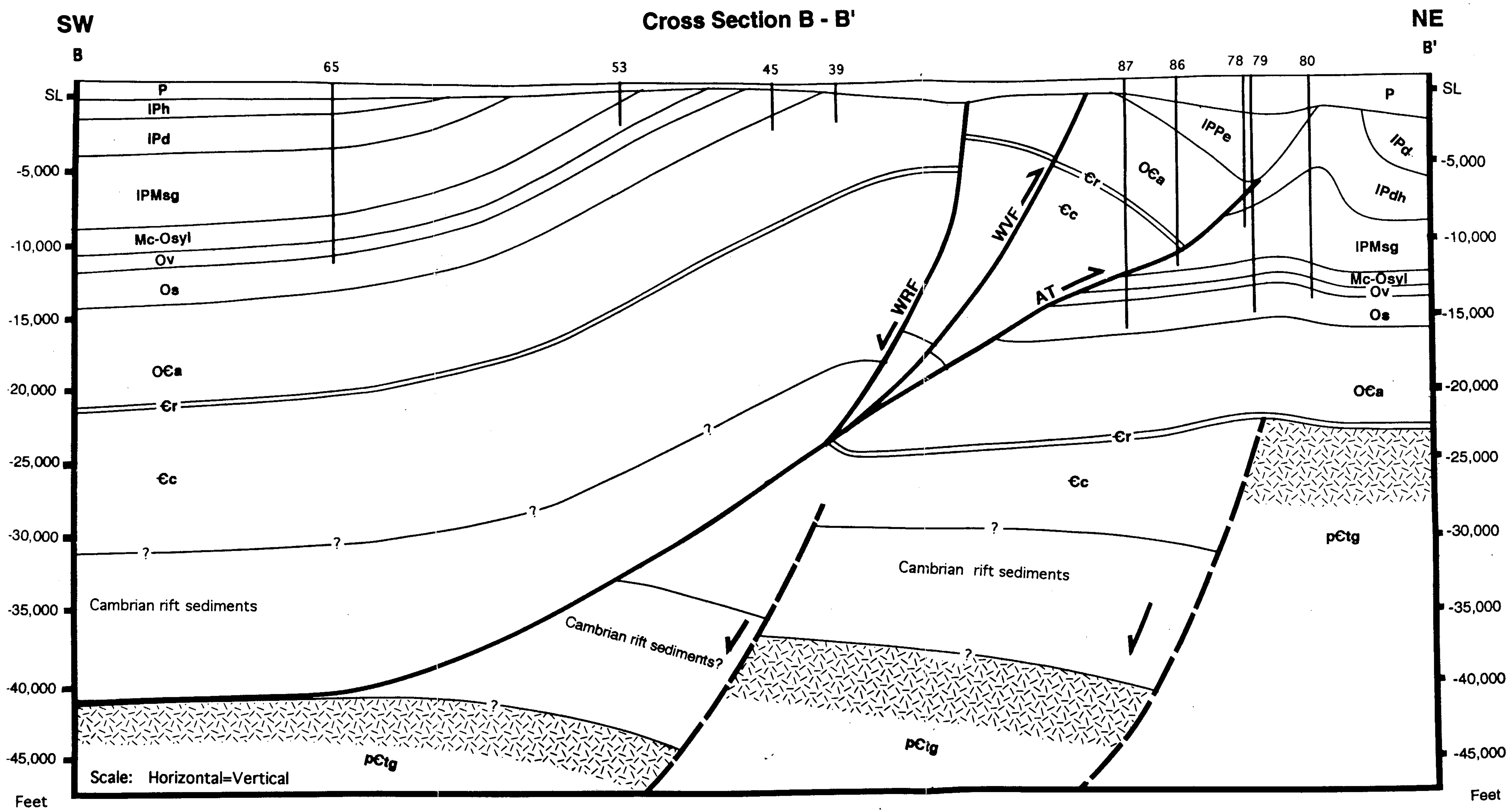


Figure 29. Southwest-northeast cross section B - B'. The hanging wall forms a "snakehead" anticline. The high amplitude fold in Pennsylvanian beds in the footwall is separated from a more open style of folding in pre-Pennsylvanian beds by detachments.


SW
B
Cross Section B - B'
NE
B'
65
53
45
39
87
86
78 79
80
SL
-5,000
-10,000
-15,000
-20,000
-25,000
-30,000
-35,000
-40,000
-45,000
Feet
P
IPh
IPd
IPMsg
Mc-Osyl
Ov
Os
O€a
€r
€c
Cambrian rift sediments
Cambrian rift sediments?
p€tg
WRF
WVF
AT
IPPe
IPd
IPdh
Scale: Horizontal=Vertical

brings the hanging wall up to form a "snakehead" anticline. Basement offset, is 27,000 feet. Geometry of the frontal portion of the uplift and Arbuckle Thrust is interpreted from several wells that penetrate the thrust. The hanging-wall anticline is offset by the Washita Valley Fault, which has almost died out, and by the Washburn Ranch Fault, which has 2,000 feet of normal separation, down to the south.

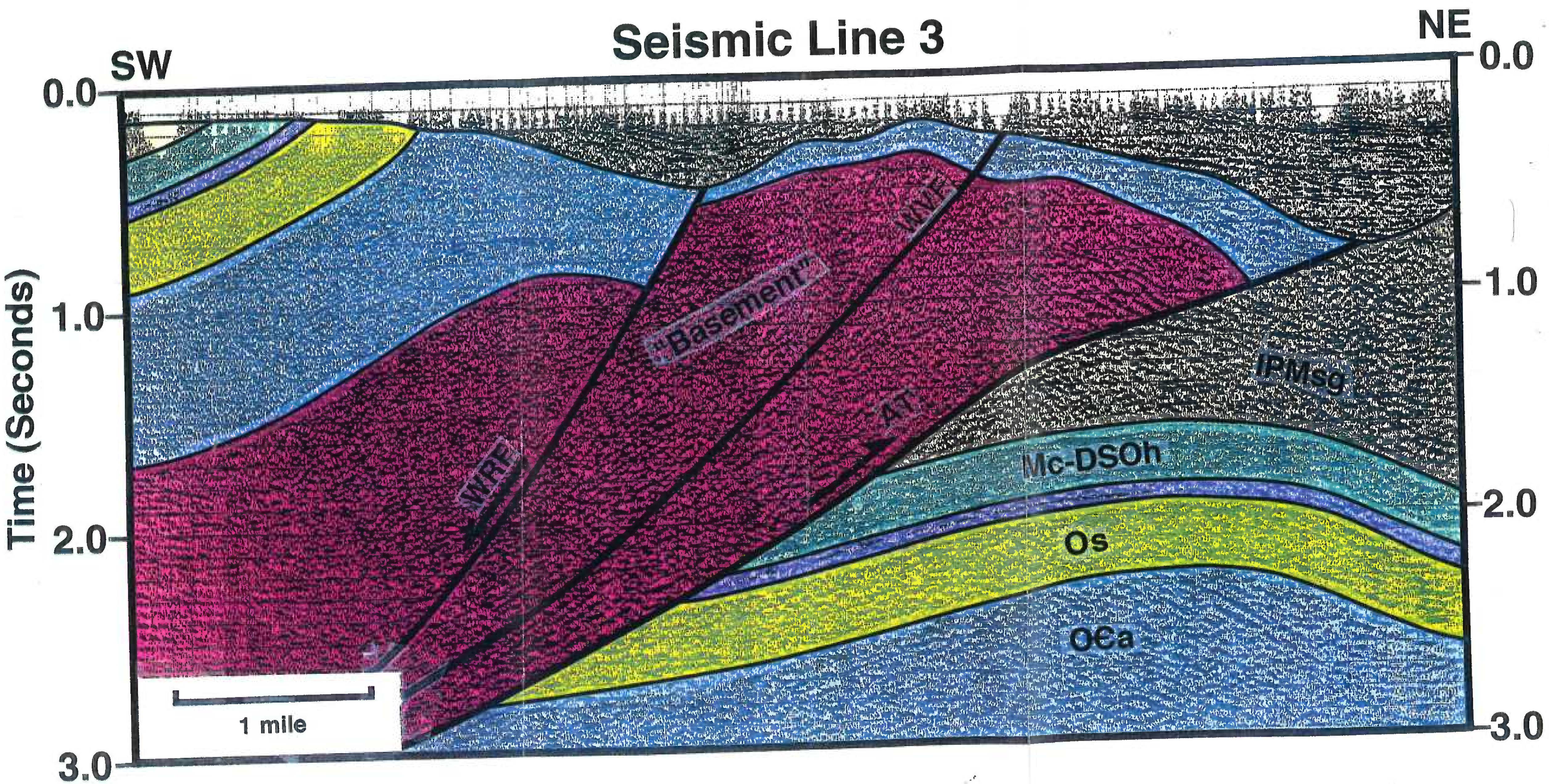
Location of the Washburn Ranch Fault is marked by a paleo-topographic fault line scarp which forms a valley on the Ponototoc unconformity. Displacement of the Washburn Ranch Fault increases to the west, and as a result, the valley becomes more pronounced and forms a distinct traceable feature on seismic lines.

Arbuckle Thrust footwall deformation is confirmed by well control and consists of a northeast-vergent asymmetric anticline, which may be the southeast plunge of Eola Anticline. In the Mississippian and older strata, the structural relief is minor, however, detachments in the Springer shales increase the fold amplitude upward in the section. The area between the hanging-wall sheet and Eola Anticline formed a pre-Pennsylvanian topographic low into which synorogenic conglomerates were deposited and preserved.

Seismic Line 3

Seismic line 3 (fig. 30) runs adjacent to the west side of cross section B - B' and seismic line 2. The dip of the Arbuckle Thrust has

Figure 30. Seismic line 3. A prominent valley with in-filling sediments is visible over the Washburn Ranch Fault which has shown increasing displacement from the east. Data provided by PGI through Texaco; interpretation is the author's.


Seismic Line 3
SW
NE
0.0
1.0
2.0
3.0
Time (Seconds)
"Basement"
WRF
MVF
AT
IPMsg
Mc-DSOh
Os
OЄa
1 mile

steepened enough to reduce the clarity of its reflector. Location of the fault-plane is constrained, however, by changes in reflection characteristics and dip panels.

The hanging-wall geometry revealed in this profile is very similar to that of cross section B - B'. Above the Washburn Ranch Fault, the paleo-valley of the pre-Pontotoc unconformity is clearly imaged. The dip of young sediments is semi-parallel to the erosional contact and valley-fill progressively flattens upwards, suggesting that the valley-fill sediments may be synorogenic, in part.

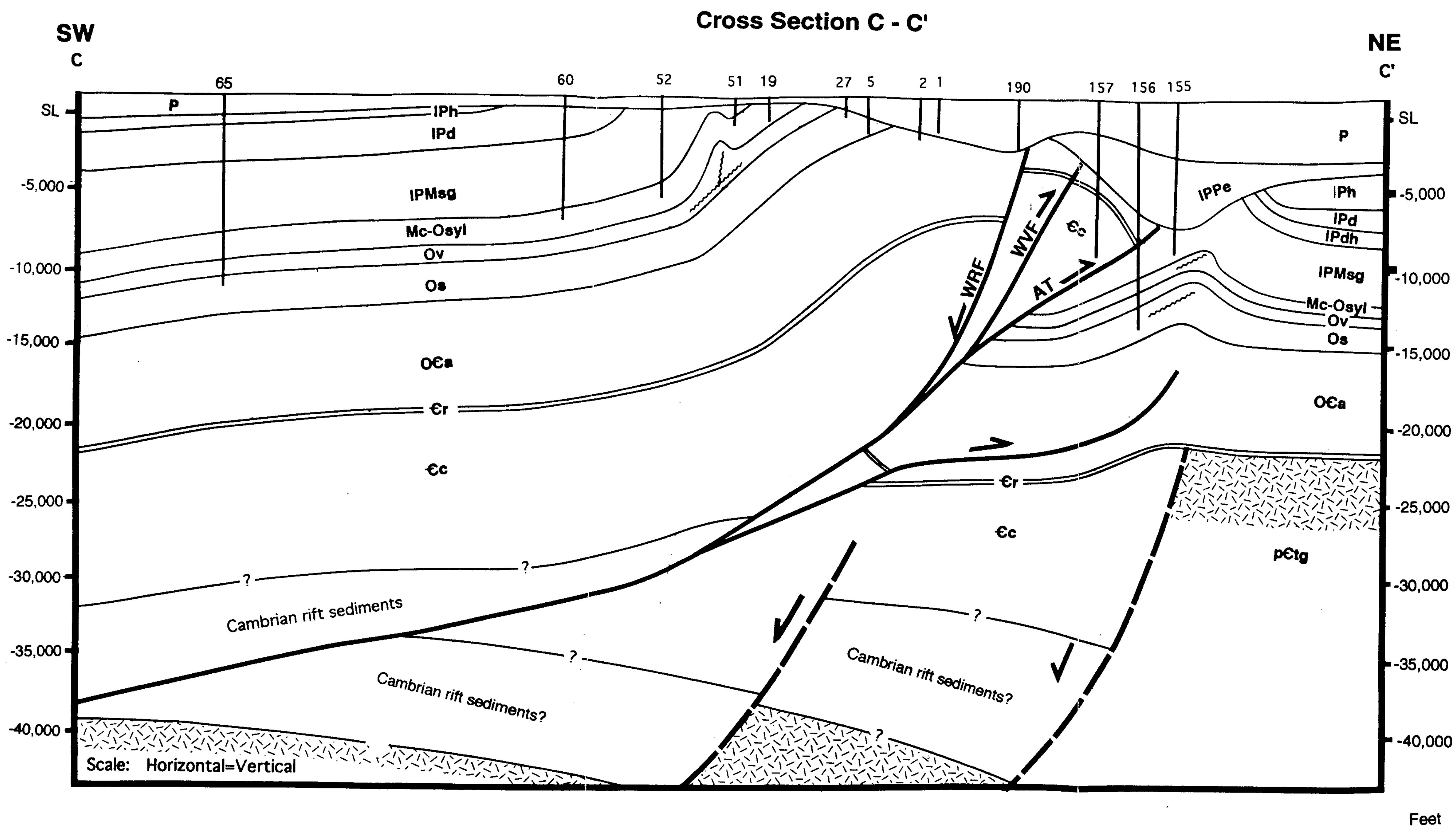
Wells drilled into the paleo-valley encounter conglomerates in the center and near the base of the valley. Information regarding dates and composition of the conglomerates would help constrain timing of motion on the Washburn Ranch Fault; this topic needs to be addressed in future studies.

Cross Section C - C'

Cross section C - C' (fig. 31) displays a “snakehead” anticline similar in overall geometry to cross section B - B', however, some important differences are present.

Compared to section B - B', the depth to the Arbuckle Thrust basement "detachment" has risen from about -43,000 to -35,000 feet. Additionally, the ramp now dips at a rate of between 30 and 35 degrees to the southwest. Alteration of the hanging-wall anticline has occurred by increased displacement of the Washburn Ranch Fault, which leaves a pronounced “suspended” basement block. Harlton

Figure 31. Cross section C - C' illustrates transition in geometry between the western outcrop and Eola region. Increase in preserved conglomerates on the northeast flank corresponds to increased steepness of the Arbuckle Thrust and higher elevation of the hanging wall block.


Cross Section C - C'
SW
C
NE
C'
65
60
52
51
19
27
5
2
1
190
157
156
155
SL
-5,000
-10,000
-15,000
-20,000
-25,000
-30,000
-35,000
-40,000
P
IPh
IPd
IPMsg
Mc-Osyl
Ov
Os
O€a
€r
€c
IPPe
IPdh
WRF
WVF
AT
p€tg
Cambrian rift sediments
Cambrian rift sediments?
Scale: Horizontal=Vertical
Feet

(1964) called this block the Robberson Horst, though he defined its northern boundary as the Washita Valley Fault rather than the Arbuckle Thrust and the southern boundary as the Robberson Fault (which he linked with the exposed Joins Ranch Thrust) rather than the Wasburn Ranch Fault.

Displacement of the Arbuckle Thrust has decreased to about 24,000 feet (as measured from basement offset), however, the hanging wall has experienced erosion to a deeper level than immediately to the east (up-plunge) due to the increased dip of the ramp in the Arbuckle Thrust, which has steepened and elevated the hanging wall. Greater amounts of conglomerate are preserved on the north flank of the uplift above the unconformity, than to the east. The pre-Pontotoc unconformity has also eroded into the footwall anticline.

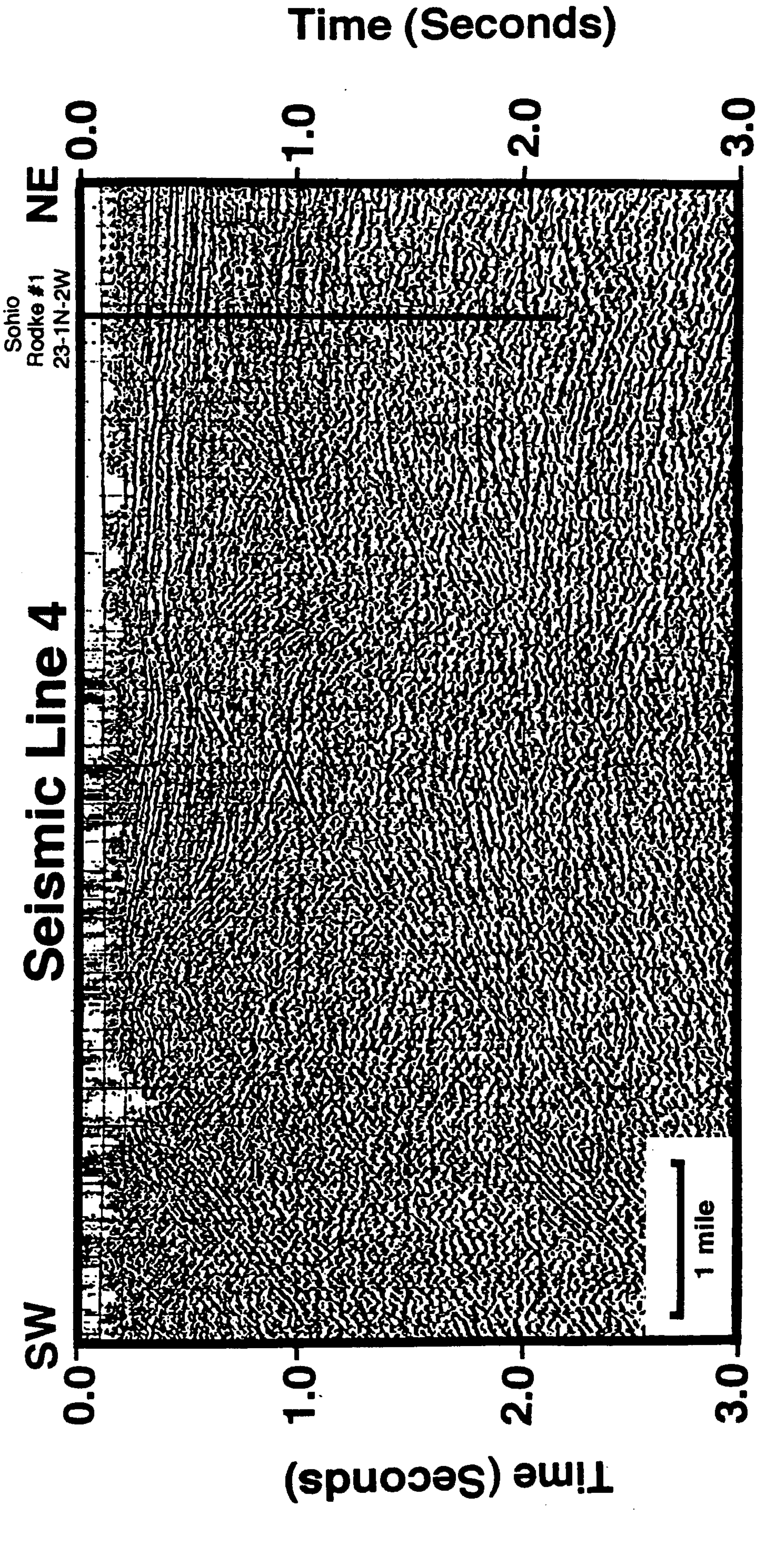
Shortening of the footwall is shown by an asymmetric anticline, which shows increased structural relief west of cross section B - B'. The footwall anticline is interpreted as having formed from a detachment within the Arbuckle Group which dies out upward in the stratgraphic section, producing a fault-propagation fold.

Comparison of Sections A - A', B - B', and C - C'

There are eight significant changes in structural geometry between the exposed uplift and the area east of Eola field:

1. Displacement along the Arbuckle Thrust decreases in a westward direction.
2. The level of basement detachment of the Arbuckle Thrust rises in a westward direction.
3. Hanging wall geometry of the Arbuckle Thrust changes from a fault-bend fold to a "snakehead" anticline as the geometry of the Arbuckle Thrust changes from a ramp-flat to a single ramp.
4. The southwest dip of the Arbuckle Thrust progressively steepens westward. As a result, the Arbuckle Uplift (hanging wall anticline of the Arbuckle Thrust) is progressively steepened, and, to the west, is eroded to deeper (older) levels.
5. The Washita Valley Fault dies out in a westerly direction.
6. Extension and vertical separation on the Washburn Ranch Fault increases towards the west.
7. Collapse and shortening of the footwall increases progressively towards the west. The footwall anticline (Eola Anticline) plunges out to the southeast. As Eola plunges, detachments in the Springer Group separate tight folds from a more open style of folding in the lower part of the stratigraphic section.
8. The bottom of the Ardmore Basin rises towards the west.

