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CORRELATION OF ATOKA AND ADJACENT STRATA WITHIN A SEQUENCE STRATIGRAPHIC FRAMEWORK, ARKOMA BASIN, OKLAHOMA

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CORRELATION OF ATOKA AND ADJACENT STRATA WITHIN A SEQUENCE STRATIGRAPHIC FRAMEWORK, ARKOMA BASIN, OKLAHOMA

A Dissertation APPROVED FOR THE
SCHOOL OF GEOLOGY AND GEOPHYSICS

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ABSTRACT

The Atoka Formation in the Arkoma Basin represents the thickest stratigraphic interval. The purpose of this study is to delineate the stratigraphy of this formation in the entire Arkoma Basin in Oklahoma covering more than 200 townships, using detailed well log correlations within a sequence stratigraphic framework. This includes establishing the criteria for defining the boundaries, lateral and shelf-to-basin distribution of the lower, middle, and upper units within the Atoka Formation. This framework helps to decipher relationships, in terms of relative age and depositional setting, for many lithostratigraphic sandstone units that have been reported in different stratigraphic positions within the Atokan section in different parts of the basin. The study also includes, both the Union Valley-Wapanucka strata at the base of the Atoka Formation, and the Hartshorne-Booch strata, at its top.

The Atoka stratigraphy is an integral part of the sequence stratigraphic realm that continued throughout Pennsylvanian time. The stratigraphic section starting from the Morrowan through the early Desmoinesian represents four third-order cycles of relative sea level changes. The section including the Cromwell sandstone through the Wapanucka prograding carbonate platform represents the Morrowan cycle. The basal Atoka LST, TST, and the lower Atoka HST represent the lower Atokan cycle. The middle Atoka LST, and the upper Atoka TST and HST represent the middle-upper Atokan cycle. Finally, the Hartshorne LST, TST, and the Booch HST represent the lower Desmoinesian cycle. Each cycle represents a third-order sequence bounded by unconformities.

The Arkoma foreland basin system consists of three depozones. The foredeep depozone is dominated by the thick deepwater turbidites. The forebulge depozone shows the highest rates of erosion along unconformities such as the Morrowan/Atokan and the middle Atokan unconformities. Shallow-water deposits and thin sedimentary section characterize the back-bulge depozone in the northwestern part of the Arkoma Basin. During Atokan time, the foredeep depozone of the Arkoma Basin received over 14,000 feet of sediments, compared to few hundred feet on the back-bulge area to the northwest of the basin.

The Arkoma foreland basin is a mature exploration province that still has opportunities for further prospecting. It can serve as a stratigraphic model for other foreland basins because of the following advantages: the wide range of sedimentary environments, the complex interaction of tectonics and sediment supply and the availability of thousands of well logs. The conductivity log is available for almost all the wells drilled in the basin. Few wells have sonic logs, which is the norm in many mature basins. The good correlation between the conductivity and sonic logs can be employed to create 2-D and 3-D pseudo-seismic models that may help in understanding the stratigraphy and exploring in other foreland basins.

CHAPTER 1

INTRODUCTION

The Arkoma Basin is a mature exploration province in terms of the number of wells drilled. According to Oil-Law Records Data Base, there are over 30,000 wells drilled in the Oklahoma part of the Arkoma Basin up till 2003. Many gas fields have been discovered. Gas production has been reported from many zones within the Atoka Formation, which represents the thickest stratigraphic interval in the entire basin. Despite this heavy drilling activity, the understanding of the stratigraphy of the Atoka Formation in the Oklahoma part of the Arkoma Basin was essentially based on extrapolation from depositional models developed for: 1) the Arkansas part of the basin, 2) outcrop studies conducted in the Ouachitas, Arbuckle uplift, and Ozark uplift regions, 3) prospect-style studies that involve only a few townships and for specific intervals in the Atokan section.

The lack of a comprehensive regional study of the Atoka Formation in the Arkoma Basin, Oklahoma, can be attributed to:

1- the dominance of shale lithology and the discontinuous nature of many sandstone units.

2- limited Atokan outcrops within the Oklahoma part of the Arkoma Basin in Oklahoma compared to those in Arkansas that may help to establish surface to subsurface correlations (Figure 1).

3- a lack of regional lithostratigraphic or biostratigraphic markers in the Atokan section.

4- the complex interaction of active tectonics and huge sediment supply during the deposition of the Atoka Formation that led to very rapid change in thickness across the basin.

Purpose and significance of the study

The age of the Atoka Formation is the Atokan Series (Early Pennsylvanian), and is divided informally into lower, middle, and upper units (Stone, 1968; McGee, 1979; Sutherland and Manger, 1979; Lonsinger, 1980; Houseknecht and Kacena, 1983; Zachary, 1983). It is bounded below by rocks of Morrowan age throughout most of the Arkoma Basin, and overlain by the Hartshorne Formation of Desmoinesian age throughout the central and southern parts of the basin (Spivey and Roberts, 1946; Zachary and Sutherland, 1984) (Fig. 2). The nature of both the upper and lower boundaries of the Atoka Formation is controversial. Moreover, the boundaries of the divisions within the formation are not defined. Despite many studies that have referred to these divisions, the bases for such divisions and their boundaries within the Atokan section in the Arkoma Basin are not defined, except for the lithostratigraphic study conducted on the Arkoma Basin in Arkansas by Zachary (1983). Sprague (1985) mentioned that the correlation of divisions within the Atoka Formation between different localities is based on criteria that have never been stated or discussed. The problems with the Atoka Formation can be summarized by the statement made by Suneson (1987): "several type sections, type localities, and type areas have been proposed in the literature for the Atoka Formation. This confusion coupled with disagreements over the definition of the Atokan Series, the problems of working with sparsely fossiliferous or unfossiliferous rocks, and lateral and basinward facies changes are the basis for some Pennsylvanian stratigraphic problems in the Ouachita Mountains of southeastern Oklahoma". This statement was made about the well-studied Ouachitas, and it is more legitimate the poorly studied Atokan section in the Oklahoma part of the Arkoma Basin.

The purpose of this study is to delineate the stratigraphy of the Atoka Formation, covering the entire Arkoma Basin in Oklahoma, using detailed well log correlations within a sequence stratigraphic framework. This includes establishing the criteria for defining the boundaries, lateral and shelf-to-basin distribution of the lower, middle, and upper units within the Atoka Formation. This framework helps to decipher relationships, in terms of relative age and depositional setting, for many lithostratigraphic sandstone units that have been reported in different stratigraphic positions within the Atokan section in different parts of the basin. It is imperative to include in this study, both the Union Valley-Wapanucka strata at the base of the Atoka Formation, and the Hartshorne-Booch strata, at its top, for two reasons: 1) it is difficult to define the boundaries of the Atoka Formation without understanding the stratigraphy of these units. 2) to demonstrate that Atoka stratigraphy is an integral part of a specific sequence stratigraphic realm.

Location and available data

The study area is about 7000 square miles covering more than 200 townships. It includes the townships between 13N to 2S from north to south, and ranges between 8E to 27E from the west to east (Figure 3). The Atokan outcrops of the Ozark uplift in the north, the Choctaw fault in the south, the Oklahoma-Arkansas border to the east, and the depositional edge (pinch out) of the Atoka section towards the central Oklahoma platform in the west and northwest, represent the limits of the study area encompassing almost the entire area of the Arkoma Basin. Selected wells in the area south of the Choctaw fault were included to examine the continuity of the stratigraphic relationships of Union Valley, Wapanucka limestone, Spiro-Foster, lower Atoka, and middle Atoka strata, into the frontal Ouachitas.

The main data source for this study was the huge accumulation of logging data for thousands of wells drilled in the study area. Also, few core descriptions that have been reported on sandstones within the Atoka Formation and the Wapanucka limestone helped in the interpretation. Out of thousands of well logs that were available, over 4500 wells were screened using two main criteria to choose the wells for this study: 1) availability of logs in the following order: conductivity, gamma ray, photo-electric factor, and porosity logs. Over one third of the screened wells have no gamma ray log, which is the common tool for correlation and application of sequence stratigraphic concepts. To overcome this problem, the conductivity log was used as the principal tool for the study. 2) significant change in the log pattern for a specific stratigraphic unit from one well to another, making sure that it is possible to correlate this pattern between two wells without the need to include a third well in between. The result of this screening process was the selection of 1224 wells that have been scanned and digitized. Only 1044 of these wells were used to create the maps and cross sections that are presented in this study (Fig. 3). A list of these wells is provided in the Appendix.