Figure 32. Uninterpreted seismic line 4, oriented at nearly 45° to the plunge of the uplift. The oblique angle distorts the image and portrays shallow, apparent dips. The majority of the visable seismic events are diffractions caused by steep dips. Compare this image to that of the seismic model in figure 33.


Seismic Line 4
SW
NE
Sohio
Rodke #1
23-1N-2W
Time (Seconds)
0.0
1.0
2.0
3.0
1 mile

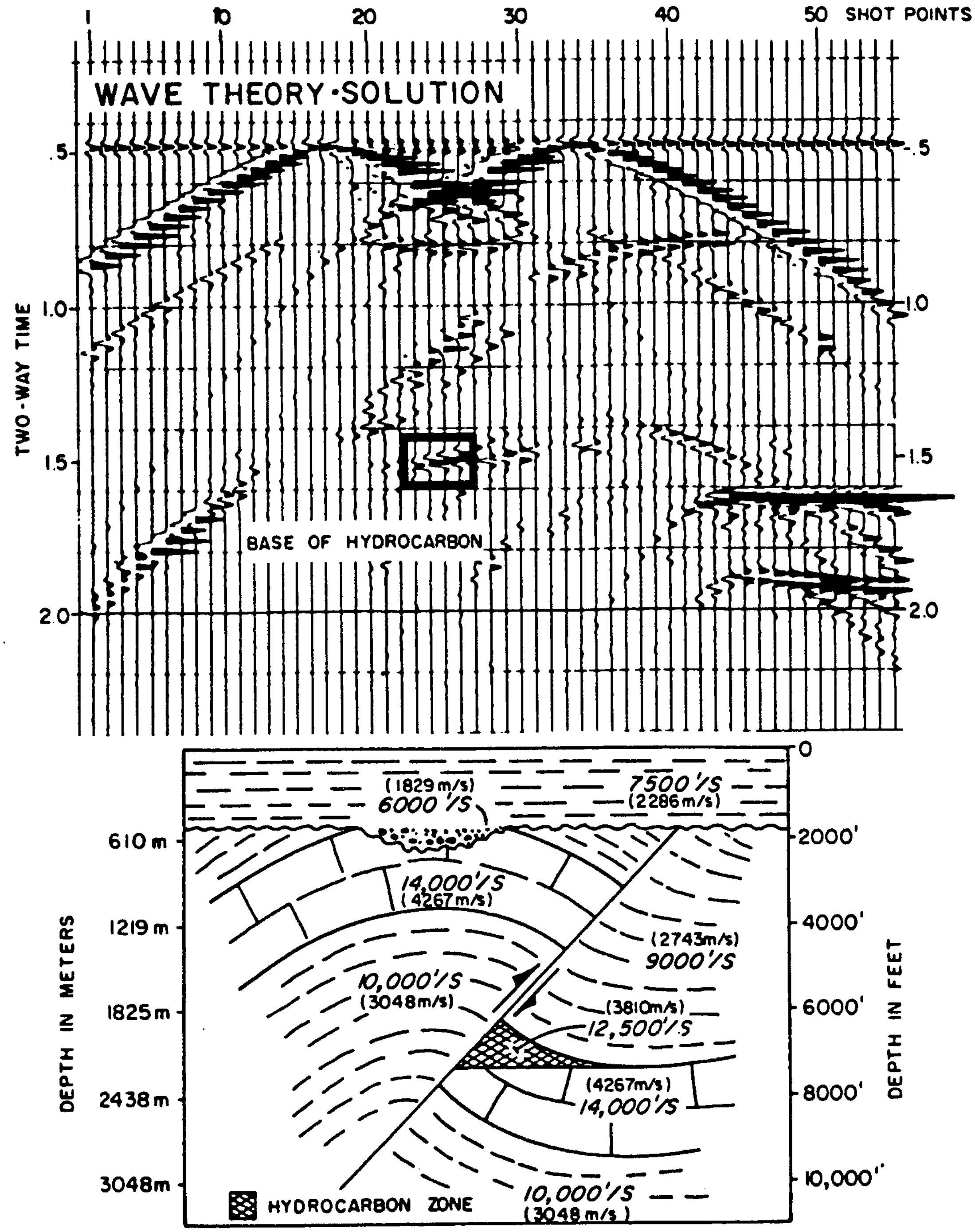
Seismic Line 4

Seismic line 4 (fig. 32) is of poorer quality than proceeding lines. Many of the reflection patterns are diffraction events caused by the steep dip of the uplift. Additionally, the oblique trace of the line with respect to the axis of the Arbuckle Uplift creates "sideswipe" interference within the processed image and provide an "apparent dip" rather than true dip. As a result, the geometry is distorted. Nonetheless, several important features are shown on this line.

Figure 33 shows a seismic trace model of a subcropping overthrust anticline with an erosional valley in its crest and the computed seismic expression. The overall geometry closely matches that of the Arbuckle Uplift in the vicinity of seismic line 4 (fig. 32) and many of the characteristics in the computed seismic expression of the model are present in seismic line 4. Note that the fault plane is too steep to image. Diffraction images, which flatten upward and dip at a rate shallower than the true dip of the fault, are prominent in the vicinity of fault. The true fault plane is located between the diffractions and the last strong footwall reflection event.

Seismic line 4 (fig. 32) is very similar to the computed seismic expression of the overthrust model (fig. 33). The Arbuckle Thrust is not imaged; however, its location and dip can be and are constrained. The location of the erosional valley above the Washburn Ranch Fault is imaged clearly. Increased separation along this fault has offset the hanging wall, creating separate geometries on either block. The approximate location of the erosional edge of the

Figure 33. Seismic model of an overthrust anticline with an erosional valley in the hanging wall with its computed seismic expression. The geometry of the model is similar to that of the interpreted geometry of the Eola region of the Arbuckle Uplift. This model shows how an overthrust fault could generate an image that could easily be interpreted as a "flower structure" (from Neidell and Poggiagliolmi, 1977).



(from Neidell and Poggiagliolmi, 1977)

Arbuckle Thrust is also discernible. The lack of a clear image in the footwall indicates a steepening of the dips, or a more complex geometry

Line 4 is important because it demonstrates that even when the resolution of a seismic line is somewhat ambiguous, it can yield important information regarding the geometry of the structure if the seismic line is tied into structural cross sections and other seismic lines based upon more specific evidence. If not considered with other data, a variety of interpretations could be imposed upon this line, including that of a “flower structure”.

Seismic Lines 5 and 6

Seismic line 5 (fig. 34) gives a clear image of the geometry of the upper portion of the hanging wall of the Arbuckle Thrust; however, reflectors are unresolvable in the area immediately in front of the Arbuckle Thrust and in its footwall. North of the Washburn Ranch Fault, elevation of the hanging wall of the Arbuckle Thrust has allowed erosion to expose the lower Arbuckle Group. On the hanging wall of the Washburn Ranch Fault, erosion cuts only to the upper Arbuckle Group. The Washburn Ranch Fault continues to be traceable by the presence of the paleo-valley.

Line 6 (fig. 35) trends oblique to the B-axis of the Arbuckle Uplift and, as a result, is less clearly imaged than other lines. The vergence of the structure, both north and south of the Washburn Ranch Fault, is distinguishable, as is the paleo-valley above the

Figure 34. Interpreted seismic line 5 across the Eola-Robberson area. Geometry of the hanging wall of the Arbuckle Thrust is well imaged. Normal dip slip motion along the Washburn Ranch Fault must have occurred relatively soon after the uplift because the hanging wall is significantly less severely eroded than its footwall.

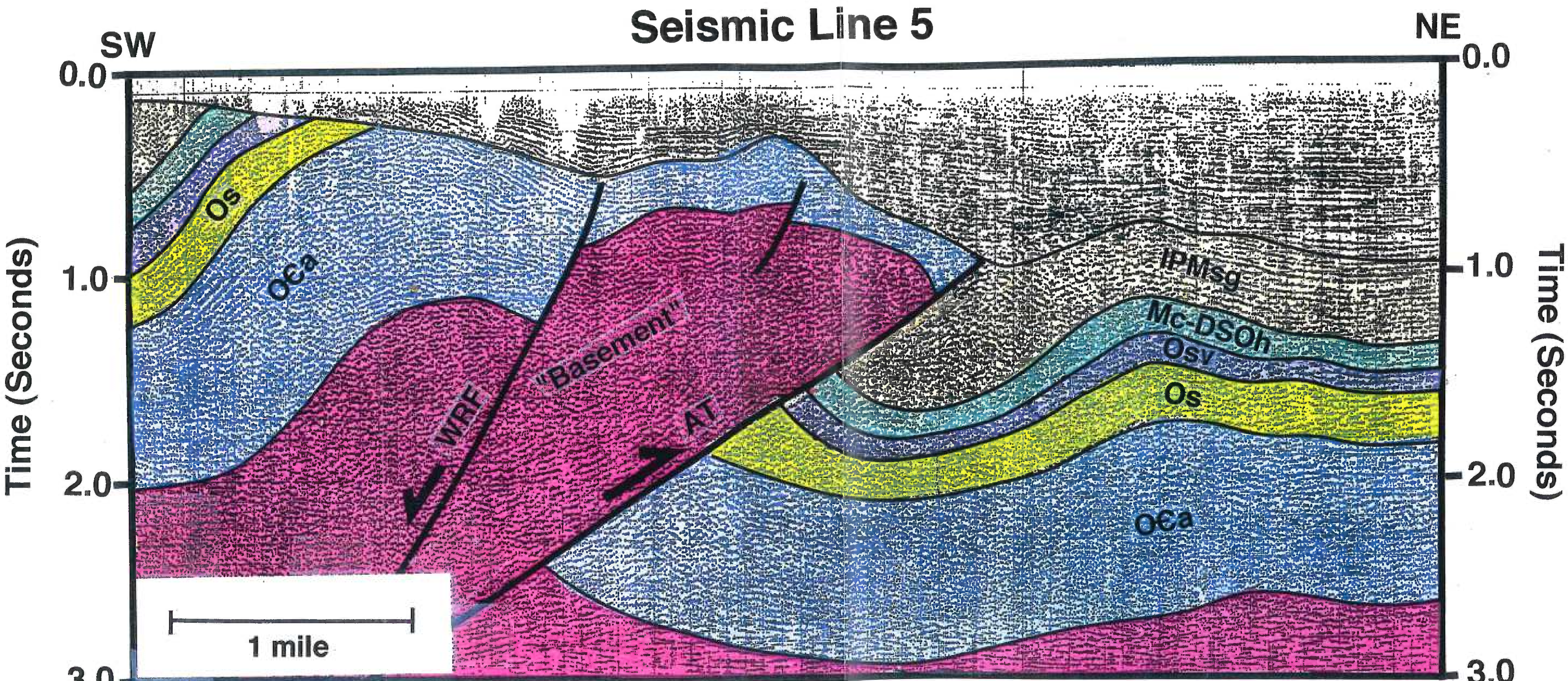
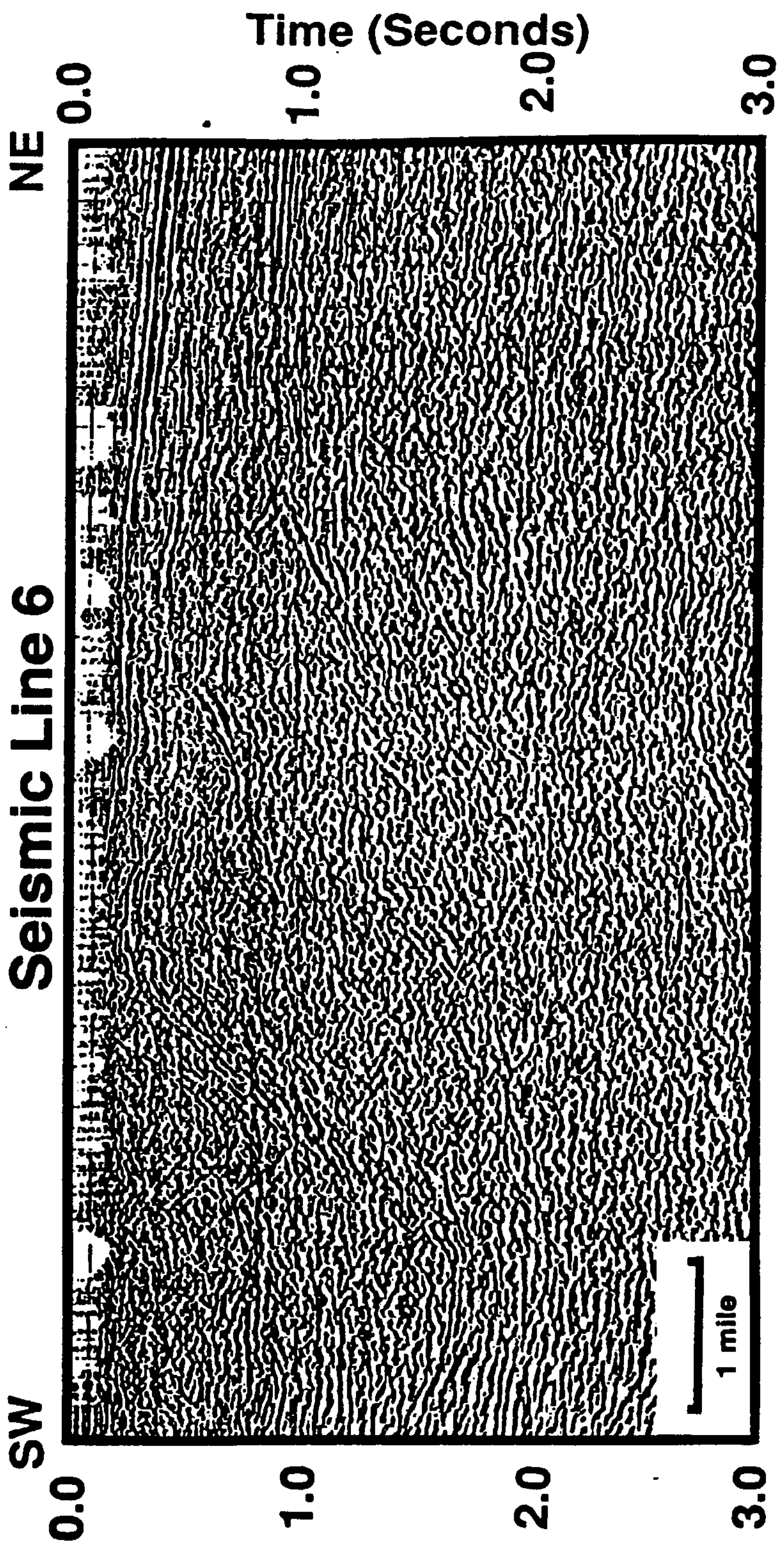

Seismic Line 5
SW
NE
0.0
1.0
2.0
3.0
Time (Seconds)
Os
OЄa
"Basement"
WRF
AT
IPMsg
Mc-DSOh
Osv
Os
OЄa
1 mile

Figure 35. Uninterpreted seismic line 6 is oblique to the axis of the structure. Poor quality of the data is due in part to orientation of the line. Without well control, or an understanding of structural styles from outcrop, a wide variety of interpretations could be applied to this line. Data provided by PGI through Texaco; interpretation is the author's.


Seismic Line 6
Time (Seconds)
0.0
1.0
2.0
3.0
NE
SW
1 mile

Washburn Ranch Fault. In part due to steep dips, the Arbuckle Thrust and the footwall are not well imaged.

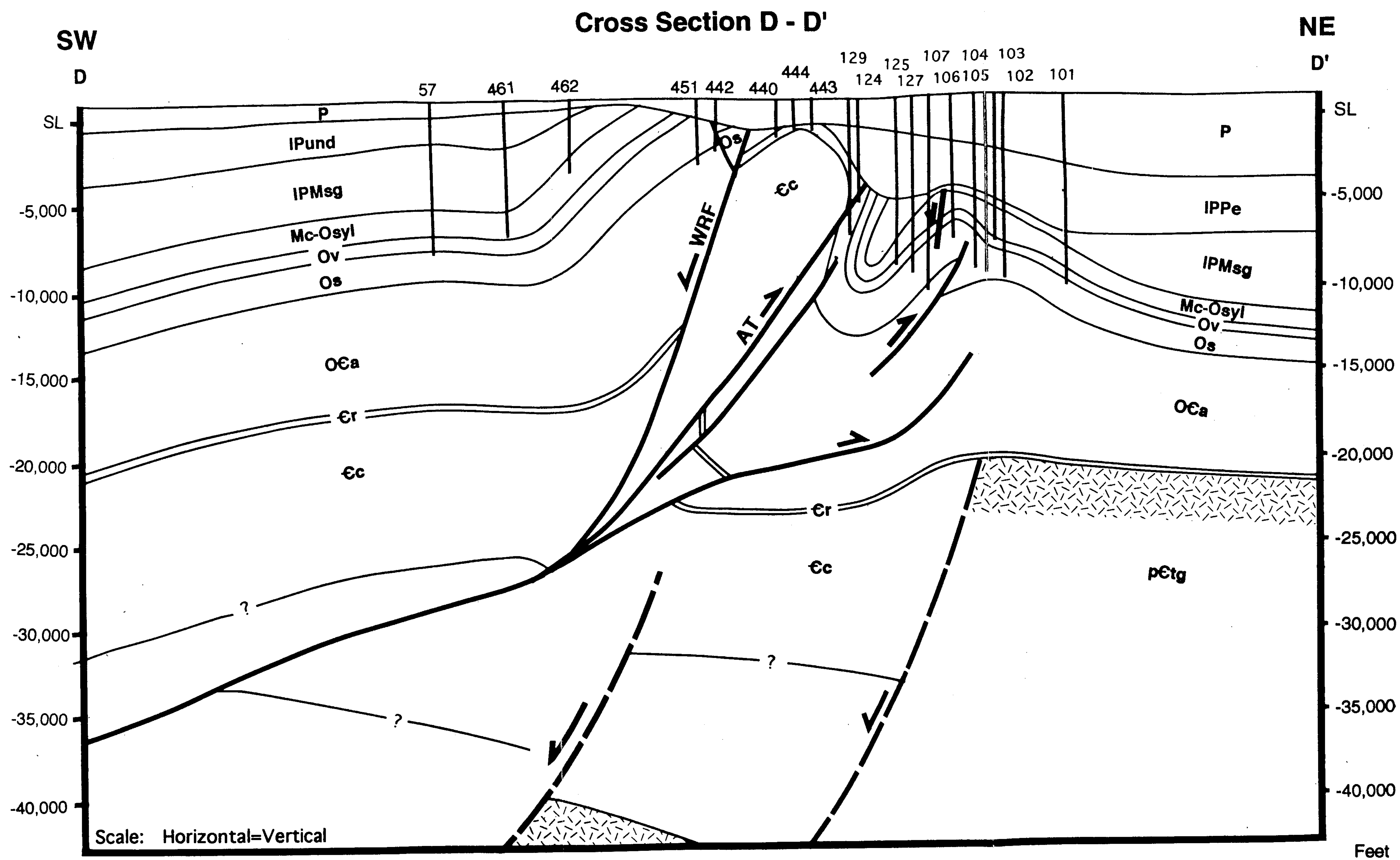
Cross Section D - D' and Seismic Line 7

Cross section D - D' (fig. 36) is constructed across Eola and Robberson Fields near the point of maximum structural elevation of Eola Anticline. Structural geometry of the buried Arbuckle Uplift is a deeply eroded fault-propagation fold, tilted to the southwest along the steeply-dipping Arbuckle Thrust, which has then been overprinted by later extension creating a suspended basement-cored block uplift (Sales, 1983), called the Robberson Horst by Harlton (1964).

The footwall of the Arbuckle Thrust has been greatly shortened by the development of an overturned syncline and the northeast-vergent Eola Anticline. Folding and faulting associated with footwall shortening of Eola Anticline may have folded and uplifted the overlying Arbuckle Thrust. Further discussion of this subject is presented in the Structural Synthesis portion of the thesis.

Steepening of the dip of the Arbuckle Thrust has elevated its hanging-wall, allowing for erosion to the level of the Timbered Hills Group (Cambrian). Up to 4,000 ft of Pontotoc conglomerates derived from the Arbuckle Uplift are deposited in a valley eroded into Springer shales in the overturned footwall syncline. The Pontotoc erosional surface cuts across the Eola Anticline, cutting down into the lower Goddard shales of the Springer Group.

Figure 36. Cross section D - D' shows the structural geometry in the Eola-Robberson region. The footwall contains an overturned syncline. The Arbuckle Thrust now forms the core of a highly eroded fault-propagation fold. This area of maximum elevation of the hanging wall is adjacent to the maximum accumulations of Eola Conglomerate (Pontotoc) and maximum extension along the Washburn Ranch Fault.