Regional Setting

DeCelles and Giles (1996) defined a foreland basin system as an elongate region of potential sediment accommodation that forms on continental crust between a contractional orogenic belt and the adjacent craton, mainly in response to geodynamic processes that include flexure due to thrust belt, sediment, and subduction loading. The Arkoma Basin is an elongate structural trough that extends from the gulf coastal plain in central Arkansas westward for 250 miles to the Arbuckle Mountains in south central Oklahoma (Zachry and Sutherland, 1984) (Fig 4). It ranges from 30 to over 70 miles in width. To the south, this foreland basin is bordered by the Ouachita orogenic belt, to which it is genetically related (Houseknecht and Kacena, 1983) (Figure 5).

The Arkoma Basin is one in a series of seven basins that occur along the leading edge of the Ouachita belt, an east-west Paleozoic overthrust trend in the southern United States that extends 1400 miles from Alabama to west Texas, where it continues into Mexico (Figure 6). Approximately 260 miles of this belt are exposed in the Ouachita Mountains and in the Marathon uplift in southwest Texas (Arbenz, 1989). These basins, now separated by pronounced basement uplifts or subtle arches, were once part of a widespread Late Paleozoic foredeep that formed in front of the Ouachita orogen as a result of tectonic loading associated with the collision of the Afro-South American and the North American continents (Meckel et al. 1992).

With the onset of the collision, the southern margin of the North American craton was depressed; Early to Mid-Paleozoic carbonate deposition terminated, and emergent highlands developed along the thrust belt serving as sediment source. Clastics began to fill the foredeep trough in front of the Ouachita thrusts. The plate collision was oblique, moving from east to west with time. Consequently, major tectonic subsidence was time transgressive across the entire Ouachita foredeep trend. In the east, downwarp started in the Black Warrior Basin during Early Pennsylvanian time. In the Val Verde and Marfa Basins, in the southwest part of the thrust belt, the subsidence developed during Late Pennsylvanian/Early Permian time (Meckel et al., 1992). The time-transgressive subsidence is also indicated by the systematic change in the age of the switch from shelf deposition (dominantly carbonate) to clastic deposition (basin-fill) from east to west along the Ouachita belt trend (Fig. 7).

Viele and Thomas (1989) described a model for the tectonic evolution of the Ouachita system that involves the closing of ocean by subduction of the North American plate beneath the Ouachita accretionary prism and island arc that lay to the south (Fig. 8). By Morrowan time, the growth of the accretionary prism probably formed a submarine ridge, imperfectly dividing the closing ocean into two primary basins of deposition, a trench to the north, and a fore-arc basin to the south. The Atokan strata of the southern Ouachitas in Arkansas and the central Ouachitas in Oklahoma compose the youngest exposed filling of a fore-arc basin. Meanwhile, the Atokan strata of the frontal Ouachitas in Oklahoma were deposited in an abyssal trough and extended northward with stratigraphic continuity into the Arkoma Basin, a peripheral foreland basin lying above the continental crust. Within this basin, the Atokan strata record several different depositional environments, ranging from a shallow-water, muddy-slope facies, to a deepwater submarine fan facies in the south. The complex stratigraphic relationships of the Morrowan Union Valley through the Desmoinesian Booch intervals, and the impact of the tectonic evolution of the Arkoma Basin on this thick stratigraphic section in Oklahoma is the theme of this study.