Cross Section D - D'
SW
D
NE
D'
57
461
462
451 442 440
444
443
129
124
125
127
107
106
105
104
103
102
101
SL
-5,000
-10,000
-15,000
-20,000
-25,000
-30,000
-35,000
-40,000
Feet
P
IPund
IPMsg
Mc-Osyl
Ov
Os
O€a
€r
€c
WRF
AT
€c
IPPe
pЄtg
?
Scale: Horizontal=Vertical

Late stage extension is manifest on both the Arbuckle Uplift and the Eola Anticline in the form of down-to-the-south normal faults. On Eola Anticline, extension is accommodated by the Eola Fault which has approximately 1,000 feet of dip separation. Dip separation of the Washburn Ranch Fault is 10,000 feet. Because of the steep dip of the Arbuckle Thrust and depth of erosion of the hanging wall, the width of the suspended basement block is relatively narrow.

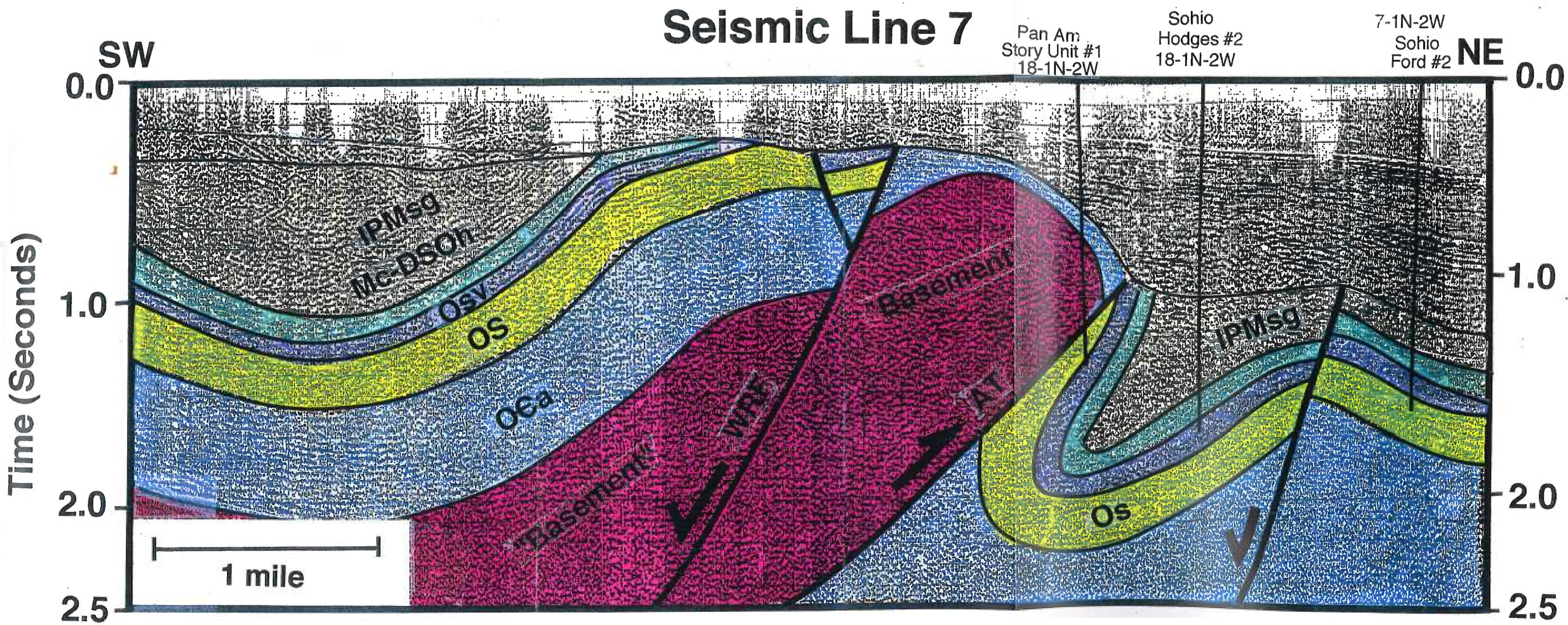
Seismic line 7 (fig. 37) is located nearly coincident with cross section D - D'. Line 7 illustrates the geometry of the buried uplift at shallow depths, but relationships become obscured as dips steepen with depth. The suspended basement block, location of the Washburn Ranch Fault, and crest of the Eola Anticline are easily distinguished, while the footwall geometry is not.

The upper portion of the downthrown block of the Washburn Ranch Fault generates clear reflectors in the vicinity of the fault. Structures in the Springer Group have not been individually interpreted, but are related to intraformational detachments. These structures form reservoirs that have been successfully exploited for hydrocarbons.

Cross Section E - E' and Seismic Line 8

Cross section E - E' (fig. 38) and seismic line 8 (fig. 39) are nearly coincident, located on the buried Arbuckle Uplift at the

Figure 37. Interpreted seismic line 7 across the Eola-Robberson area, near cross section D - D'. Footwall structure doesn't image well due to steep dips and structural complications. Data provided by PGI through Texaco; intepretation is the author's.



Seismic Line 7
SW
NE
Pan Am
Story Unit #1
18-1N-2W
Sohio
Hodges #2
18-1N-2W
7-1N-2W
Sohio
Ford #2
0.0
1.0
2.0
2.5
Time (Seconds)
IPMsg
Mc-DSOh
Osv
OS
OEa
Basement
"Basement"
WRF
AT
Os
1 mile

Figure 38. Cross section E - E' across the northwestern end of Eola-Robberson area. Descreased structural elevation of the Eola Anticline from the southeast corresponds with the decreased dip of the Arbuckle Thrust.

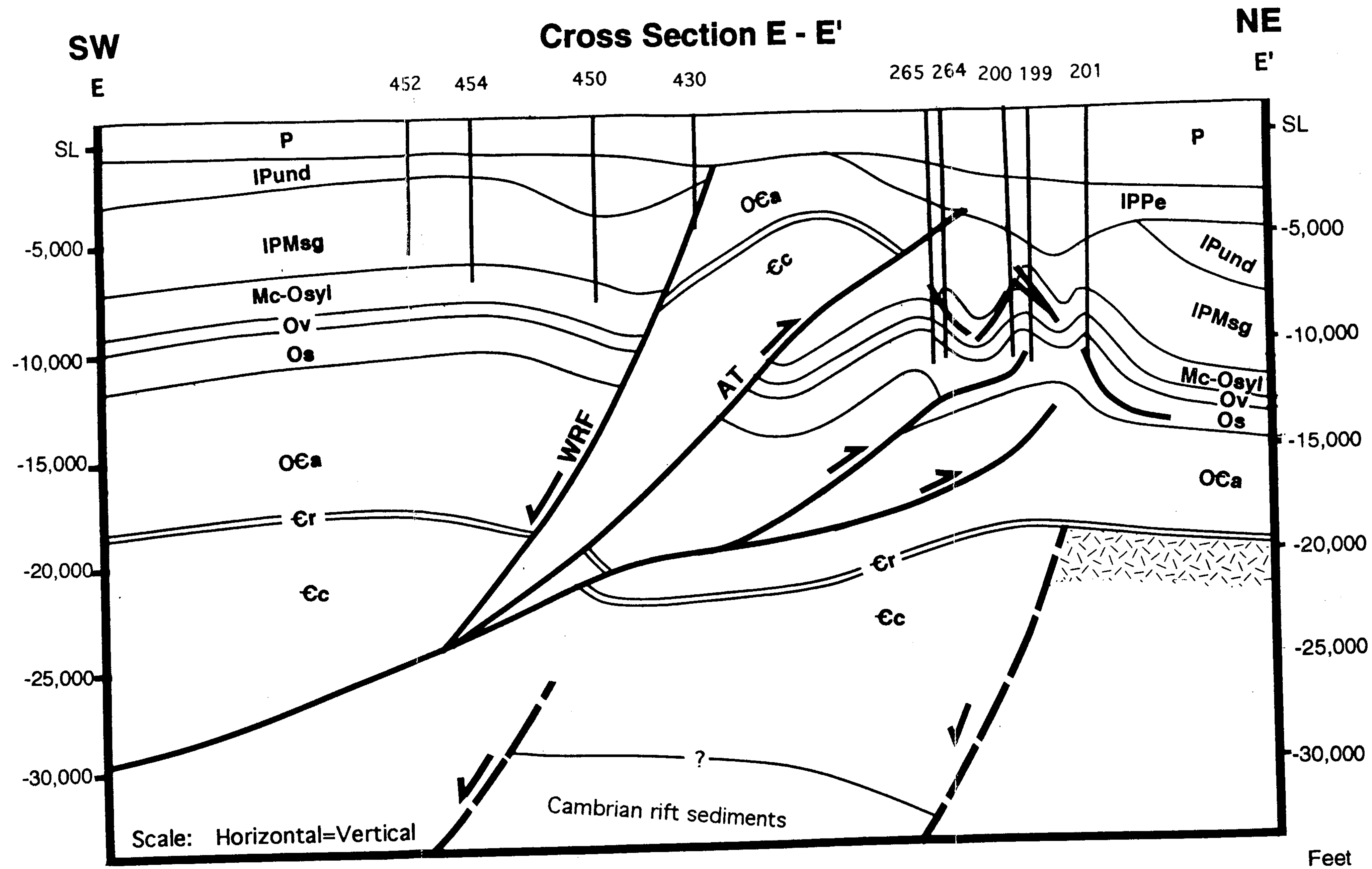
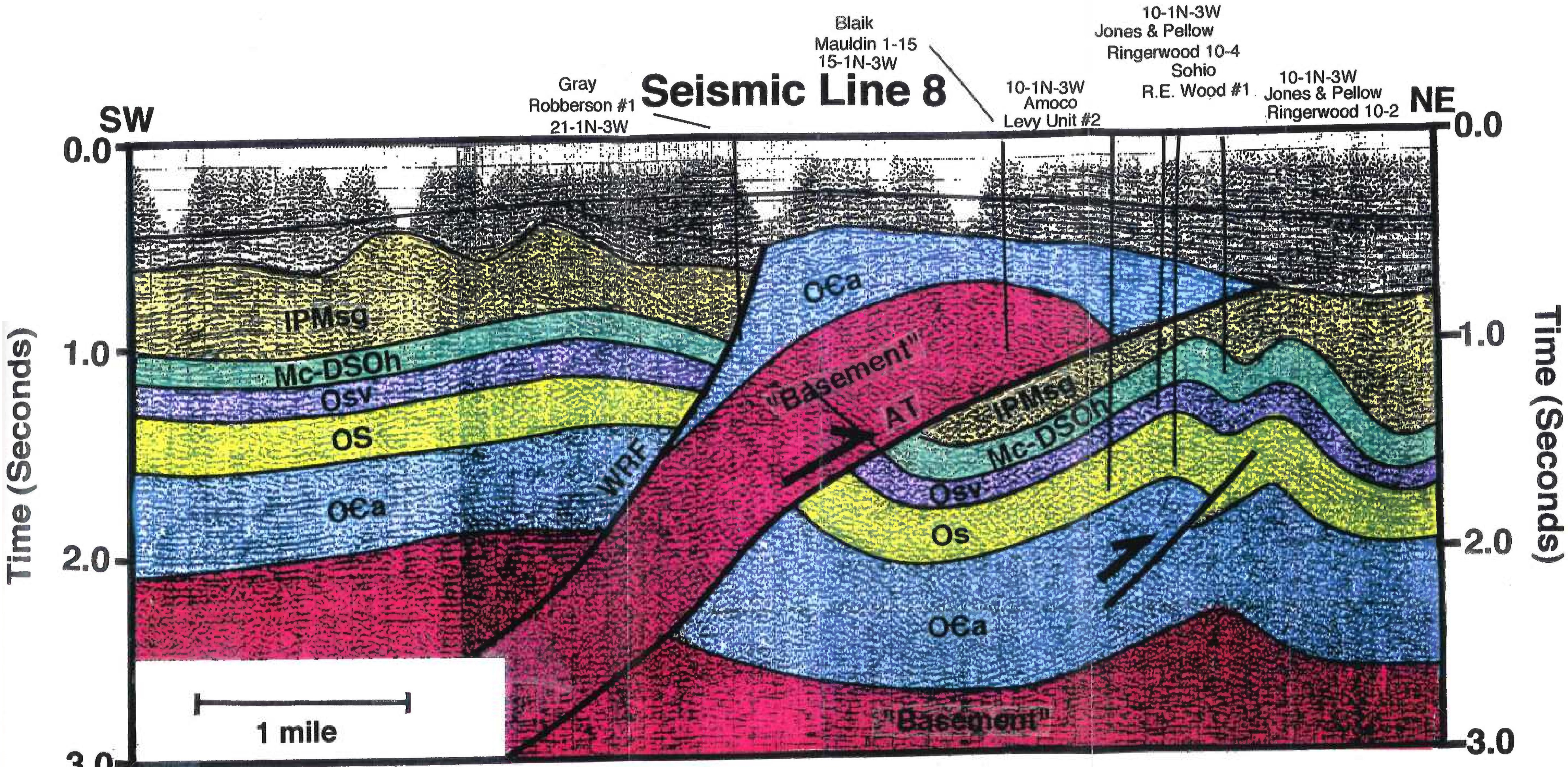

Cross Section E - E'
SW
E
NE
E'
452 454 450 430 265 264 200 199 201
SL
-5,000
-10,000
-15,000
-20,000
-25,000
-30,000
P
IPund
IPMsg
Mc-Osyl
Ov
Os
O€a
€r
€c
WRF
AT
IPPe
?
Cambrian rift sediments
Scale: Horizontal=Vertical
Feet

Figure 39. Interpreted seismic line 8 showing structural geometry at the northwest end of the Eola-Robberson area. Data provided by PGI through Texaco; interpreation is the author's.



Seismic Line 8
SW
NE
Gray
Robberson #1
21-1N-3W
Blaik
Mauldin 1-15
15-1N-3W
10-1N-3W
Amoco
Levy Unit #2
10-1N-3W
Jones & Pellow
Ringerwood 10-4
Sohio
R.E. Wood #1
10-1N-3W
Jones & Pellow
Ringerwood 10-2
0.0
1.0
2.0
3.0
Time (Seconds)
IPMsg
Mc-DSOh
Osv
OS
O€a
"Basement"
AT
WRF
Os
1 mile

northwestern plunge-end of Eola Field where the uplift consists of a fault-bend fold which has been normal faulted, leaving a suspended basement block. The Arbuckle Thrust climbs up from a basement flat, through the Cambrian-Ordovician section, and then flattens to a relatively shallow dip of 30° in the Springer shales. The location and geometry of the hanging wall are constrained by seismic line 8. Involvement of the basement in the hanging wall is confirmed by the Blaik Mauldin No.1 B-13 well located in section 15 of T. 1 N., R. 3 W. This well drilled a nearly complete sequence of Arbuckle carbonates, before encountering 4,750 feet of granite and rhyolite basement at a depth of 3,670 feet below sea level. Dip separation on the Arbuckle Thrust is on the order of 21,000 feet.

Normal dip-separation on the Washburn Ranch Fault is 12,000 feet. The presence of this fault is confirmed by the Texaco Downey Estate No. 1 well, located in section 22 of T. 1N., R. 3W. which encountered the fault at 3,892 feet below sea level, where it placed Goddard Shale of the Springer, against Arbuckle Group carbonates.

Eola Anticline has undergone a decrease in structural elevation and is now plunging to the northwest. Though still not clearly imaged on seismic, some indication can be seen of the intense amount of shortening which is accommodated by detachments.

Comparison of Sections D - D' and E - E'

Two important changes in the structural geometry occur between D - D' and E - E':

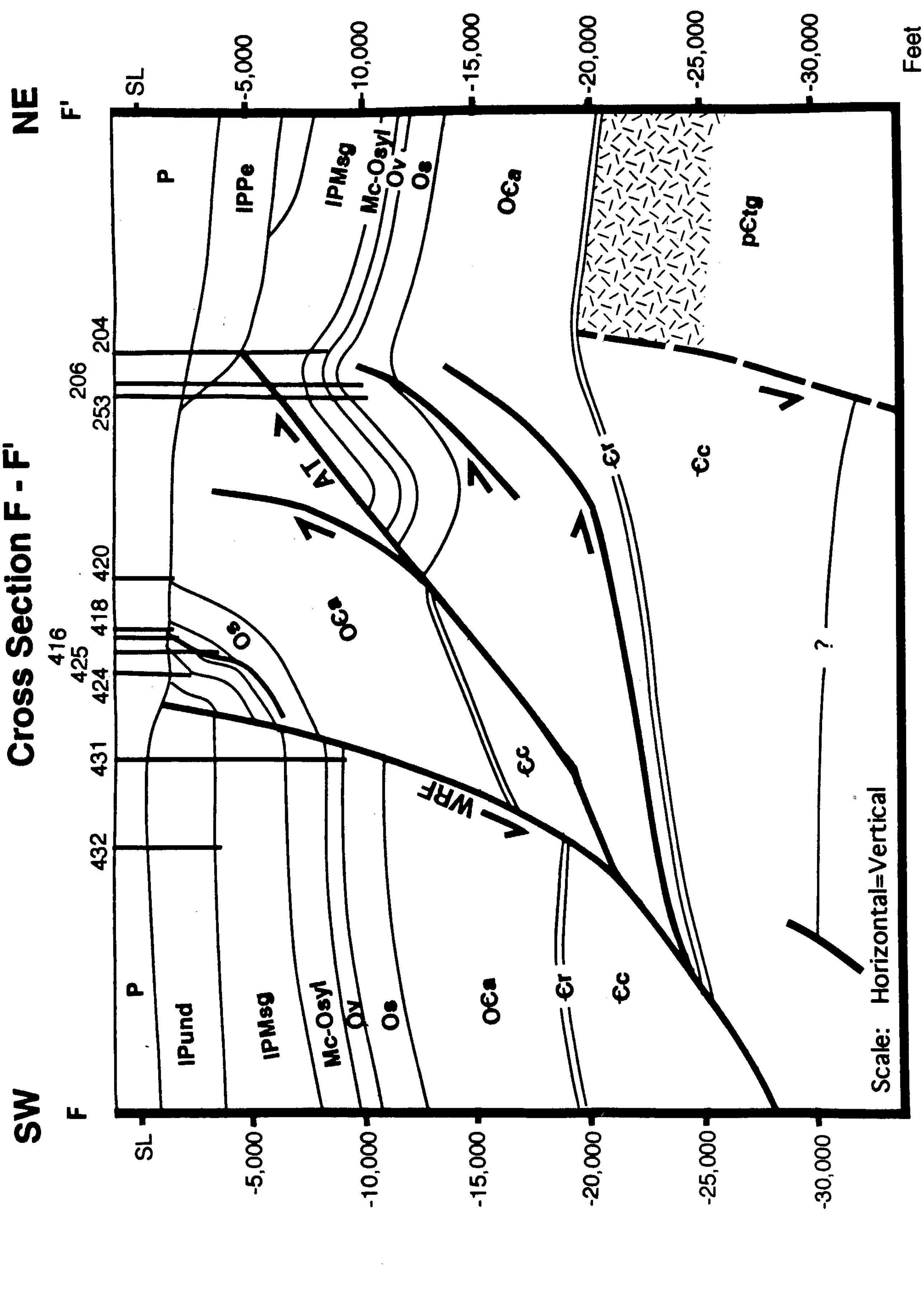
1. Dip of the Arbuckle Thrust decreases to the northwest, causing a loss of elevation of the hanging wall, and subsequent erosion is less deep westward along the hanging wall. The decrease in depth of erosion is reflected by a decrease in thickness and change in character of the Pontotoc (Eola) conglomerates on the northeastern flank of the uplift.
2. Eola Anticline plunges to the northwest. The decrease in structural elevation of Eola Anticline is accompanied by a decrease in steepness of dip of the overlying Arbuckle Thrust (which was uplifted and folded by footwall deformation to the east).

Cross Section F-F'

Northwest of cross section E - E', a substantial change occurs in the geometry of the Arbuckle Uplift. Cross section F-F' (fig. 40) shows that the Arbuckle Thrust ramps up into the Arbuckle Group, forms a minor flat, and then climbs to the northeast through the rest of the section (at nearly 40°), increasing the fault cut-off length in the Arbuckle Group. Basement displacement is on the order of 20,000 ft, with a greater horizontal than vertical component.

A shallowing of the dip of the Arbuckle Thrust lowers the upper plate, which effectively “moves” the hanging wall further north of the basement ramp. Because it links to the ramp of the Arbuckle Thrust, the Washburn Ranch Fault has moved its erosional trace south of the Springer-Caney contact. Well-logs reveal the

Figure 40. Cross section F -F' illustrates the structural geometry east of Royal Pool Field. The ramp of the Arbuckle Thrust is interrupted by a small flat within the lower Arbuckle Group.


Cross Section F - F'
SW
F
NE
F'
SL
-5,000
-10,000
-15,000
-20,000
-25,000
-30,000
Feet
432
431
424
425
416
418
420
253
206
204
P
IPund
IPMsg
Mc-Osyl
Ov
Os
OЄa
Єr
Єc
IPPe
pЄtg
AT
WRF
?
Scale: Horizontal=Vertical

Caney-Simpson interval to contain back-limb thrusting with Simpson-rooted detachments. This style is similar with that observed on the exposed Arbuckle Anticline and in the immediate subsurface plunge.

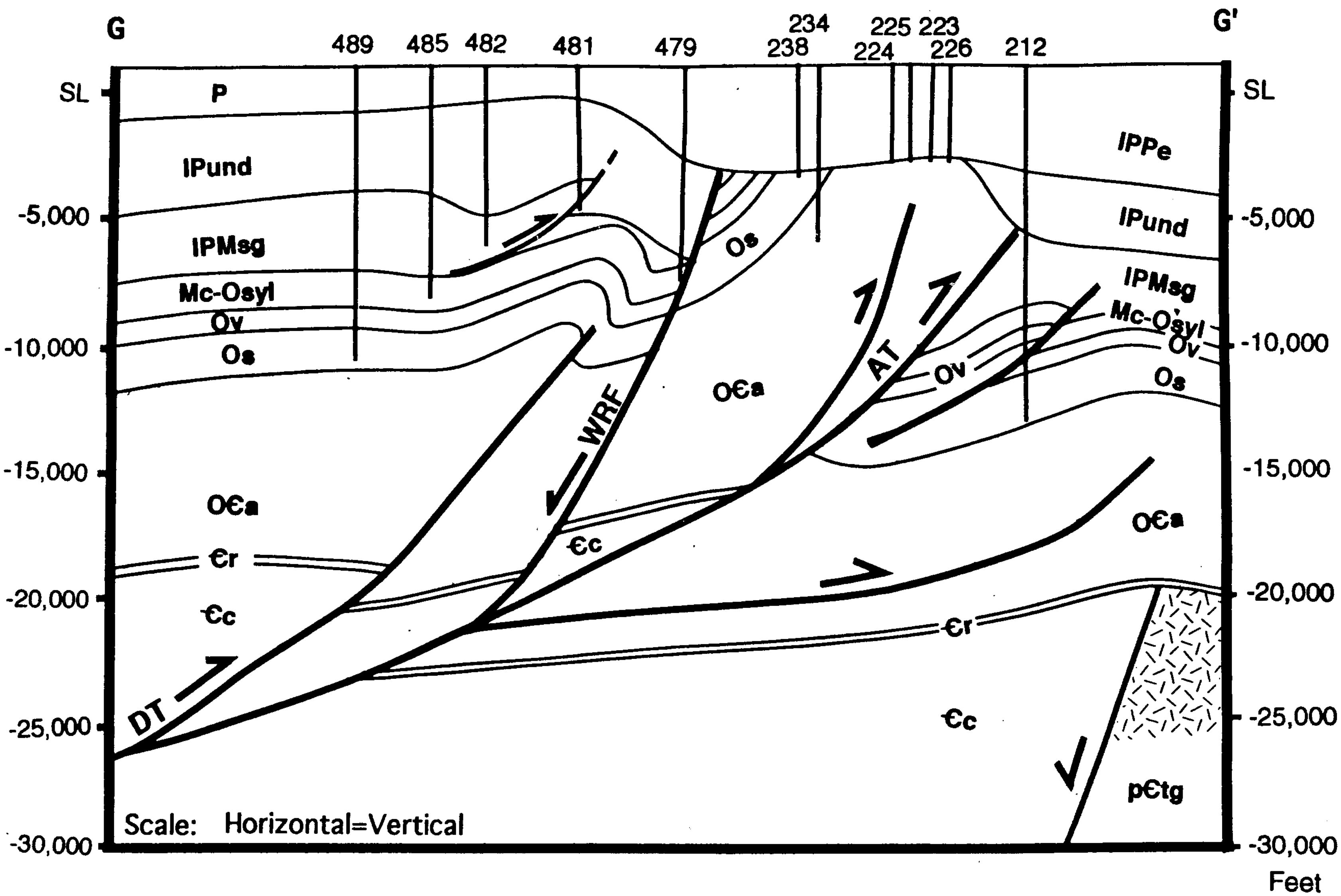
Along with decreasing elevation of the Arbuckle Thrust there is a rapid decrease in displacement (5,000 feet) of the Washburn Ranch Fault. It is not clear what the mechanical relationship is between displacement of the Washburn Ranch Fault and the geometry of the Arbuckle Thrust, though one does seem to exist.

Cross Section G - G'

This cross section (fig. 41) crosses Royal Pool at the northwestern end of the study area. Structural geometry depicted in this cross section is very similar to that of a thin-skinned fold and thrust belt. In the carbonates of the Arbuckle Group, the Arbuckle Thrust ramps up from a shallow basement detachment, at a dip of 30° southwest. The thrust then steepens to nearly 50° southwest dip in the Upper Paleozoic section. This has the effect of further increasing the fault cut-off length within the Arbuckle Group as the uplift plunges out. Palladino (1986) documented the same geometry (long flats in the Arbuckle Group, followed by steep ramps in the upper part of the stratigraphic section) on the southeast plunge of the Arbuckle Anticline (fig. 7).

Figure 41. Cross section G -G' illustrates the structural geometry in the Royal Pool area. Overall geometry is similar to that of a fold and thrust belt. Displacement along the Washburn Ranch Fault has substantially decreased from east to west.

Cross Section G - G'



In the footwall of the Arbuckle Thrust, Eola Anticline shows little structural relief, as it plunges out to the northwest. This structure contains a back-limb thrust; subsidiary structures of interest to explorationists may be present along the northwest plunge.

Displacement of the Washburn Ranch Fault is relatively minor. The downthrown block of the Washburn Ranch Fault preserves back-limb structures of the hanging wall of the Arbuckle Thrust. The Sun Blaydes #1 in section 3 T. 1N., R. 4W. encountered over 4,000 feet of conglomerates. Like most voluminous deposits of conglomerate in southern Oklahoma, this conglomerate is preserved in a footwall syncline of a northeast-vergent thrust fault, in this case a thrust (possibly the Doyle Thrust) in the hanging wall of the Arbuckle Thrust. Though some of the conglomerate may have been sourced from activity along the Washburn Ranch Fault, it is more likely that the conglomerate represents a downthrown depocenter related to a back-limb thrust.

Comparison of Sections E - E', F - F', and G - G'

Important changes in structural geometry take place from section E - E' to G- G' as follows:

1. Westward decrease in the dip-slip separation of the Arbuckle Thrust from 21,000 feet to 17,000 feet.
2. Long cut-off lengths develop within the Arbuckle Group. The long cut-off length means that the basement ramp occurs further to the southwest and must either be

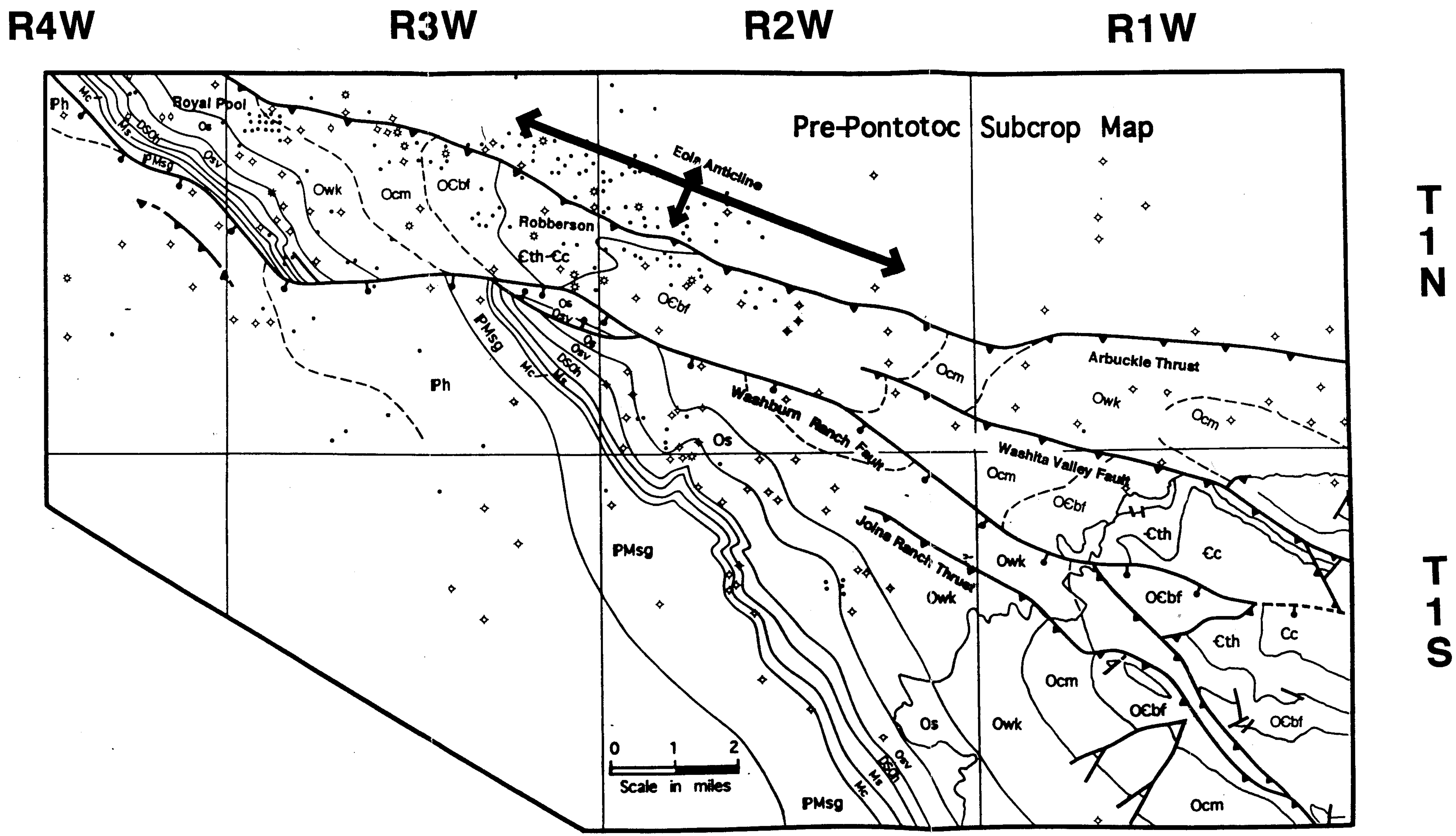
at a relatively low angle or must flatten quickly in the Arbuckle Group. The geometry is similar to that of the southeast plunge of the Arbuckle Uplift.

3. Westward decrease in plunge of the Eola Anticline. From an exploration point of view, this means the plunge-out of a prolific trap. Subsidiary structures developed from detachments higher in the section, which accommodate decreasing fault displacement (possible exploration targets), may also be present to the northwest.
4. Westward increase in preserved back-limb structures as the uplift plunges. These structures are present throughout the Arbuckle Uplift, however, many have been removed by erosion due to the steep dip of, and increased elevation of the uplift in the Eola-Robberson region. The along-strike decrease in elevation combined with the plunge of the Arbuckle Uplift, make possible the presence of these structures, many of as hydrocarbon traps.

Subcrop Map

Figure 42 is a geologic map combining the present-day outcrop of the Arbuckle Uplift and a subcrop map on the pre-Pontotoc unconformity along the northwest continuation of the uplift. This map was created to illustrate the aerial extent and relationships of the faults discussed and the styles of deformation along the buried Arbuckle Uplift.

Figure 42. Subcrop map of the Arbuckle Uplift created on the pre-Pontotoc unconformity. The outcrop exposures are tied into the subcrop map to extend the contact patterns beneath the on-lapping younger sediments.


R4W
R3W
R2W
R1W
T1N
T1S
Pre-Pontotoc Subcrop Map
Royal Pool
Robberson
Eola Anticline
Arbuckle Thrust
Washburn Ranch Fault
Washita Valley Fault
Joins Ranch Thrust
Owk
Ocm
OЄbf
Єth-Єc
Os
Osv
DSOh
Ms
Mc
PMsg
Ph
Єth
Єc
0 1 2
Scale in miles

Arbuckle Uplift

The Arbuckle Uplift is a hanging-wall structure of the Arbuckle Thrust. It is bounded to the north by the buried trace of the Arbuckle Thrust which is well documented from subsurface data. The present outcrop and sub-crop pattern of the Arbuckle Uplift is determined by the geometry and relative displacement along the Arbuckle Thrust, and level of erosion and magnitude of extension along the Washburn Ranch Fault.

Near the western edge of its surface exposure, the Arbuckle Uplift is composed of three imbricate thrust blocks; the Arbuckle Anticline, the Garrison Creek Anticline, and SE Hoover thrust sheet. As the uplift plunges under onlapping Permian sediments, the width of the subcrop pattern narrows. The Garrison Creek and Washita Valley Faults, which imbricate the exposed northeastern edge of the uplift, respectively sole-out with the Arbuckle Thrust and die out along strike, simplifying the subcrop pattern.

This significant subcrop pattern plunges to the northwest and is interrupted by the Washburn Ranch Fault, an erosional reentrant in the Arbuckle Thrust near Eola Field, and an apparent uplift indicated by a doubly-plunging anticlinal pattern in the Robberson area.

Contacts forming the southern boundary of the exposed anticline wrap around to the north as the Arbuckle Uplift plunges under Permian sediments. In subcrop, the Springer-Caney contact trends northwestward toward the south boundary of the Robberson area. Here the contact is truncated by the subcrop trace of the

Washburn Ranch Fault which then becomes the southern boundary of the Arbuckle Uplift.

Dip of the Arbuckle Thrust is steepest near the Eola-Robberson area. The steeper dip accounts for the higher structural and topographic elevation of the hanging wall anticline which allowed for erosion to cut deeper into the hanging wall, creating an anticlinal subcrop pattern, along with forming an erosional reentrant in the subcrop trace of leading edge of the thrust. The anticline plunges in two directions away from the Robberson area as the Arbuckle Thrust becomes more shallow in dip. Thus, the doubly-plunging "anticline" at Robberson is the result of a local change in the geometry of the Arbuckle Thrust, rather than a local increase in displacement of the Arbuckle Thrust.

Washita Valley Fault

In the Garrison Creek area, outcrop exposures of the Washita Valley Fault display relatively little stratigraphic offset, placing lower Arbuckle strata over middle Arbuckle rocks. In the subsurface, the Washita Valley Fault loses displacement to the northwest, and appears to die out as it approaches the Eola-Robberson region. Alternatively, the Washita Valley Fault may be interpreted as turning to the northwest, re-joining as a splay with the Arbuckle Thrust just west of section 31 of T.1 N., R.1 W. Lack of deep wells in this area and relatively minor offset along the Washita Valley Fault, make a definitive answer difficult. However, due to increased erosion and the plunge of the Arbuckle Anticline, the erosional trace of a southwest dipping fault losing displacement, which subsurface data indicates the Washita Valley Fault is, should deflect toward the south.

Joins Ranch Thrust

The Joins Ranch Thrust is a low-angle fault located on the downthrown hanging wall of the Washburn Ranch Fault. As the Joins Ranch Thrust loses displacement northwestward, the hanging wall of the Washburn Ranch Fault (on which it is contained) increases in displacement northwestward.

Off the northwest plunge of the south flank of the Arbuckle Anticline, there is an unnamed anticline in the Viola located near sections 9 and 10 of T. 1 S., R. 2 W. This anticline is similar in structural and stratigraphic position to the Woodford and Spring Creek Anticlines, which are exposed to the southeast. Down-plunge relationships suggest that the unnamed anticline is a cross-crestal structure that compensates for loss of displacement along the Joins Ranch Thrust. Alternatively, the location of this anticline is compatible with that of an up-plunge structure, also an adjustment for the loss of displacement along the Joins Ranch Thrust.

Washburn Ranch Fault

The Washburn Ranch Fault is a normal fault with down-to-the-south displacement. The Washburn Ranch Fault has an arcuate surface trace which extends obliquely across the buried uplift, truncating previously formed compressional features. Maximum displacement is in the vicinity of the Robberson area, near the crest of the fault's arcuate surface trace. This also coincides with the steepest dip of the Arbuckle Thrust and development of greatest footwall shortening. The Washburn Ranch Fault is interpreted to link with the Arbuckle Thrust at basement ramps allowing the Washburn Ranch Fault to inherit the basement decollemont of the Arbuckle Thrust, forming its listric (concave upward) geometry. The listric interpretation explains the variation in displacement along strike as well as the arcuate fault shape.

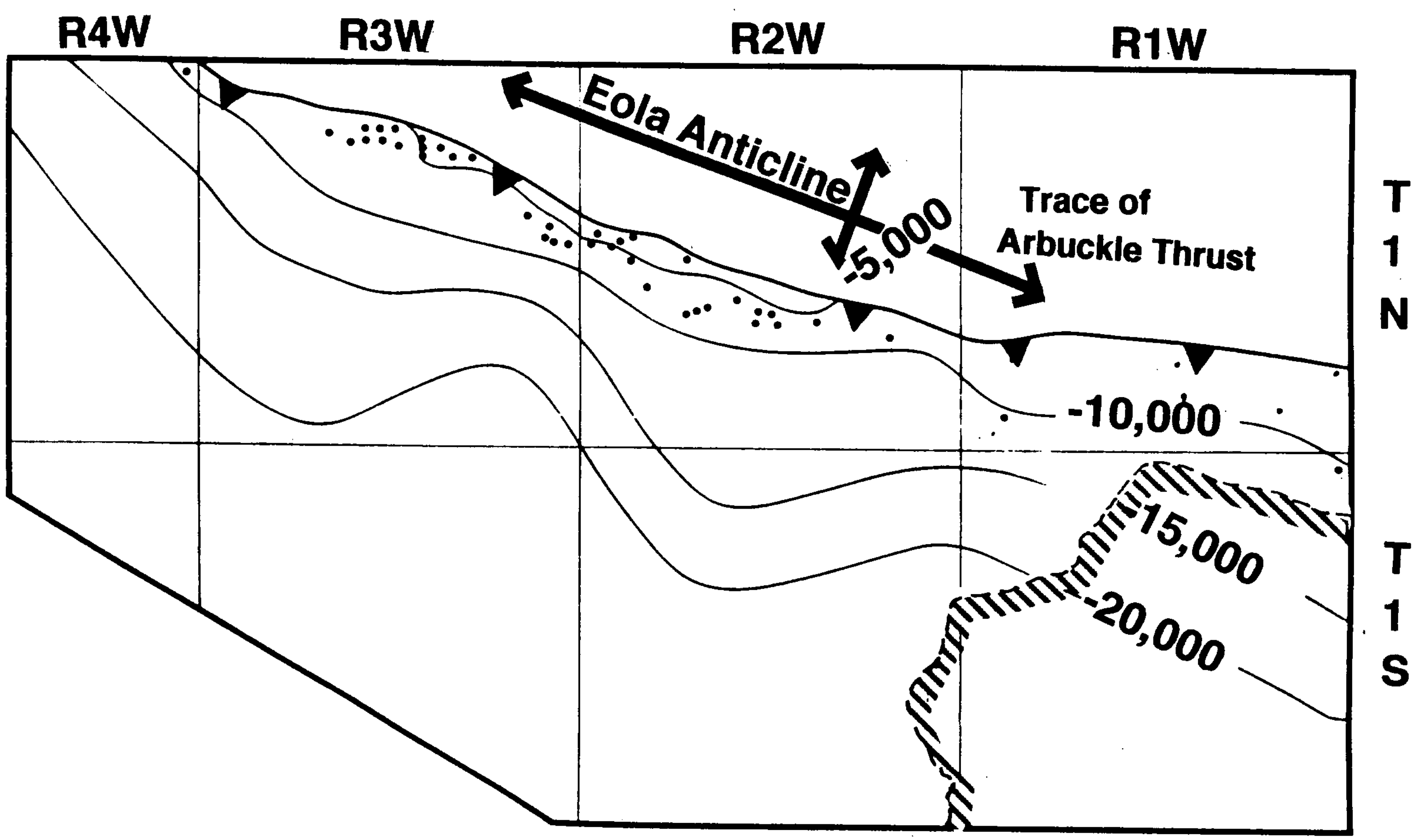
Timing of the Washburn Ranch Fault is constrained by its relationship to other structural features. The Washburn Ranch Fault cuts across the Arbuckle Uplift displacing the hanging wall and truncating N60°W trending thrusts and folds. No offset is observed in the overlying Permian strata, implying that the Washburn Ranch Fault post-dated the uplift but predated the erosional cover.

Structural Contour Map of the Arbuckle Thrust

Figure 43 is a structural contour map of the Arbuckle Thrust plane, contoured on 5,000 foot intervals. This map illustrates changes in fault-plane geometry along strike and yields insights into the relationship of the hanging wall to the footwall. This map can be divided into three intervals of related patterns: the southeastern area, the middle area, and the northwestern area.

Figure 43. Structural contour map of the Arbuckle Thrust plane based upon well control and previously presented series of cross sections.