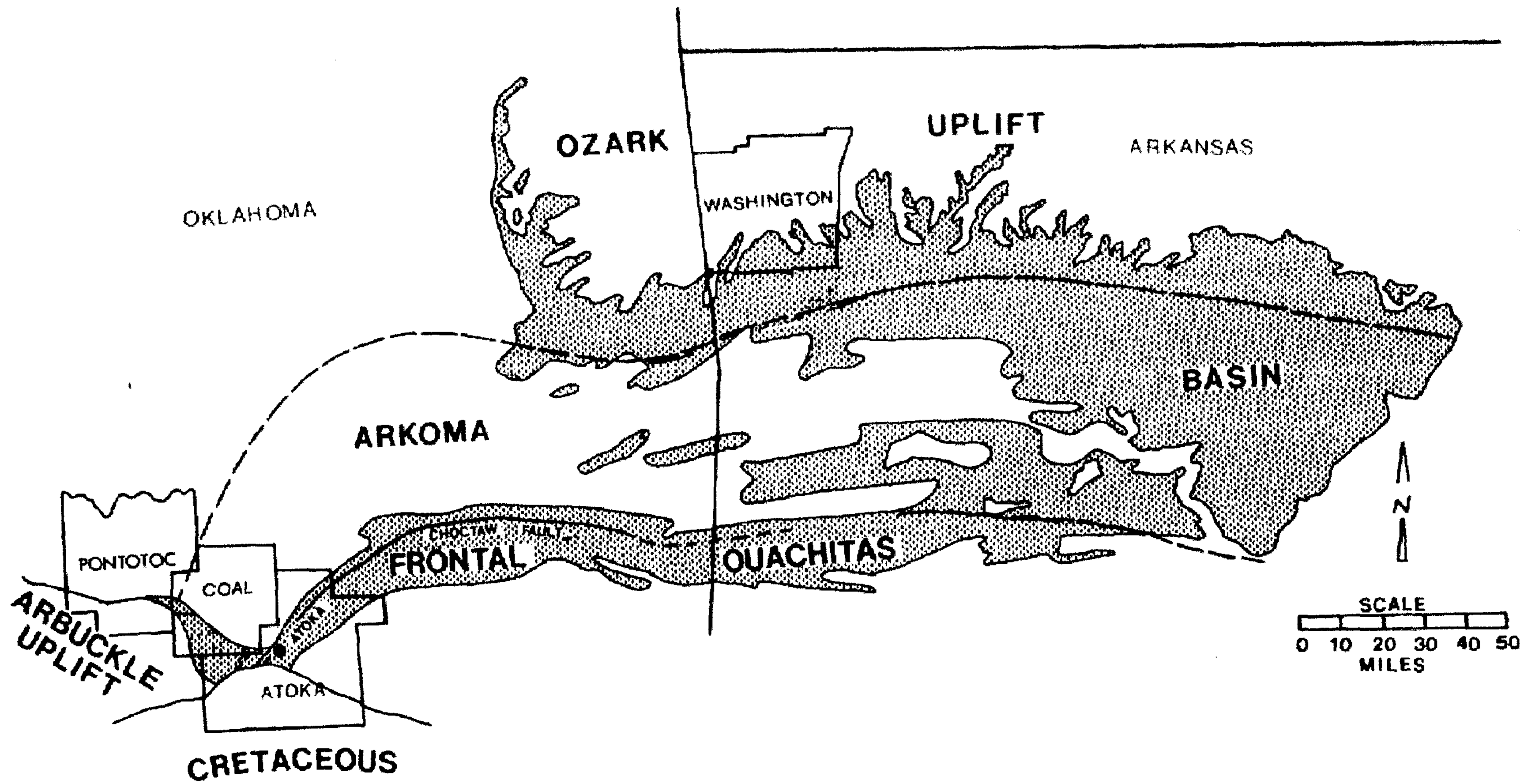


Figure 1. Distribution of Atoka Formation outcrop belts in Arkoma Basin and its surroundings (stippled area). Very limited Atokan rocks crop out in the Oklahoma part of Arkoma Basin. Most Atokan outcrops are in the Arkansas part of Arkoma Basin, Frontal Ouachitas, and Ozark uplift (after Zachry and Sutherland, 1984).