Structural Contour Map of the Arbuckle Thrust



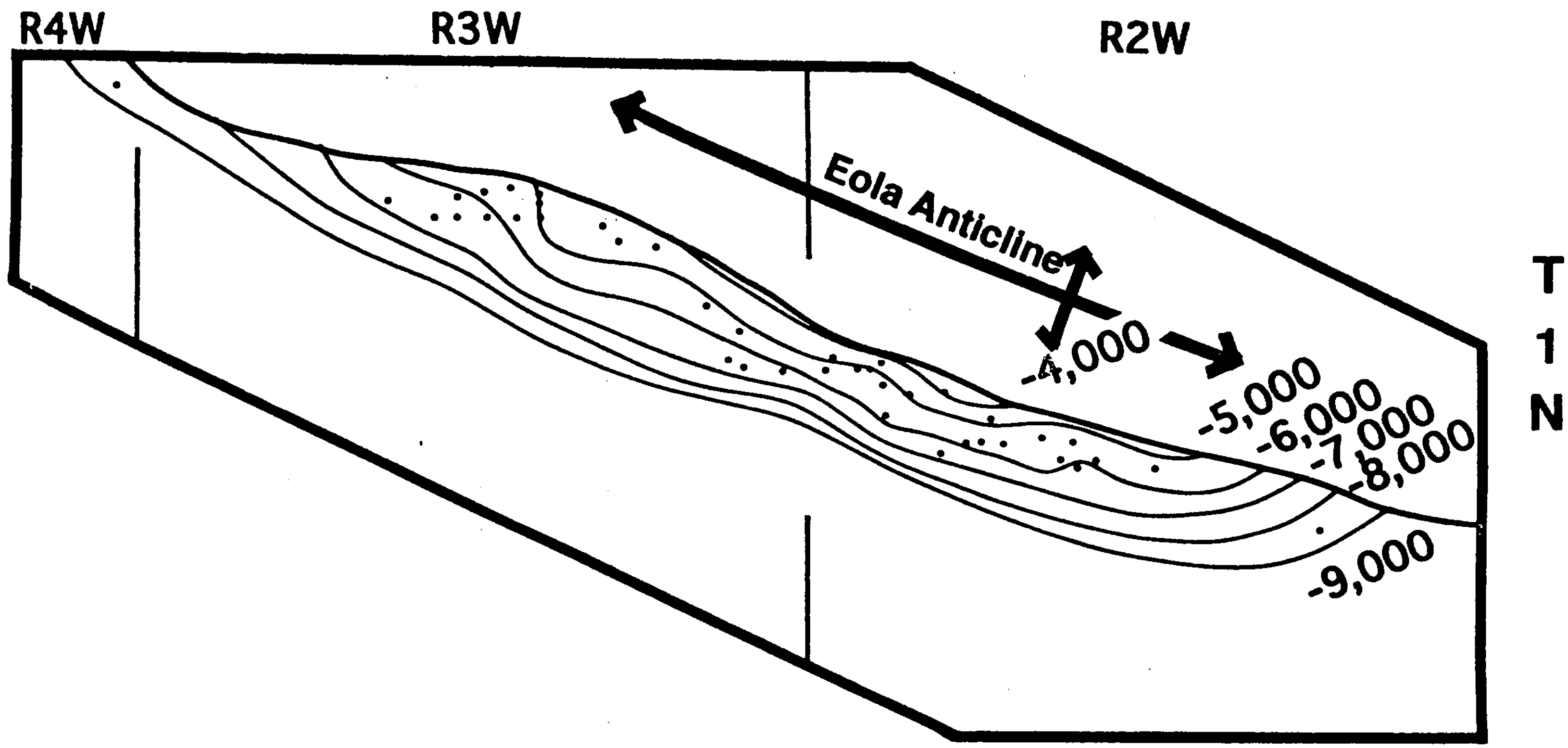
The southeastern area corresponds to the fault-bend fold geometry of the outcropping Arbuckle Anticline. The contours are spaced further apart in the northeast than the southwest indicating the ramp and flat in the Arbuckle Thrust. Northwestward, the further-spaced contours which define the flat are truncated by the erosional reentrant of the trace of the Arbuckle Thrust.

The middle portion corresponds to the area near Eola Field. Here the fault contours are closely spaced, reflecting the steep dip of the ramping Arbuckle Thrust. The contours show two divergent "warps". One is concave to the southwest and affects most of the thrust. The other is located adjacent to the erosional trace of the fault, is less severe than the other, and is concave to the northeast. The concave southwest warp appears to be due to a northern bowing in the footwall cut-off of the Arbuckle Thrust. The southwestern warping affects the area of the Arbuckle Thrust adjacent to Eola Anticline. This portion of the Arbuckle Thrust was folded by Eola Anticline as it grew underneath the overlying Arbuckle Thrust.

Figure 44 is an enlargement of the northern area, contoured on 1,000 foot intervals. This figure shows the relationship of the northern "warp" to the Eola Anticline. The area of maximum folding of the Arbuckle Thrust is directly across the area of maximum elevation of Eola Anticline. Eola Anticline plunges to the northwest and southeast, corresponding with the decrease in "warping" of the Arbuckle Thrust. This relationship is evidence that Eola Anticline, as a footwall structure to the Arbuckle Thrust, was deformed subsequent to the emplacement of the Arbuckle Thrust and therefore

Figure. 44. Structural contour map of the Arbuckle Thrust highlighting the area near Eola Field. Younger deformation of the footwall which formed Eola Anticline may have uplifted and folded the overlying Arbuckle Thrust.

<10,000' Contour Interval (AT)



uplifted and folded the Arbuckle Thrust. More discussion regarding the relationship of the fault-contour map and Eola Field is offered in the Structural Synthesis portion of the thesis.

The northwestern portion corresponds to the area of Royal Pool. Here the uplift is plunging-out along abrupt basement ramps that shallow on the Arbuckle carbonates before resuming relatively steep dips.

STRUCTURAL SYNTHESIS

Introduction

The purpose of this section is to integrate the structural geometry presented in the previous structural analysis, with that of the entire Arbuckle Uplift and to discuss the relationship and implications of this geometry within the framework of the southern Oklahoma foreland.

Inherited Weaknesses

Cambrian rifting undoubtedly imparted a strong, if imperfectly understood fabric(s) to the basement of southern Oklahoma. Anisototropies and fabrics imparted include normal faults which are probably down-to-the-south and listric, infill sediments, and layered volcanic sequences, all of which impart a "layering" to the basement within the rift. The rift-craton boundary defines a contrast in mechanical properties of the basement. The influence of the differing mechanical properties on structural styles resulting from subsequent Pennsylvanian deformation is quite evident in outcrop. Uplifts formed within the cratonic basement (Tishomingo Uplift) are bounded by faults which dip 45 degrees or more whereas uplifts cored by "layered" basement show geometries more often associated with fold and thrust belts. The exact location and geometry of this important boundary is not known due to depth of burial and the inability of current seismic methods to resolve useful images at such depths and under structural complications.

The rift likely behaved as a large, layered mechanical trough. Subsequent horizontal compression at a wide variety of angles to the rift boundary could have shortened the rift, generating out-of-the-basin thrusting. Structures resulting from such a situation would reflect not only local stresses (specific to individual uplifts or segments of uplifts) but reflect a regional pattern at the scale of the uplift. Analysis of these structures might indicate something about the state of stress within the shortened rift, but is much less likely to be specific about the supra-regional stress(es) which shortened the rift.

Rift-induced structural grains and boundaries may have influenced shortening in the following ways:

1) Normal faults may have become re-activated as either reverse, oblique-reverse, or strike-slip faults. Re-activation of normal faults as oblique or dip-slip reverse faults was most likely along flats or fault segments of very low dip because the amount of sliding friction needed to be overcome by a horizontal compressive force is significantly less where the shear stress is nearly parallel to the fault surface.

2) The rhyolite/granite boundary may have acted as a locus for the formation of fault ramps. Fault scarps of down-dropped granite blocks may have had a similar influence on the location of ramp formation in a overlying thrust fault.

3) Layer-parallel anisotropies in volcanic rocks and in-filling rift sediments may have exherted mechanical control or influence on the location and geometry of later thrusts.

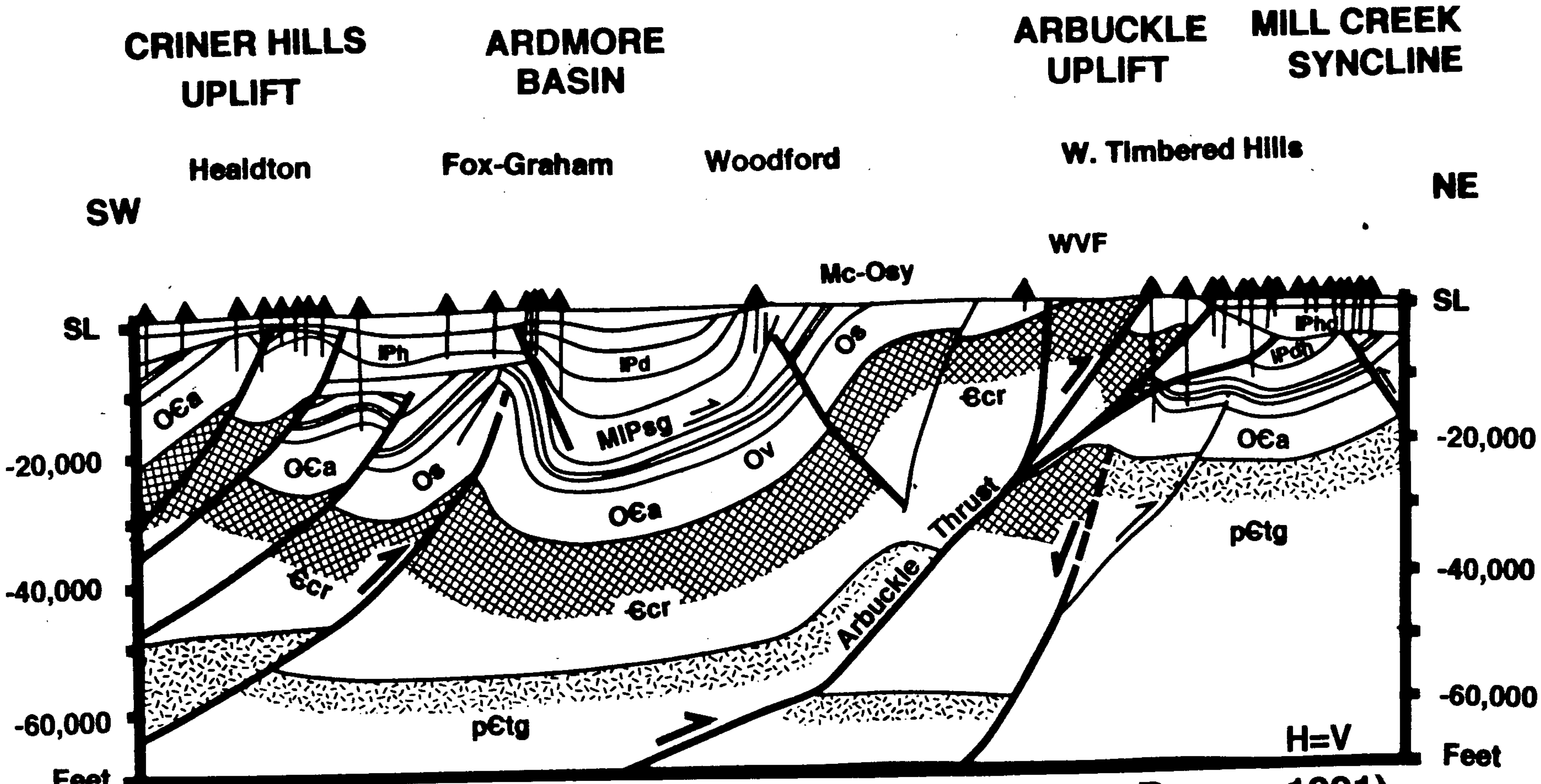
It is important to note that because of the previously mentioned uncertainties and lack of deep control, these concepts must be regarded as speculative.

Geometry of the Arbuckle Uplift

Recent studies by Brown (1984), Palladino (1986), Beck (1987), and Bixler and Willis (1993) have yielded insights into the style of deformation and structural geometry of the Arbuckle Uplift. These studies show the Arbuckle Uplift was formed as a result of northeast-vergent thrusting along the Arbuckle Thrust. In his regional cross section (fig. 45), Brown (1984) speculated that the uplifts of southern Oklahoma may be related by a common basement decollement. Using extensive seismic data, Cooper (1992) reached a similar interpretation.

Figure 46 combines the surface and subcrop maps of the Arbuckle Uplift. The combined maps show the Arbuckle Uplift to be a continuous, doubly-plunging anticline, with the characteristic "bow and arrow" map pattern of thrust sheets (Elliot, 1976). To form this pattern, the greatest amount of dip-slip transport occurs in the area of maximum convexity of the fault trace and decreases along either flank. If the fault geometry consists of two flats

Figure 45. Regional cross section through southern Oklahoma showing a possible regional basement decollement. The presence of such a detachment would help explain the southwest-to-northeast timing of deformation and the northeast vergence of the basement involved structures within the southern Oklahoma foreland (from Brown, 1991)



(modified from Brown, 1991)

separated by a ramp (as in cross section A-A'), and the maximum slip transports the hanging wall over the ramp (dip-slip motion) onto the upper flat, the hanging wall forms a fault bend fold. Decreasing slip to either side fails to push the hanging wall up and over the ramp, resulting in a progressive geometrical interchange along strike from fault-bend fold, to “snakehead” anticline, to fault-propagation fold (fig. 47). This progressive change in geometry, characteristic of dip-slip motion, occurs in the Arbuckle Uplift from cross sections A-A' to G-G' Interruption of the "bow and arrow" pattern occur locally at SE Hoover, which exhibits imbrication, and at Eola, where the Arbuckle Thrust is folded by severe footwall shortening. The exposed Arbuckle Anticline is located near the center of the “bow”, which is the area of maximum transport (about 8 miles). Here the uplift is characterized by a basement-cored fault-bend fold. The geometry changes symmetrically (fig. 46) along either plunge; fault-bend folding give way to the formation of “snakehead” anticlines as displacement decreases. Further down plunge, large flats develop in the sedimentary section, particularly in the Arbuckle Group carbonates. Comparison of figures 40 and 41 (cross sections across the northwest plunge) with figure 7 (cross sections across the southeastern plunge) reveals that the structural styles are similar. Northwest of the study area, the Arbuckle Uplift may continue as the Carter-Knox Anticline, a northest-vergent fault-propagation fold.

The geometry of the Arbuckle Uplift is further influnced by the "scallop" shape of the Arbuckle Thrust (fig. 47). On a thrust fault which is “scallop”-shaped in strike profile (concave upward, rising

Figure 46. Combined surface and subcrop map for the entire Arbuckle Uplift. The wide outcrop pattern in the middle corresponds to fault-bend fold geometry and maximum reverse dip-slip transport (in a southwest to northeast direction). As the uplift plunges in either direction long flats are developed within the Arbuckle Group.

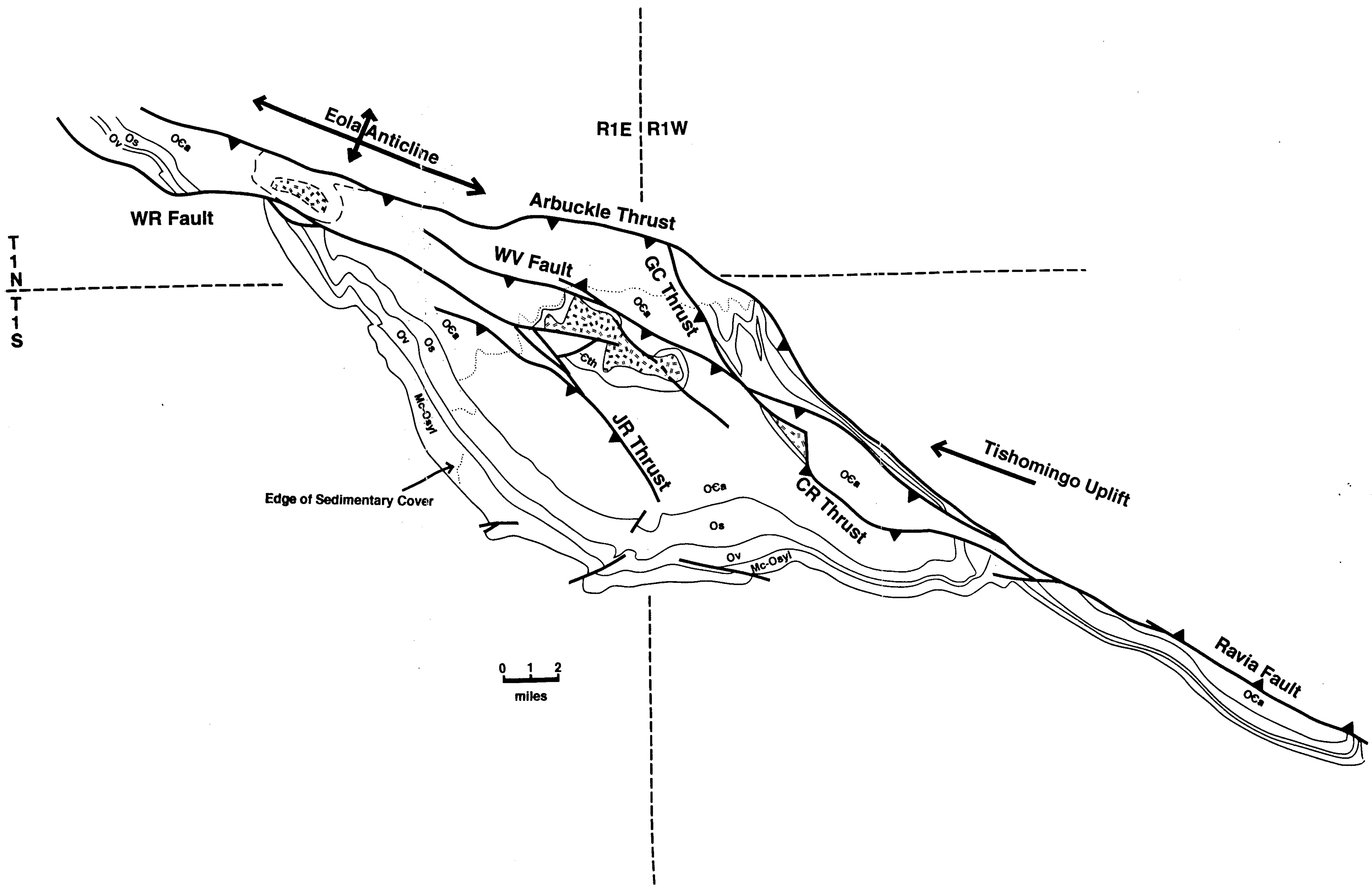
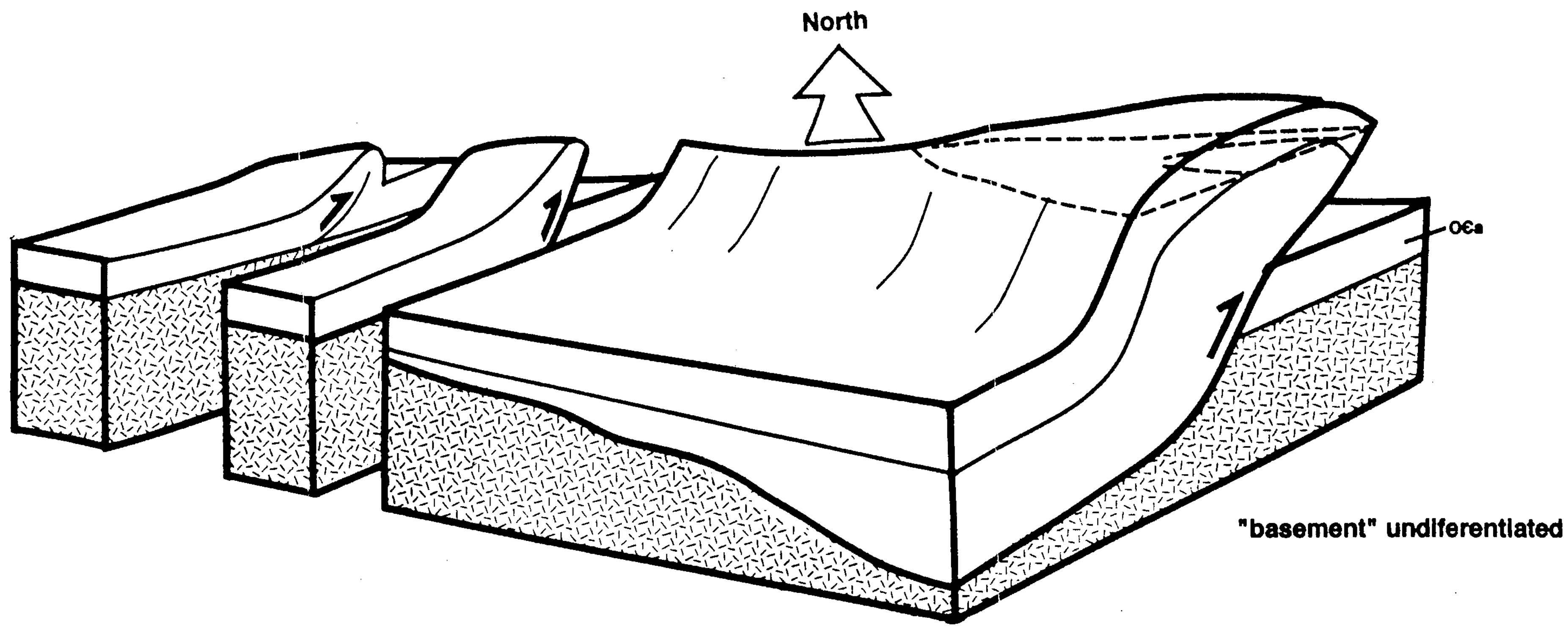
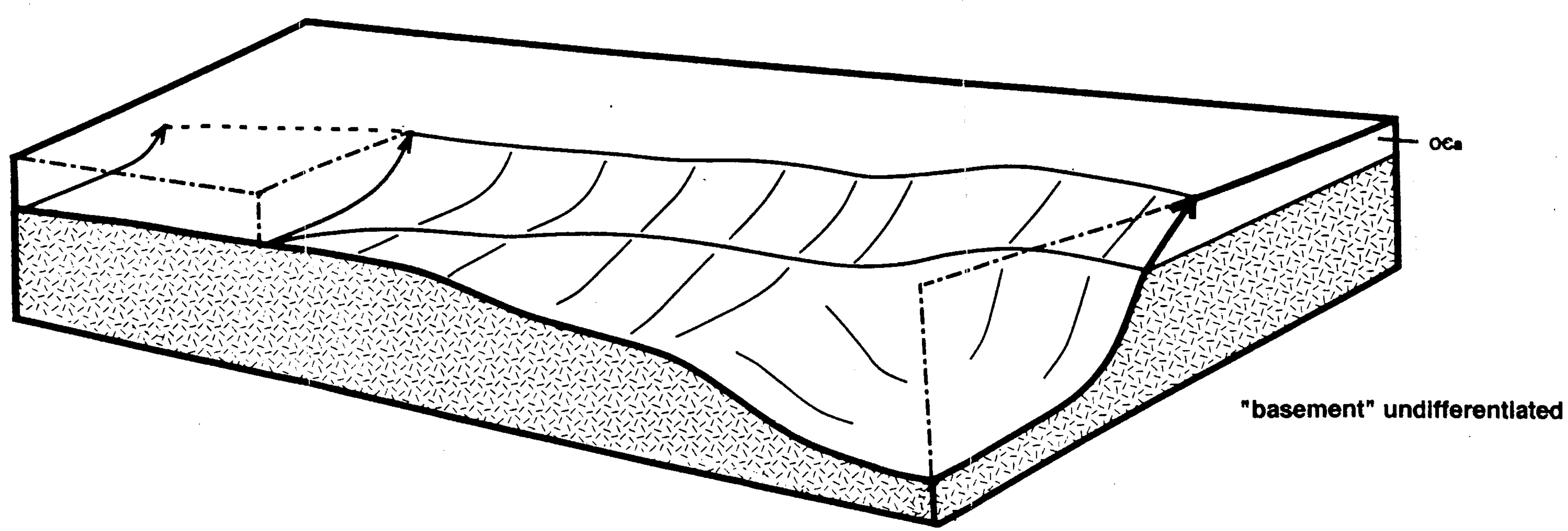

Eola Anticline
R1E
R1W
Arbuckle Thrust
WR Fault
T
1
N
T
1
S
WV Fault
GC Thrust
JR Thrust
CR Thrust
Tishomingo Uplift
Ravia Fault
Edge of Sedimentary Cover
Ov
Os
O€a
€th
Mc-Osyl
0 1 2
miles

Figure 47. Schematic block diagram depicting the hanging wall geometry of the northwest plunge of the Arbuckle Uplift in relation to the shape of the Arbuckle Thrust and differential dip-slip movement. The Arbuckle Thrust rises in relative elevation to the northwest, coincident with progressive decrease in dip-slip transport. The result is that the hanging wall not only changes from a fault-bend fold to a fault-propagation fold, but the thickness of basement in the hanging wall decreases along plunge. Note that if the Arbuckle Thrust had a significant component of left-lateral motion, the upper plate have to move down-dip, forming a structural style of extension rather than the observed style of shortening.