	SERIES	ARKOMA BASIN			OUACHITA MOUNTAINS
PENNSYLVANIAN	Desmoinesian	Krebs Gp.	Boggy Fm.	₽bg	
			Savanna Fm.	₽sv	
			McAlester Fm. (Booch)	₽ma	
			Hartshorne Fm. Upper / Lower	₽hs	
	Atokan	Atoka Fm.		₽a	Atoka Formation
	Morrowan	Wapanucka Ls.		₽m	Johns Valley Shale
		Union Valley Ls. Cromwell ss.			Jackfork Group
MISSISSIPPIAN	Chesterian	"Caney" Sh.		MD	Stanley Shale
	Meramecian				
	Osagean				
	Kinderhookian				

Figure 2. The upper part of the stratigraphic column for the Arkoma Basin and Ouachita Mountains (modified after Johnson, 1988).

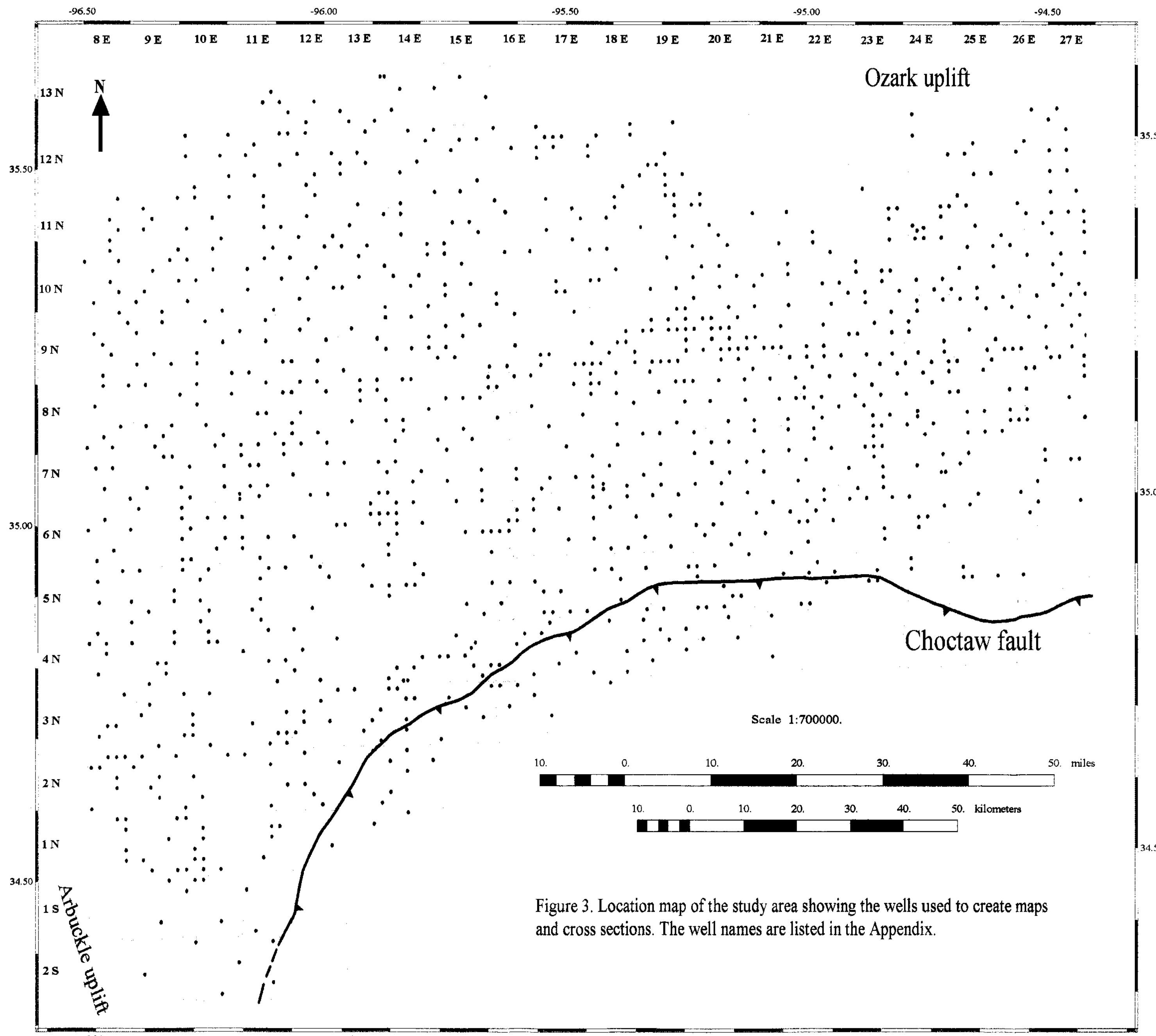


Figure 3. Location map of the study area showing the wells used to create maps and cross sections. The well names are listed in the Appendix.