North
OЄa
"basement" undiferentiated


OЄa
"basement" undifferentiated

on either side laterally along strike), dip-slip transport of the hanging wall up a ramp to a flat forms a doubly plunging anticline which, in map view, is an inverted image of the scallop shape.

When addressing slip direction, lateral changes in fault geometry become important. The location and geometry of the hanging wall structures constrains the range of slip directions. In the case of the Arbuckle Uplift, large components of left-lateral strike-slip motion along the Arbuckle Thrust can be ruled out. Lateral motion parallel to the trace of the Washita Valley Fault or Arbuckle Thrust would entail low-angle dip-slip normal faulting along the western plunge end of the uplift given left-lateral motion, or along the eastern plunge end of the uplift given right lateral motion. The resultant structural style would be that of extension along a detachment plane (Arbuckle Thrust) on the trailing plunge end of the Arbuckle Uplift (fig. 47). Extension would balance, or come close to balancing the shortening. Clearly such a geometry and large-scale extension do not typify the outcrop/subcrop pattern of the Arbuckle Uplift. Extension present in the Washburn Ranch Thrust is not within the correct orientation or of the neccesary magnitude for either left- or right-lateral motion. Additionally, the extension along the Washburn Ranch Fault clearly post-dates the shortening which formed the Arbuckle Uplift. Extension associated with large lateral motion would be coincident with shortening elsewhere along the fault.

Eola region

The area near Eola and Robberson Fields is of interest because it is where several interrelated structural features show cause-and-effect relationships. These features are directly across from each other, one, in the hanging wall and one in the footwall of the Arbuckle Thrust.

The deformation of the Arbuckle Thrust by shortening of the footwall to form Eola Anticline was addressed in the discussion of the contour map of the Arbuckle Thrust plane. The relationship of Eola Field and the "folded" part of the Arbuckle Thrust is offered as evidence of a lack of major lateral motion along the Arbuckle Thrust. Other relationships which strengthen this assertion, exist along this portion of the Arbuckle Uplift and are addressed here.

Figure 48 is a map that plots the footwall cut-off of the Arbuckle Thrust and the surface-subcrop trace of the Washburn Ranch Fault on the fault-plane contour map of the Arbuckle Thrust. The following occur in a northeast-southwest line perpendicular to the axis of the Arbuckle Uplift:

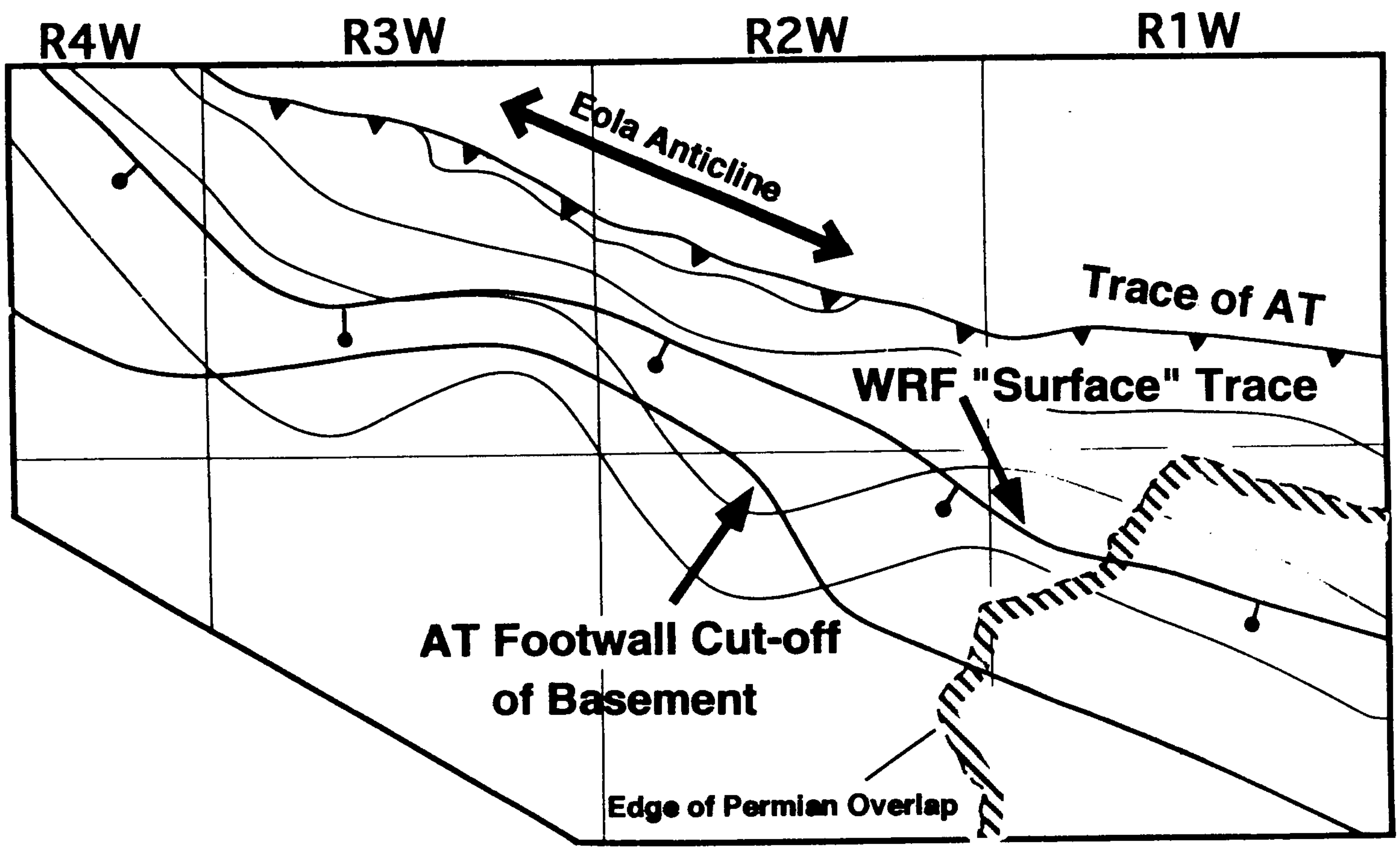
1) The Arbuckle Thrust is steepened and folded by footwall deformation at Eola.

2) The trace of the footwall basement cut-off of the Arbuckle Thrust makes a marked indentation to the northeast immediately adjacent to Eola Anticline.

3) The trace of the Washburn Ranch Fault makes a marked indentation to the northeast.

Figure 48. Map showing the relationship between the Arbuckle Thrust fault plane, footwall cut-off, and subcrop trace of the Washburn Ranch Fault. If the Washburn Ranch fault dips to the southwest and links with reactivated basement ramps of the Arbuckle Thrust, then its position should mimic the footwall cut-off of the Arbuckle Thrust which will be to the southwest.

Fault Relationship Map



4) The Washburn Ranch Fault reaches maximum displacement directly across from Eola Anticline.

5) Eola Anticline and the hanging-wall of the Arbuckle Thrust reach maximum structural elevation.

6) Maximum thicknesses of Pontotoc conglomerate are collected in the footwall syncline, and over Eola Anticline. Near the Arbuckle Thrust they contain greater amounts of Arbuckle carbonate clasts and "granite" wash.

These features are related in the following manner:

The Arbuckle Uplift developed by fault-bend folding of the hanging wall the Arbuckle Thrust. In the Eola region, the Arbuckle Thrust footwall was shortened and thrust northeastward. Development of the footwall anticline lifted and folded the overlying Arbuckle Thrust. Increased elevation of the Arbuckle Uplift allowed for deeper erosion, sourcing the Pontotoc conglomerate with an unroofing sequence of Arbuckle clasts and "granite" wash. The conglomerate was collected in the footwall syncline between the Arbuckle Thrust and Eola Anticline, which was cored by easily-eroded Goddard shales.

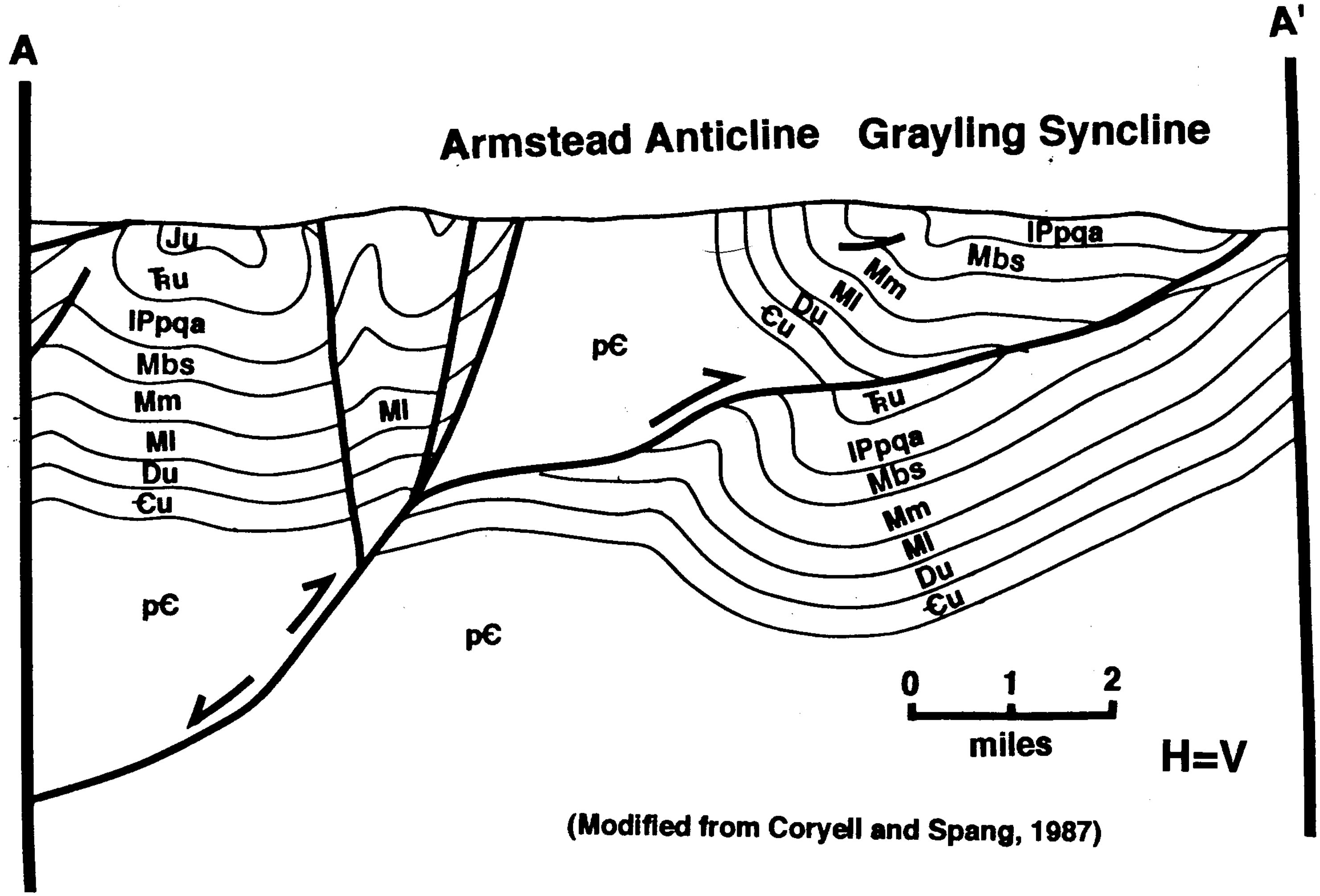
The tilted hanging wall was mechanically unstable and, during a period of relaxation of the principal compressive stress at the end of the orogeny, the Washburn Ranch Fault developed, which linked with the footwall basement ramp of the Arbuckle Thrust. This relationship is demonstrated by the subcrop trace of the Washburn Ranch Fault which stays to the north of the trace of the basement cut-off of the Arbuckle Thrust, mimicking its sinuous trace.

Post-Compression Extension

Overprinting of the previously-formed compressional styles by extensional deformation in a manner which reactivates pre-existing faults, has been documented in several compressional regimes. In thrust-belts, the extension takes the form of normal faults in the hanging wall which localize above, and cut down to join with, ramps (Dahlstrom, 1970, Royse and others, 1975). Because the various thrusts are linked by a common regional basal decollement, the extension may occur at several ramps within one thrust sheet. In basement-cored individual uplifts of the Rocky Mountain foreland, collapse of the uplifts occurs along normal faults which merge with the root-zone of the thrust that raised the uplift (Sales, 1983, Coryell and Spang, 1988). The extension can be of nearly the same magnitude as the compression (fig. 49).

There is some question as to whether or not structures of the southern Oklahoma foreland are individual uplifts or are related by a regional decollement (Cooper, 1992). If they are related by a decollemont, then the extension present in the Washburn Ranch Fault may be present in other structures along the same decollement. Several other prominent structures of southern Oklahoma, including Velma Anticline and the Criner Hills, show down-to-the-south normal faulting on their southern flanks. Normal dip slip motion of the Meers Fault, in the Wichita Mountains, creates a suspended basement block geometry remarkably similar to that of numerous Rocky Mountain uplifts.

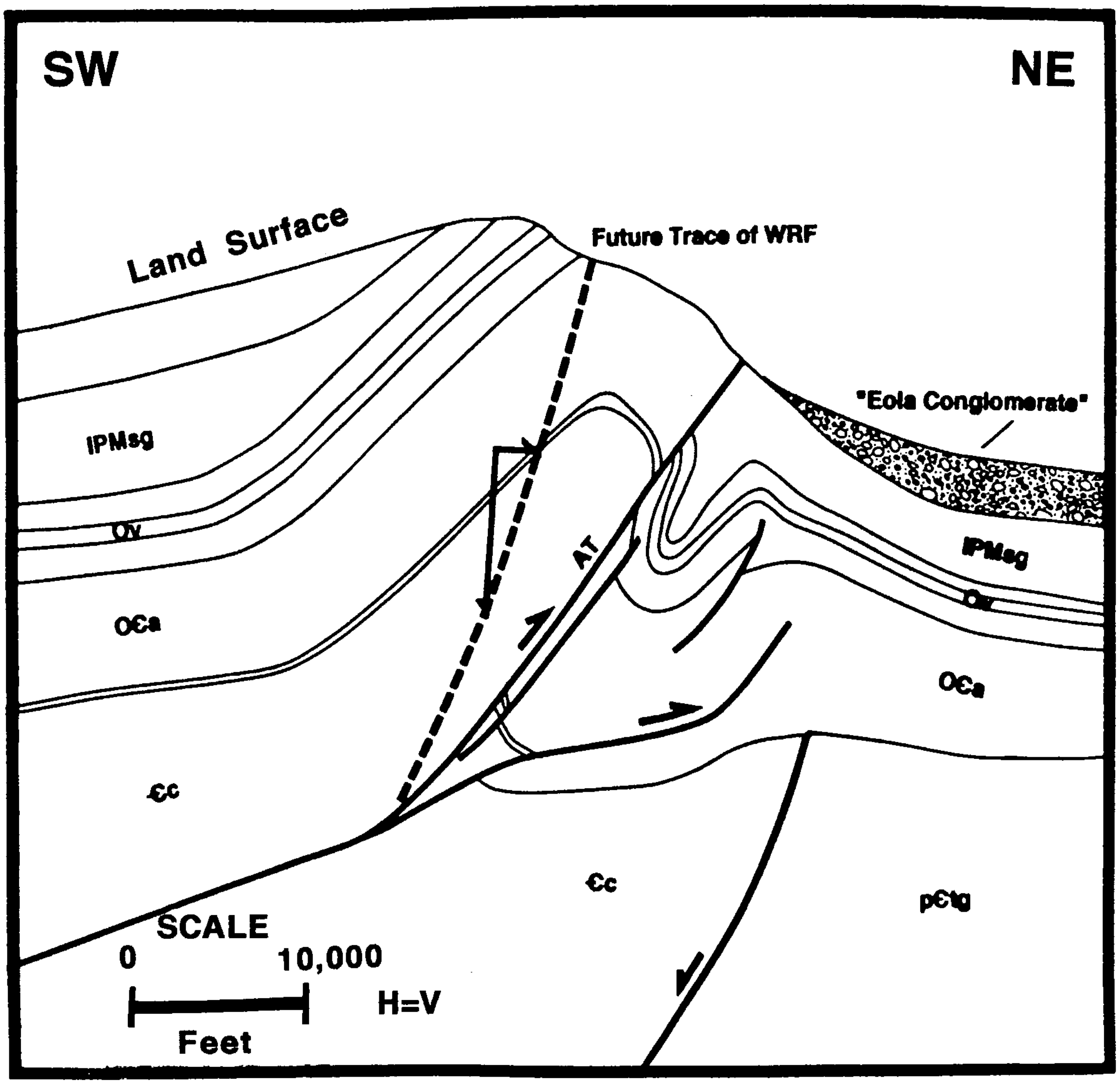
Figure 49. Cross section across Armstead Anticline in southwest Montana illustrating the geometry of a "beheaded" basement-cored uplift. Extension on the normal fault has lowered the basement to it's previous structural elevation. Compare geometry with cross sections in the Eola region (modified from Coryell and Spang, 1987).



(Modified from Coryell and Spang, 1987)

Little research has been directed towards the study of basement collapsed structures, and, as a result, much remains unknown about them. Sales (1983) speculated that the cause of collapse of Rocky Mountain uplifts was due differences in gravity between the relatively dense basement-cored uplifts and the less-dense, synorogenic sediments. The less dense synorogenic sediments lacked the mechanical ability to support the basement-cored uplifts. The basement-cored uplifts failed along normal faults which merged with the root of the fault zone which had originally raised the uplift. Similar reasoning may be applicable to the Arbuckle Uplift (especially in the Eola-Robberson area) which was being continuously eroded as it was being uplifted, forming a prominent topographic high and generating vast quantities of sediments (Tommlinson and McBee, 1958). At Eola, footwall deformation helped to tilt back the hanging wall southward which was already highly elevated by a steep ramp. Thus, at the Robberson area, the dense basement formed prominent topographic high and, without supporting synorogenic material, a sharp density-gravity differential. The steep dip of the Arbuckle Thrust lessened the area across which the downward gravitational force acted, further concentrating the stress on the back limb of the uplift. The compressive forces which helped push the Arbuckle Uplift up the Arbuckle Thrust were relaxed (end of the Arbuckle Orogeny). The forceh had acted in opposition to the gravity-density contrast and mechanically supported the structurally and topographically high Robberson area. The withdrawal of compressive forces locally shifted the maximum stress from compressive support up the

Figure 50. Cross section through Eola region at the end of the Arbuckle Orogeny. Elevation of the uplift is controlled by restoring the unconformity on the hanging wall of the (incipient) Washburn Ranch Fault. Minimum elevation would be 10,000 feet above present sea level. The restored section shows the asymmetry of erosion formed by the hanging wall rising into a shallow sea.