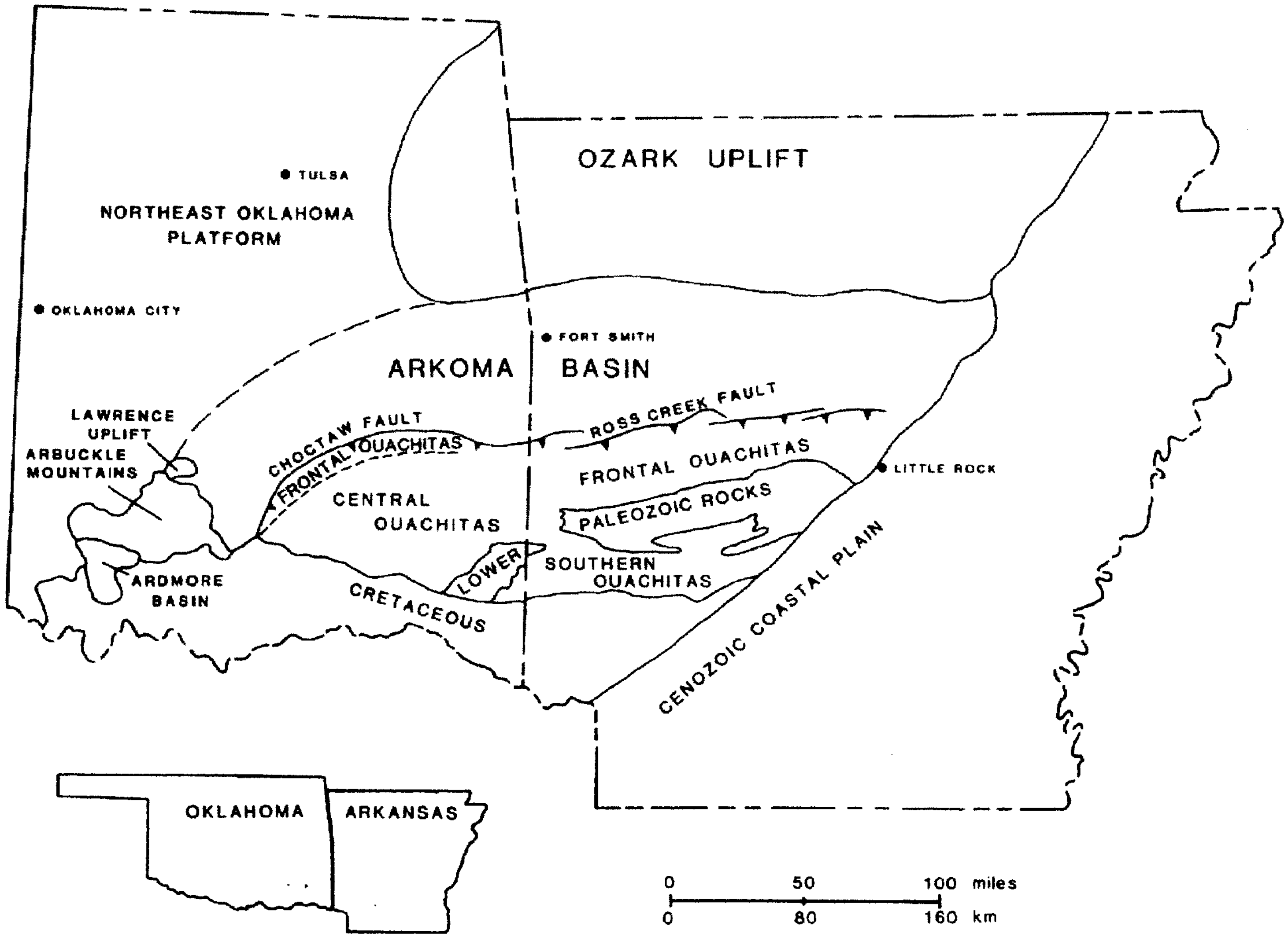


Figure 4. Map showing the location of Arkoma Basin in Oklahoma and Arkansas, and the surrounding geologic provinces (after Johnson et al., 1989).