SW
NE
Land Surface
Future Trace of WRF
"Eola Conglomerate"
IPMsg
Ov
O€a
€c
AT
IPMsg
Ov
O€a
€c
p€tg
SCALE
0
10,000
Feet
H=V

Arbuckle Thrust, to extension back down the Arbuckle Thrust, forming the Washburn Ranch Fault, which merged with the Arbuckle Thrust at depth. This hypothesis explains the timing as well as the geometry of the major fault systems within the study area.

Figure 50 is a cross section (D-D') through the Eola region restored along the hanging wall of the Washburn Ranch Fault. The restored elevation of the present-day pre-Pontotoc unconformity is a minimum value for the elevation of the Eola region just prior to extension. The slope of the erosional surface on the northeastern flank was drawn along the angle of the line connecting the restored hanging wall unconformity and the base of the Pontotoc unconformity in front of Eola Anticline. The topographic elevation of the restored section is nearly 10,000 feet above present sea level. Because the restored unconformity probably includes a component of post-extensional erosion, it is likely that the elevation was a few thousand feet higher. Although at this location there is considerable throw on the Washburn Ranch Fault, because of its steep dip (within the hanging wall of the Arbuckle Thrust), the heave (true measure of extension) is much smaller.

Restoring the hanging wall raises the bottom of the Ardmore Basin, creating an asymmetric paleo-topography at maximum elevations of 10,000 to 15,000 feet above present-day sea level. This topographic restoration explains why thick accumulations of Pontotoc conglomerate occur northeast of the Arbuckle Uplift whereas southwest of the uplift, in the Ardmore Basin, contemporaneous deposits are much thinner. The paleo-topographic elevation decreases in either direction along strike from the

Robberson area. Correspondingly, the thickness of preserved Pontotoc conglomerate also decreases. This juxtaposition of maximum paleo-topographic elevation and maximum accumulation of synorogenic conglomerate strongly supports the thrusting and post-uplift collapse interpretation. Collapse along the Washburn Ranch Fault must have taken place soon after compression because it is overlain by unfaulted Permian redbeds.

TECTONIC DISCUSSION

Introduction

Modern plate tectonic theory shows that during the Late Pennsylvanian a variety of principal stresses at various orientations could have affected southern Oklahoma. Clearly a measurable amount of shortening took place across the Southern Oklahoma Aulacogen. However, care must be taken in trying to use geometric arguments (strain) to reconstruct tectonic settings (stress).

As previously mentioned in the Structural Analysis Section, stresses oriented at a wide variety of angles to the boundaries of the initial Cambrian rift basin could generate compression resulting in out-of-the-basin thrusting. Present-day structures record the strain suffered by the aulacogen and the local stress fields, but may not directly reflect the regional stress which acted upon the initial rift basin. Any theory presented must, however, be able to explain the vergence of the uplifts towards the northeast, the low-angle thrusting, and crustal shortening, and apparent southeast to northwest sequence of deformation.

Two general schools of thought dominate interpretations of the deformation of the Southern Oklahoma Aulacogen; the first is that the dominant style observed is a result of largely left-lateral strike-slip motion (or "transpressive" strike-slip motion), the other being that the deformation occurred along dominantly dip-slip reverse faults. Both interpretations of regional deformation will be examined and compared in light of the evidence presented in this study.

Strike-Slip and Transpressive Deformation

To preface this argument, a clear definition of "transpression" a word gaining popular usage, must be given. It is best to use caution when encountering this word. "Transpression", as first used by Harland (1971), refers to stress at an angle oblique (neither parallel nor perpendicular) to a plane across which it acts. Though inherently an extremely broad term describing a state of stress, it has been used to explain a variety of very different geometries (strains) and to infer a structural style. The term brings to mind: a local geometry on a strike-slip fault (Sylvester, 1976), a regional explanation for patterns in thrust belts (Harland, 1971), oblique low-angle basement thrusting (Donovan, 1986), or regional state of stress that may imply various structural styles (Namson and Davis, 1988). Because the term implies different things to different people, and the original usage of transpression as a stress term is so vague as to be virtually meaningless (virtually all faults are wholly or partially transpressive in this usage), I argue for the removal of this term from the geologic vocabulary.

Traditionally, interpretations of strike-slip faulting in Southern Oklahoma have called upon major uplift-bounding faults to be high-angle (nearly vertical). Clearly, the Arbuckle Thrust does not fit this description. The observation can be made that a fault which was initially at a low angle can be rotated to a steeper angle of dip by imbrication or other deformation of the footwall. Thus, the presence of a fault with a high angle of dip need not exclude a reverse fault interpretation. Many areas held as example of "high angle" faulting (Eola Anticline, Velma Anticline) can be shown to be considerably shortened by imbricate thrusting.

Interpretations involving strike-slip motion in Southern Oklahoma run into several problems with material balance. Numerous instances of demonstrable left-stepping bends, which should produce pull-apart basins on a left-lateral strike-slip fault, show either no extension, or, most often, northeast-vergent compressive structures (Mills Ranch Field). Additionally, many faults and uplifts die into folds and detachment structures. Strike-slip faults cannot simply end as fault tips. Most modern strike-slip systems accommodate strain at either end by linking with transform systems or accommodating either shortening or extension in fault systems located roughly perpendicular to the trend of the strike-slip system. Clearly no such orientation of structures exists within the Southern Oklahoma Aulacogen.

Recent work by Namson and Davis (1988) along the San Andreas strike-slip system in California has shown that it is possible to develop a dual structural style that resolves the regional stress into shear and compressive components. The result is a strike-slip fault bounded to either side by a thrust-belt, perpendicular to the trend of the strike-slip fault.

Such a system in southern Oklahoma is possible, though unlikely, because of the overall asymmetry of the uplifts to the northeast and the lack of conclusive proof of a major strike-slip fault south of the Arbuckle Mountains. Additionally, along the San Andreas Fault, the strike-slip motion is accomadated at either end by transform faults and is driven by plate spreading. No such mechanisms, or counterparts, appear to have existed in southern Oklahoma.

All pervious estimates of lateral motion along the Arbuckle Thrust (Washita Valley Fault System) have been shown to be accountable for by dip-slip or oblique dip-slip motion, or to be based upon unreliable evidence or questionable methods.

Lastly, the state of regional stress to initiate left-lateral strike-slip motion across the Southern Oklahoma Aulacogen is at odds with the current interpretations of plate convergence vectors for the Pennsylvanian and Permian (Kluth and Coney, 1981).

Dip Slip Reverse Faulting

There has been an undeniable northeast-southwest component of shortening across the Southern Oklahoma Aulacogen during the Wichita and Arbuckle Orogenies. However, the vast majority of the literature which attempts to quantify slip along faults within the Southern Oklahoma Aulacogen address only the lateral component of motion across faults which are classified as strike-slip (Booth, 1981, Carter, 1979, Tanner, 1967, Walper, 1970) with no attempt to quantify the amount of shorting and to reconcile the shortening with the postulated lateral-slip. Oddly, this has been the persistent case within the literature even though minimal amounts of shortening can be established and must be explained by any regional tectonic history.

Seismic and well data have clearly established the presence of shortening within the Southern Oklahoma Aulocogen. Major uplift-bounding faults such as the Mountain View Fault and the Arbuckle Thrust are relative low angle faults with geometries akin to those found in the Wyoming foreland. Dip-slip reverse faulting can account for all geometries observed within the Southern Oklahoma Aulacogen, as well as most adequately explain the facies and distribution of synorogenic sediments.

Based on reconstructions of relative plate motions (fig. 14) during the Pennsylvanian (Kluth and Coney, 1981), a stress field that was approximately perpendicular to the trend of the Southern Oklahoma aulacogen is judged to be the most likely to have been in place. Such a stress field would result in shortening the aulacogen. The undeformed aulacogen could be considered akin to a broad syncline, with strata dipping inward from the margins. Compressing the aulacogen is like tightening a syncline, with out-of-the basin thrusts analogous to out-of-the syncline crowd structures. Given the postulated half-graben shape of the aulacogen, the approximately south-to-north direction of regional stress, and the tendency for thrusts to break towards the foreland, it is very possible that the squeezing of the aulacogen resulted in the creation of a northeast-directed fold-belt. Cooper (1992) postulated that a regional decollement underlying the Ardmore Basin could accommodate shear and result in a fold-belt. It may also be possible that shear components could be absorbed by the increase of thrusting along strike and by oblique thrusting.

A compressive tectonic setting would explain observed structural style, observed progression of deformation, and fit in well with recent plate reconstructions.

SUGGESTED FUTURE STUDIES

Many studies need to be done involving the northwestern Arbuckle Uplift. Several possibilities are:

1. A comprehensive structural study of Eola Field. This study should explore the possibility of using a northeast-southwest directed compressive stress in the interpretation. Cross sections should be drawn perpendicular to the B-axis of the fold and structural models should be compatible with those observed in outcrop in the Arbuckle Mountains.
2. A study of the facies and distribution of the Pontotoc Group Conglomerate. Emphasis should be placed on relation to contemporaneous topographic highs and conglomerate distribution based upon restored structural cross sections and isopach maps.
3. An analysis of the timing of the Washburn Ranch Fault. This could be made utilizing pollen data from the conglomerate which fill the fault depressions and from the rocks above and beneath the conglomerate. Shallow reflection seismic reflection profiles would also be of value.
4. Extend the present structural study of the Arbuckle Uplift from Royal Pool area to Doyle Field.

Improvements upon this study could be made by integrating dipmeter data and accurate bottom-hole locations.

5. Structural analysis of the entire Ardmore Basin utilizing the concepts of fault-bend folding.
6. Documentation of post-compression extension along other uplifts of the southern Oklahoma foreland.

CONCLUSIONS

1. The geometry of the Arbuckle Uplift is most consistent with that of low-angle, northeast-directed thrusting, and is in general agreement with the principles of fault-bend folding. Along its entire trend, the uplift is a northeast-vergent structure in both the hanging wall and footwall. Structural styles present include: fault-bend folding, fault-propagation folding, bedding-parallel thrusting, cross-crestal faulting, out-of-the-syncline faulting, and lateral ramps.

2. The Tishomingo Uplift plunges out underneath the Arbuckle Uplift. Because of severe differences in the amount of offset, fault geometry, and field relationships, the Dougherty Thrust (Reagan Fault) cannot be interpreted as the northern bounding fault for the Southeast Hoover area and thus, the Arbuckle Uplift, nor does the Reagan Fault extend into the Eola region.

3. The Arbuckle Thrust controlled the formation of the exposed Arbuckle Anticline and buried Arbuckle Uplift. The Arbuckle Thrust is continuous across the entire study area and remains burried, beneath synorogenic conglomerates and river alluvium, for its entire length.

4. Geometry changes laterally along the Arbuckle Thrust. The exposed Arbuckle Anticline is a fault-bend fold, but to the northwest, near Robberson-Eola, the geometry changes to a fault-propagation fold. West of Eola, changes in geometry of the uplift are related to changes in the geometry and displacement of the Arbuckle Thrust

5. The Arbuckle Thrust loses displacement continuously westward. Shortening measured from basement offset at the western limit of outcrop is approximately 39,000 feet. This decreases to approximately 17,000 feet in the Royal Pool area.

6. The Arbuckle Thrust cuts up-section westward along strike where the thrust develops long cut-off lengths in the Arbuckle Group. This geometry is similar to that documented by Palladino (1986) for the southeastern plunge-end of the Arbuckle Anticline.

7. The Arbuckle Thrust and its hanging wall were later uplifted and folded by younger footwall deformation by the shortening of Eola Anticline.

8. The Washburn Ranch Fault is the surface continuation of Harlton's (1964) Robberson Fault. The Washburn Ranch Fault is a normal fault, formed by extension which post-dates the Arbuckle Uplift, but pre-dates the covering by Permian sedimentary rocks.

9. The Washburn Ranch Fault merges at depth with basement ramps of the Arbuckle Thrust, leaving behind a "beheaded" or "collapsed" basement-cored uplift. Maximum extension seems to correlate with maximum topographic elevation and the fault-propagation folding style of structural style.

10. Large volumes of Pontotoc (Eola) Conglomerate were deposited on the northeast flank of the Arbuckle Uplift, directly across from areas of greatest paleo-topography. Restoration of the Arbuckle Uplift utilizing fault-bend fold geometry provides the best explanation for the geometry, location and preservation of the conglomerate.

APPENDIX I

Listing of Wells Used in Study

Carter County

T. 1S., R. 2W

Well #	Section	Company	Lease	Total Depth	Logs
1	3	Chapman	Pearson #1	3,007	e
2	3	Earl Gray	Pearson No.1	2,752	e
3	3	Schafer	Pearson #1	1,705	e
4	4	Chapman	Young No.1	2,313	e
5	4	Nubs	Edwards #1	2,030	i
6	4	Dobbins	Robinson #1	2,159	e
7	4	Sun	Epley #4	2,550	e
8	4	Van Grisso	Robinson No.1	2,557	e
9	5	Mid-America	Brady No.1	1,948	s
10	5	Woodworth	Robinson #1	3,644	e
11	5	Terminal	Carter #1	1,380	e
12	5	Oxxo.	Rose-Dixon No.2	2,683	di
13	5	Oxxo.	Rose-Dixon No.3	2,665	di
14	5	Oxxo.	Rose-Dixon No.5	2,974	di
15	5	Walker	Low #1	1,800	i
16	6	Aurora	Sparks 31	3,155	e
17	6	Aurora	Evans-Carter #1	3,519	m
18	9	Gordin	Luster No.2	1,135	e
19	9	Walker	Luster No.1	1,307	e
20	9	Gordin	Williams No.1	1,150	e
21	9	Wallace	Luke No.1	900	di
22	9	Lewis	Morris & Luster #1	2,591	e
23	9	Neustadt Bros.	Reed #1	999	i
24	9	Gordin	Luster #3	1,073	e
25	9	Hefner	Hefner "J" #1	1,845	e
26	9	Hiawatha	Luster No.1	5,200	di
27	9	Gordin	Neustadt No.1	1,286	e
28	10	Oxxo.	Rock'n JB No.105	1,912	d
29	10	Texaco	Sutton #2	515	i
30	10	Magnolia	Fish #3	1,065	e
31	10	Magnolia	Roberts No.1	852	e
32	10	Magnolia	Fish #2	1,058	e
33	10	Walker	Fish #1	1,126	i
34	10	Oxxo	Rockin' JB 108	2,300	di
35	10	Texaco	Sutton-Meeks Unit #	13,000	i
36	10	Huffman & Malloy	Fish #1	3,008	e
37	11	Intl. Nuclear	Fish No.1	2,701	di
38	11	Nubs	Rose-Dixon	1,845	di
39	14	Sinclair	Sparks #1	2,268	i
40	15	Oxxo.	Rockin'JB No.103	1,640	di
41	15	Davis	Rose #3	2,361	di

42	15	Great Plains	Goddard #1	1,501	di
43	15	Davis	Rose No.1	2,250	di
44	15	Putnam and Putnam	Smith #1-B	995	e
45	15	William and Davis	Rose #4	3,525	di
46	15	Davis	Rose #4	3,350	di
47	15	Davis	Goddard #1	1,004	di
48	15	Davis	Rose #2	1,784	e
49	16	Dunlap/Moody	Luster #2	1,571	e
50	16	Dobbins	Oakman No.1	1,744	m
51	16	Sutton	Luster #1	1,684	e
52	18	Little	McClary No.1	6,225	e
53	21	Blaylock	Goddard #1	5,058	e
54	26	Gilless	Sparks Ranch No.1	3,919	e
55	27	Blaylock	1-Majors	2,373	e
56	34	Amoco	Akers No.1	10,735	di

T. 1S., R. 3W.

Well #	Section	Company	Lease	Total Depth	Logs
57	2	Cleary	Shadel #1-2	9,018	di
58	3	Stanolind	Nicholson	10,494	e
59	11	Cleary	Williams	8,060	di
60	13	Jones & Pellow	Varner No.1-13	7,790	di
61	14	Texaco	Lucas Unit No.1	8,527	di
62	23	Mobil	Gill Unit No.1	8,726	di
63	33	Cox and Cox	Cobb No.1	7,718	di

T. 2S., R. 2W.

Well#	Section	Company	Lease	Total Depth	Logs
64	2	Goff-Leepr	Riggins No.1	4,894	e
65	8	Skelly	Pierce "D" #1	12,059	e

Murray County

T. 1S., R. 2E.

Well #	Section	Company	Lease	Total Depth	Logs
66	10	Conoco	Greer A#1	6,257	di
67	16	Haliburton	Healy #1	6,686	di
68	16	Sohio	Healy No.1-A	6,947	di
69	17	Lone Star	Knapp#1	8,027	di
70	17	Skelly	Knapp#1	7,972	di
71	18	Cleary	State No.1 1-18	6,443	di
72	20	Skelly	James "A"No.1	6,439	d
73	20	Placid	Joyce No.1	7,764	di
74	20	Lone Star	James No.1	5,877	di
75	21	Cleary	Knapp No.1-21	6,022	di

Garvin County

T. 1N., R. 1W.

Well#	Section	Company	Lease	Total Depth	Logs
76	9	Carter	Yeary-Vaughn #1	7,650	e
77	16	Stanolind	J.F.McGahy #1	7,668	e
78	20	Sohio	Holbrook #1	10,051	e
79	20	Humble	Hennepin Unit #1	15,917	i
80	20	Sohio	Freeman Heirs #1	14,815	e
81	25	Magnolia	Grant Estate #1	5,004	e
82	25	Cleary	Allen #1-25	11,906	di
83	26	Home Pet.	Freeman #1	2,502	e
84	27	Carter-Wolf	Bolling #1	3,018	e
85	27	Lone Star	Bolling #1-A	14,315	i
86	30	Humble	Alvis Frost #1	13,109	i,s
87	31	Unocal	C.A.Morton #1-31	16,610	di
88	32	C&D	Petty #1	3,280	e
89	32	Taylor	Morrow #1	16, 123	di
90	33	Pace	Morrow #1	2,990	e
91	34	Pan Am.	Allsup Unit #1	9,535	i
92	35	Shears	Palmer #1	2,501	e
93	35	Chevron	J.Johnson #1	16,160	cnd
94	36	Lausen & Dixon	Freeman #1	2,719	e

95	36	L.M. Richardson	Richardson #1	920	di
96	36	Robinson Drilling	Freeman #1	2,134	di
97	36	Gen. Machine	Freeman #1	4,035	e
98	36	Frankfort Oil	Cornell #1	6,897	e

T. 1N., R. 2W.

Well#	Section	Company	Lease	Total Depth	Logs
99	6	Dome Pet.	Cook #3-6	11,045	di
100	6	Dome Pet.	Ferguson #11-6	11,075	di
101	6	Dome Pet.	Taliferro 2-6	11,290	di
102	7	Sohio	Ford #2	9,885	e
103	7	Sohio	Ford #4	8,520	di
104	7	Tex-Con	ENFBU #12-5	10,500	di
105	7	Sohio	Ford #3	10,117	e
106	7	Sohio	Cassell D#2	9,920	e
107	7	Sohio	Freeman #2	8,335	e
108	7	Sohio	ENFBU 5-7	10,160	di
109	7	Sohio	Franklin #A-1	9,643	e
110	7	Sohio	Franklin #A-2	8,487	e
111	7	Sohio	Franklin #B-1	10,008	e
112	7	Sohio	Franklin #B-2	9,771	e
113	7	Sohio	Franklin #B-3	5,700	di
114	7	Sohio	Harrell #A-4	9,880	e
115	7	Sohio	Harrell #A-5	9,556	e
116	7	Sohio	Harrell #C-1	10,130	e
117	7	Sohio	Harrell #A-6	10,303	e
118	18	Sohio	SEBSU Howard D#1	12,170 e	e
119	18	Sohio	SEBSU W#20	12,087	e
120	18	Pan Am.	Williams Unit#E-1	2,399	i
121	18	Sohio	Cassell #1	9,640	e
122	18	Sohio	Cassell #B-1	6,572	e
123	18	Sohio	Cassell #B-2	10,791	e
124	18	Pan Am.	Ball Unit#D-1	6,564	di
125	18	Sohio	Hodges #1	9,820	e
126	18	Sohio	Hodges #2	9,616	e
127	18	Sohio	M.Taylor #1	11,175	e
128	18	Sohio	Whitehead #1	10,697	i
129	18	Pan Am.	Story Unit #1	8,200	i
130	18	Sohio	SEBSU #2-2	11,032	di
131	18	Pan Am.	Pickett B #1-A	8,582	i
132	18	Pan Am.	Pickett B #1	7,501	i
133	18	Pan Am	Pickett Unit #1	7,878	i
134	18	Sohio	Henderson #1	10,414	e
135	18	Pan Am.	Jones E#1	7,840	e
136	19	Pan Am.	Jarman Unit 31	8,659	i
137	19	Sunray	Romine #1	1,777	e
138	19	Sunray	Romine #3	3,487	e

139	19	Potter	Ringer #7	2,215	e
140	19	Potter	Henderson #1	1,810	e
141	20	Pan Am.	Williams Unit#C-1	9,070	i
142	20	Pan Am.	SEBSU #13	9,396	i
143	20	Pan Am.	SE Eola #12	9,280	i
144	20	Pan Am.	Williamns #D-2	8,972	i
145	20	Pan Am.	Williams #D-1	9,479	i
146	20	Pan Am.	Williamns #G-1	8,718	i
147	20	Pan Am.	Davis Unit #1	8,117	i
148	20	Pan Am.	Moore Unit #B-1	2,410	i
149	20	Sohio	Moore #1	5,186	e
150	20	Parks	Harrell #1	2,569	di
151	20	Pan Am.	Fields Unit#1	2,650	i
152	20	Pan Am.	Moore Unit B #1-A	9,419	i
153	21	Pan Am.	Satterwhite #1	8,542	i
154	21	Pan Am.	Stephenson #1	8,671	i,s
155	21	Pan Am.	Whyte Unit #1	9,398	i,s
156	21	Pan Am.	Moore Unit #C-1	8,683	i
157	21	Edwin Cox	Kilcrease #1	8,225	di
158	22	Boswell	Yeary #1-22		di
159	22	Highlands et al.	Yeary #1-22	8,368	di
160	23	Sohio	Rodke #1	4,226	e
161	26	Pan Am.	Kennedy B#1	14,265	d i,s
162	26	Sohio	Kennedy #1-a	9,990	e
163	28	Shebester et al.	Sarkey #1	3,011	e
164	29	B&D Drilling	Eastep #1	2,007	e
165	30	Continental	Goodman #1	2,415	e
166	30	Cox and Hamon	Buck #1	1,351	e
167	30	Continental	Goodman #1	2,420	e
168	30	Lewis	Busey #1	2,390	e
169	30	Van Grisco	Mount #1	2,250	i
170	31	Tidewater	Jane Royalty #3	2,190	e
171	31	Paco Oil	Canada #1	2,970	e
172	31	Tidewater	Prince #1-A	2,698	e
173	31	Tidewater	Davenport #1	1,053	e
174	31	Preston Carter	Jane Royalty #1	750	i
175	31	R&D Oil Co.	Jane Royalty #11	1,640	i
176	31	Tidewater	Jane Royalty #7	963	e
177	31	R&D Oil Co.	Jane Royalty #12	1,600	i
178	31	R&D Oil Co.	Jane Roylaty #9	1,680	i
179	31	Tidewater	Canada #1	1,021	e
180	31	Continental	Prince #1	1,039	e
181	31	Tidewater	Jane Royalty #8	2,265	i
182	31	Paco Oil	Lynn #1	1,020	e
183	31	Tidewater	Culpin #1	927	e
184	32	Continental	Prince #1	1,828	i
185	32	Continetal	Prince #2	1,606	i
186	32	Continental	Smart #1	2,471	i
187	32	Neustadt	Prince #1	1,965	e
188	32	Tripledee	Smart #1	2,362	i
189	32	Dean Well Serv.	Price #4	1,779	i
190	32	Dean Well Serv.	Prince #5	1,802	i
191	32	Jones & Pellow	Moore #32-1	2,680	i
192	32	Woods Pet.	Smart #1	3,805	i

193	32	Mid-America	Prince #1	2,759	i
194	32	Tidewater	Prince #1-B	1,010	e
195	33	Pierson & Moss	Kennedy #1	2,967	e
196	34	Dunlap	Meeks #1	3,074	e
197	35	C&D Drilling	Meek #1	3,187	i
198	35	Hefner	Meeks #1	3,256	di,s

T. 1N., R. 3W.

Well#	Section	Company	Lease	Total Depth	Logs
199	2	Superior	Akers Unit #1	11,732	e
200	2	Superior	Akers Unit #2	11,369	e
201	2	Amex-Ferguson	Agerine #1	12,056	i
202	3	Pan Am	F.Garrison #1	11,444	i
203	3	Superior	Milburn Unit #1	13,103	e
204	4	Phillips	Terrell #1-A	9,412	di
205	4	Sohio	Terrell #2	8,725	i
206	4	Pan Am.	Lynn Wiley #1	11,320	i
207	4	Pan Am.	Lynn Wiley #2	11,410	i
208	4	Hart	Jeneva #3	2,742	i
209	4	Post Pet.	Wiley #1-A	3,000	e
210	4	G.A.Brown	Terrell #1	3,056	e
211	4	Hart	Jeneva #2	2,967	i
212	5	Shell Oil	Johnson #1	10,181	e
213	5	Pet. Inc.	Cook #1	3,224	e
214	5	Republic	Doc Dole #1	3,998	e
215	5	Shell Oil	Cole Unit #1	12,937	i
216	5	Fain-Porter	Cook #1	13,038	i
217	5	Republic	Doc Cole #2	3,800	e
218	5	Bunker Explor.	Owen #1-5	13,645	di
219	6	Republic	Blanton #1	3,816	e
220	6	Shell Oil	Rose #2	2,906	e
221	6	Shell Oil	Rose #3	3,835	e
222	6	Shell Oil	Rose #4	3,635	e
223	6	Shell Oil	Rose #5	3,618	e
224	6	Shell Oil	Rose #6	3,629	e
225	6	Shell Oil	Rose #7	3,610	e
226	6	Shell Oil	Doc Cole #1	3,700	e
227	6	Shell Oil	Doc Cole #2	3,599	e
228	6	Shell Oil	Doc Cole #3	3,598	e
229	6	Republic	Blanton #2	3,800	e
230	6	Republic	Blanton #3	3,629	e
231	6	Republic	Blanton #4	3,930	e
232	6	Republic	Blanton #5	3,807	e
233	6	Republic	Blanton #6	4, 061	e
234	7	Shell Oil	Snodgrass #1	6,850	e
235	7	Shell Oil	Townsend #1	4,173	e
236	7	Daube Co.	Perkins #1	4,011	i

237	7	Shell Oil	Townsend #2	3,597	e
238	7	Williams	Eugene #1	4,254	e
239	8	Tripledee	Derdyn #1	4,356	e
240	8	State oil Co.	Derdyn #5	2,603	i
241	8	State Oil Co.	Derdyn #3	2,703	i
242	8	State Oil Co.	Dedyn #6	2,598	i
243	8	State Oil Co.	Derdyn #4	2,601	i
244	9	Fain-Porter	Mays Unit #1	12,777	i
245	9	Post	Garrison #1	2,660	i
246	9	Fain-Porter	Good #1	11,853	i
247	9	Pan Am.	F. Garrison #1	11,444	e
248	9	Post Pet.	Helvey #7	2,670	e
249	9	Post Pet.	Garrison #7	2,674	e
250	9	Post Pet.	Garrison #4	2,625	e
251	9	Hendrick	Garrison #1	11,104	e
252	9	Post Pet.	Helvey #9	2,773	e
253	9	Pan Am.	Helvey #1	12,300	e
254	9	Post Pet.	Garrison #2	2,350	e
255	9	Post Pet.	Garrison #2	2,400	e
256	9	Skaggs	Good #1	2,371	e
257	10	Sohio	R.E.Wood	11,900	e
258	10	Jones & Pellow	Ringerwood #1	11,641	e
259	10	Post Pet.	Wood #1	2,632	di
260	10	Jones & Pellow	Ringerwood 10-2	8,495	e
261	10	Amoco	Levy #2	11,865	di
262	10	Jones & Pellow	Ringerwood #10-4	9,680	di
263	10	Sohio	Levy Unit #1	11,703	e
264	11	Pan Am.	Harkreader #1	11,909	i
265	11	Pan Am.	Webb Unit #C-1	11,644	i
266	11	Stanolind	Mays Unit #1	11,170	e
267	11	Pan Am.	Willens-Mulligan	10,490	n
268	11	Stanolind	Willens #A-2	11,660	e
269	11	Amerada	Hart #1	11,222	e
270	11	Stanolind	Willens #1	10,079	e
271	11	Pan Am.	Harkreader #B-1	10,866	i
272	11	Pan Am	Willens #B-2	10,980	i
273	11	Pan Am.	Willens #A-3	7,220	i
274	11	Pan Am.	Harkreader 32	5,700	e
275	11	R & D Oil	Hart-Newberry #4	1,945	i
276	11	Home	Ringer #2	2,126	e
277	11	Hall Oil	Wood #1	8,351	di
278	11	Stanolind	Harkreader #1	11,190	e
279	11	Stanolind	Willens #B-1	11,644	e
280	11	Stanolind	Willens-Muligan	9,720	n
281	12	Pan Am	McKey #B-2	11,500	e
282	12	Texas-Pacific	Ella Cook #A-3	7,295	e
283	12	Texas Pacific	Ella Cook #A-4	8,590	e
284	12	Sohio et al	Carpenter #1	11,625	e
285	12	Sohio	ENFBU #3-7	9,995	i
286	12	Pan Am.	McKey #2	7,106	e
287	12	Sohio	ENFBU #2-2	9,200	di
288	12	Pan Am.	McKey #B-3	6,900	i
289	12	Amoco	ENWBOC Unit #25	11,500	di
290	12	Sohio	ENFBU #7-5	10,172	di

291	12	Stanolind	McKey #A-4	11,454	e
292	12	Stanolind	McKey #A-2	10,260	e
293	12	Carter Oil	Lynn #1	7,290	e
294	12	Stanolind	McKey B#1	11,600	e
295	12	Sohio	Carpenter #	11,255	e
296	12	Sohio	Harrell B #2	9,740	e
297	12	Texas Pacific	Ella Cook A#2	7,295	e
298	12	Texas Pacific	Ella Cook B#2	8,732	e
299	12	Texas Pacific	Ella Cook C #1-A	6,955	di
300	12	Texas Pacific	Ella Cook A#5	7,418	i
301	12	Amoco	McKey Unit #2	6,769	di
302	12	Sohio	Harrell D #3	10,412	e
303	12	Sohio et al	Harrell D #1	10,869	e
304	12	Sohio	Harrell D #2	10,080	e
305	12	Sohio et al	Harrell D#4	10,280	e
306	12	Texas Pacific	Ella Cook B #1	10,404	e
307	12	Parker	Vaughn #1	10,021	e
308	12	Pan Am	McKey #A-5	7,500	e
309	12	Parker	Vaughn #2	9,472	e
310	12	Sohio	ENFBU 5-2	10,177	i
311	12	Sohio et al	Cook Unit #1	10,149	e
312	13	Pan Am.	Sparks Unit B#1	10,447	di
313	13	Pan Am.	Bullard Unit #1	8,333	i
314	13	Pan Am.	Ferguson #1	12,089	i
315	13	Duncan	Ferguson #1	2,459	di
316	13	Parker	Hudson-Henderson	10,568	e
317	13	Pan Am.	Love Unit #1	10,710	i
318	13	Gay Drlg.	Farris #1	1,580	i
319	13	Sohio	Henderson-Cox	11,752	i
320	13	Pan Am.	Ringer Unit B#1	9,441	i
321	13	Home Pet.	Newberry #1	1,795	e
322	13	Gay Drlg.	Ferguson #7-A	1,650	i
323	13	Halliburton	Rader #1	1,520	e
324	13	Gay Drlg.	Ferguson #3-A	1,590	i
325	13	Gay Drlg.	Ferguson #12-A	1,760	i
326	13	Duncan	Ferguson #3	2,078	i
327	14	Galaxy Oil	Cochran #6	1,602	i
328	14	Home Pet.	Newberry #2	1,841	i
329	14	Gay Drlg.	Hart #1-A	1,634	i
330	14	Gay Drlg.	Hunton #5-A	1,602	i
331	14	Gay Drlg.	Scrivner 34-A	1,607	i
332	14	Gay Drlg.	Newberry #3-A	1,750	i
333	14	Gay Drlg.	Newberry #24-A	1,700	i
334	14	Gay Drlg.	Bosey #7	1,750	i
335	14	Trend Pet.	Schrivner #2	1,903	i
336	14	R&D Oil	Cowan #11	1,491	i
337	14	Galaxy Oil	Douglas #7	1,625	di
338	14	R&D Oil	Cowan #3-A	1,620	i
339	14	R&D Oil	Jones #22	1,555	i
340	14	Alspaugh et al	Newberry #1	1,900	e
341	14	Gay Drlg.	Neustadt #2-A	1,654	i
342	14	Gay Drlg.	Pearce #1-A	1,797	i
343	14	Home Pet.	Newberry #1	1,840	i
344	14	Trend Pet.	Cowan #1	2,395	e

345	14	Gay Drlg.	Shippey #1	1,620	i
346	14	Gay Drlg.	Park #5-A	1,505	i
347	14	Gay Drlg.	Newberry #7-A	1,674	i
348	14	Gay Drlg.	Scrivner #5-A	1,708	i
349	14	Gay Drlg.	Neustadt #5-A	1,652	i
350	14	Gay Drlg.	Neustadt #4-A	1,621	i
351	14	Gay Drlg.	Sullivan #2-A	1,780	i
352	14	Trend Pet.	Newberry-Neustadt	1,656	e
353	14	Trend Pet.	Newberry-Neustadt	1,902	e
354	14	Gay Drlg.	Newberry #8	1,654	i
355	14	Gay Drlg.	Newberry #1-A	1,803	i
356	14	Gay Drlg.	Neustadt #3-A	1,641	i
357	14	Home Pet.	Luke #1	1,592	i
358	14	R&D Oil	Jones #21	1,544	n
359	14	San Andres	Jones 31	1,800	e
360	14	R&D Oil	Jones #24	1,593	i
361	14	Galaxy Oil	Cochran #8	1,650	i
362	14	Alspaugh & Bryan	Cowan #2	1,950	e
363	14	Alspaugh et al	Cowan #2	1,641	e
364	14	Beard Estate	Perkin #1	1,838	e
365	14	Magnolia Pet.	Pearce #2	2,000	i
366	14	Gay Drlg.	Newberry #4-A	1,862	i
367	14	Magnolia Pet.	Jones #13	2,200	e
368	14	Trend Pet.	Schrivner #1	1,889	i
369	14	Gay Drlg.	Park #3-A	1,394	i
370	14	Gay Drlg.	Park #4-A	1,520	i
371	14	Gay Drlg.	Park #6-A	1,774	i
372	14	Trend Pet.	Minerva #1	1,800	i
373	14	Magnolia Pet.	Jones #14	1,902	e
374	14	Pet. Investment	Cochran #5	1,90	i
375	14	Trend Pet.	Perkins #2	2,260	i
376	14	Magnolia Pet.	Jones #12	2,195	e
377	14	Trend Pet.	Cowan #2	1,821	e
378	14	Gay Drlg.	Scrivner #2-A	1,691	i
379	14	Gay Drlg.	Park #2-A	1,570	i
380	15	Blaik oil	Mauldin #1B-13	9,399	n
381	15	Johnson	Cowan #1	2,530	e
382	15	Mobil	Mauldin B#14	1,870	di
383	15	Gay Drlg.	Cowan #6-A	1,922	i
384	15	Alspaugh & Bryan	Ringer #1	1,856	e
385	15	KRM	Cowan #41	2,052	di
386	15	KRM	Cowen #39	2,128	di
387	15	KRM	Cowan #36	1,659	di
388	15	Gay Drlg.	Cowan #3-A	1,591	i
389	15	Mobil	Cowan #33	1,892	i
390	15	Gay Drlg.	Cowan #2-A	1,500	i
391	15	Gay Drlg.	Cowan #1-A	2,001	i
392	15	Beard Estate	Cowan #2	1,937	e
393	15	KRM	Mauldin B-16	1,660	di
394	16	Tomlinson et al	Harris #1	2,265	e
395	16	KRM	Mauldin A-10	2,138	di
396	16	Tomlinson	Harris #2	2,727	di
397	16	KRM	Harris #14	1,800	di
398	16	Walker	Mauldin #3	1,992	i

399	16	Home Pet.	Pernell #2	1,778	e
400	16	Mobil	Harris #8-A	1,706	di
401	16	Continental	Orr #14	1,694	di
402	16	Texas Pacific	Richardson #12	1,703	i
403	16	Texas Pacific	PernellAC/1 #3-A	1,700	i
404	16	Tomlinson	Mauldin #2	1,862	e
405	16	Walker	Harris #B-1	2,102	e
406	16	Texas Pacific	Richardson #5	1,853	i
407	16	Walker	Harris B-6	2,150	di
408	16	KRM	Harris #15	2,184	di
409	16	Mobil	Harris #13	1,859	i
410	16	Texas Pacific	Richardson #13	1,706	i
411	16	Magnolia Pet.	Mauldin A#9	2,073	e
412	16	Tomlinson	Mauldin #1	1,956	e
413	16	Mobil	Orr #13	1,608	i
414	17	Texaco	Derdyn A #17	2,265	e
415	17	Cleary	Patsy B-1	2,505	e
416	17	Jones	Derdeyn #2	2,502	i
417	17	Jones	Meinders #1	2,496	i
418	17	Walker	Derdeyn#15	2,497	e
419	17	Cleary	Derdeyn No.B-1	2,540	e
420	17	Texas Pacific	Derdeyn A-4	2,664	e
421	17	Texas Co.	Derdyn A#18	2,229	e
422	17	Sohio	McKee#1	10,310	e
423	18	Texas Pacific	Case-Derdeyn #2	5,267	e
424	18	Jones	Derdyn C#1	2,615	i
425	18	Jones	Meinders #2	4,585	i
426	18	Jones	Meinders #1-B	3,658	i
427	18	Doric	Meinders #1	5,320	di
428	18	Dunlap	Derdyen #1	2,920	i
429	18	Kirpatrick	Derdeyn #1	4,380	i
430	19	Cimarron	Jones #1	4,153	e
431	19	Conoco	Blanton-Thompson	10,024	di
432	19	Cobb & Davis	Jones #1	4,679	e
433	21	Grey	Roberson#1	6,627	d
434	21	Walker	Bailey #1	2,778	e
435	22	Texaco	Downey Estate #1	5.174	e
436	23	Jackson et al	Freeman #1	2,284	e
437	23	Trend Pet.	Abrams #1	2,597	i
438	23	Shawnee	Abrams #1-A	3,401	di
439	23	Cleary	Poyser #1	3,491	e
440	24	Potter	Low #1	1,970	e
441	24	Dunlap	Hudson #1	1,745	i
442	24	Sohio	Buckner #1	3,152	e
443	24	Potter Oil	Kimbrell #1	1,978	e
444	24	Potter Oil	Walter #2	1,975	
445	24	C&L Drlg.	Moss #1	2,332	e
446	24	Walters	Fee #1	1,902	e
447	24	Dunlap	Potter #1	1,910	i
448	24	B&B Drlg.	Low #1	2,005	e
449	25	Arco	Ringer 31	1,400	di
450	25	Walker	Lucy Wie 31	2,555	di
451	25	Sohio	Moore #1	3,677	e
452	25	Little	Harrel #1	4,312	i

453	25	Carlock	Moore #1	2,625	e
454	26	Shawnee	Abrams-Bonifield	2,388	di
455	27	Ardmore Drlg.	Nooner #27-1	8,785	di
456	29	Cox	Derdeyn No.1	9,042	di
457	32	Cox	Engle No.1	7,820	d
458	32	Cox	Henderson #1	7,810	di
459	33	Cox and Berry			di
460	34	Cox	London #1	8,800	di
461	35	Boswell En.	Tucker #1-35	8,165	di
462	35	Conoco	Humble #1	4,341	i

T. 1S., R. 1W.

Well#	Section	Company	Lease	Total Depth	Logs
463	1	Frankfort	Freeman Heirs No.1	14,858	e
464	3	Frankfort	Digby Strat Test	3,996	e
465	4	Masters	Jacobs No.1-A	647	di
466	4	CWN	Williams 1-4	2,967	di
467	32	Frankfort	Sparks No.1	12,872	e

Stephens County

T.1N., R. 4W.

Well#	Section	Company	Lease	Total Depth	Logs
468	1	Dunlap	Brown No.1	4,510	e
469	1	Midwest Oil	Dean No.1	10,530	i
470	1	Texas Co.	Strehlow #1	8,453	e
471	2	Phillips	Chism No.2	7,997	i
472	2	Phillips	Chism #1	10,822	e
473	2	Phillips	Norman A#1	10,148	e
474	2	Phillips	Oakman #1	9,476	e
475	2	Bunker Expl.	Michael No. 1-2	13,000	i
476	3	Sun	Blaydes #1	15,515	i
477	8	Texas Co.	Lundy #1	8,430	e
478	9	Eason	Oakman No.1	17,000	i
479	12	Carter Oil	Harrell #1	8,481	e
480	13	Jones & Pellow	Adams #13-1	7,949	i
481	13	Ardmore Drlg.	Middleton #1	5,737	i
482	14	Skelly Oil	Browning #1	7,007	i
483	17	Hudson Pet.	Wade No. 1-17	10,620	i
484	21	Magnolia	Lee #1	7,506	e

485	22	Jones & Pellow	MacKinnon 22-1	9,168	i
486	22	Buchanan	Brennan #1	7,394	e
487	24	Post Oak	Tussey #24-1A	9,200	i
488	26	Helmerich	Dyche No.1	8,925	di
489	27	Humble	Neal No.1	11,972	i
490	36	Pathfinder	Sims No.1	8,495	d

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