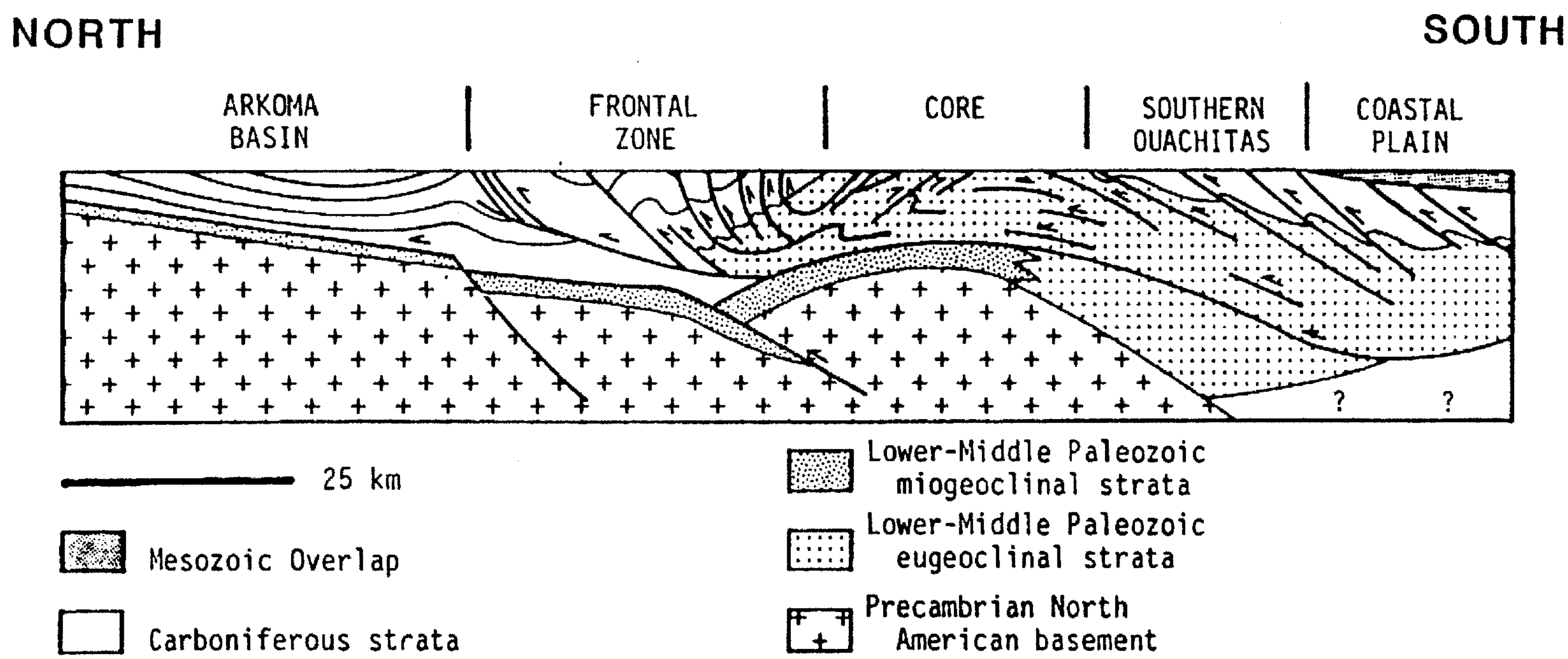


Figure 5. Generalized structure cross section showing the structural relationship between the Arkoma Basin and Ouachita orogenic belt (after Lillie et al., 1983).

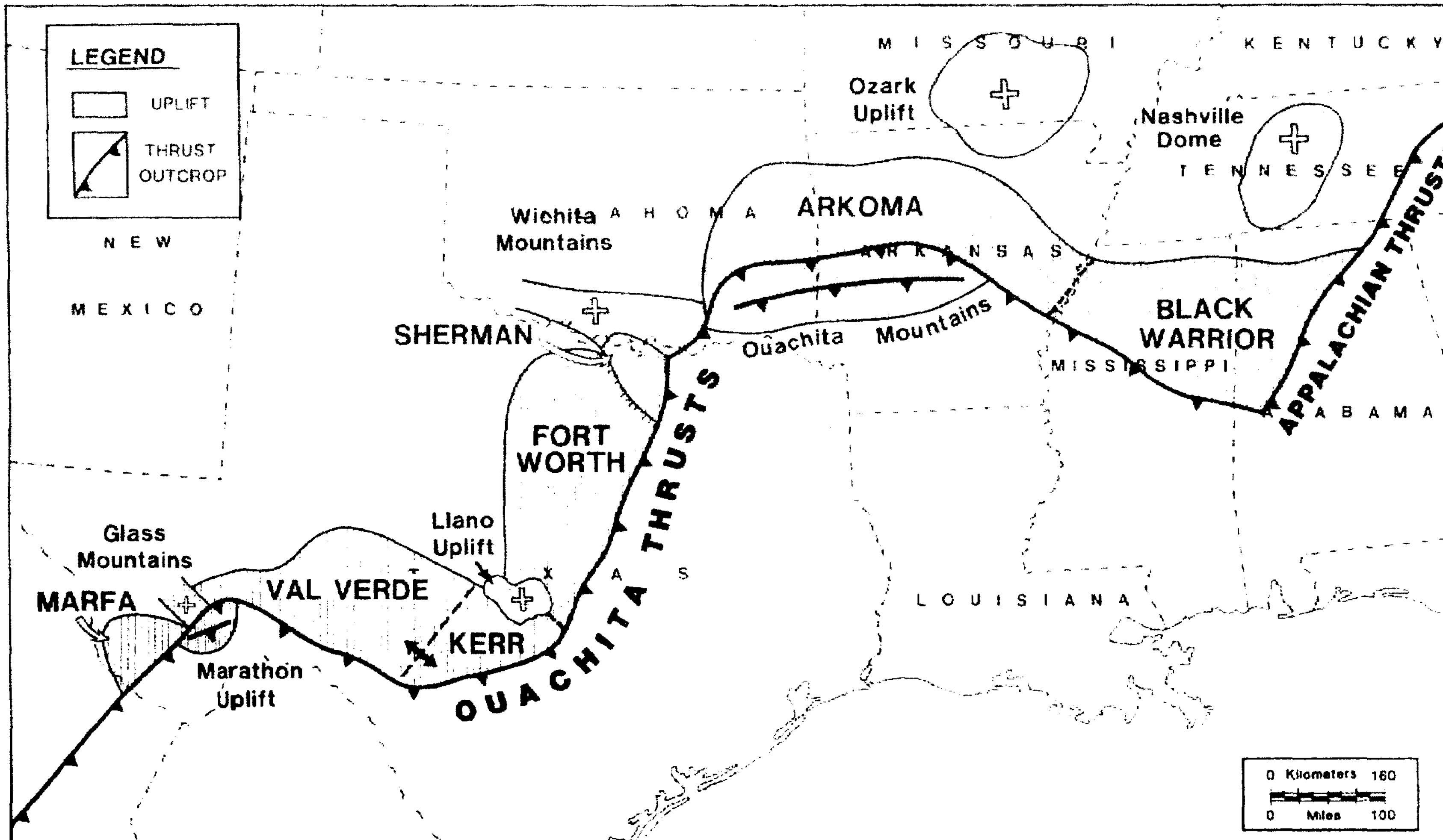


Figure 6. Map showing the Arkoma Basin as one of a series of seven basins occur along the leading edge of the Ouachita thrust which extends from Alabama in the southern United States to Mexico (after Meckel et al., 1992).

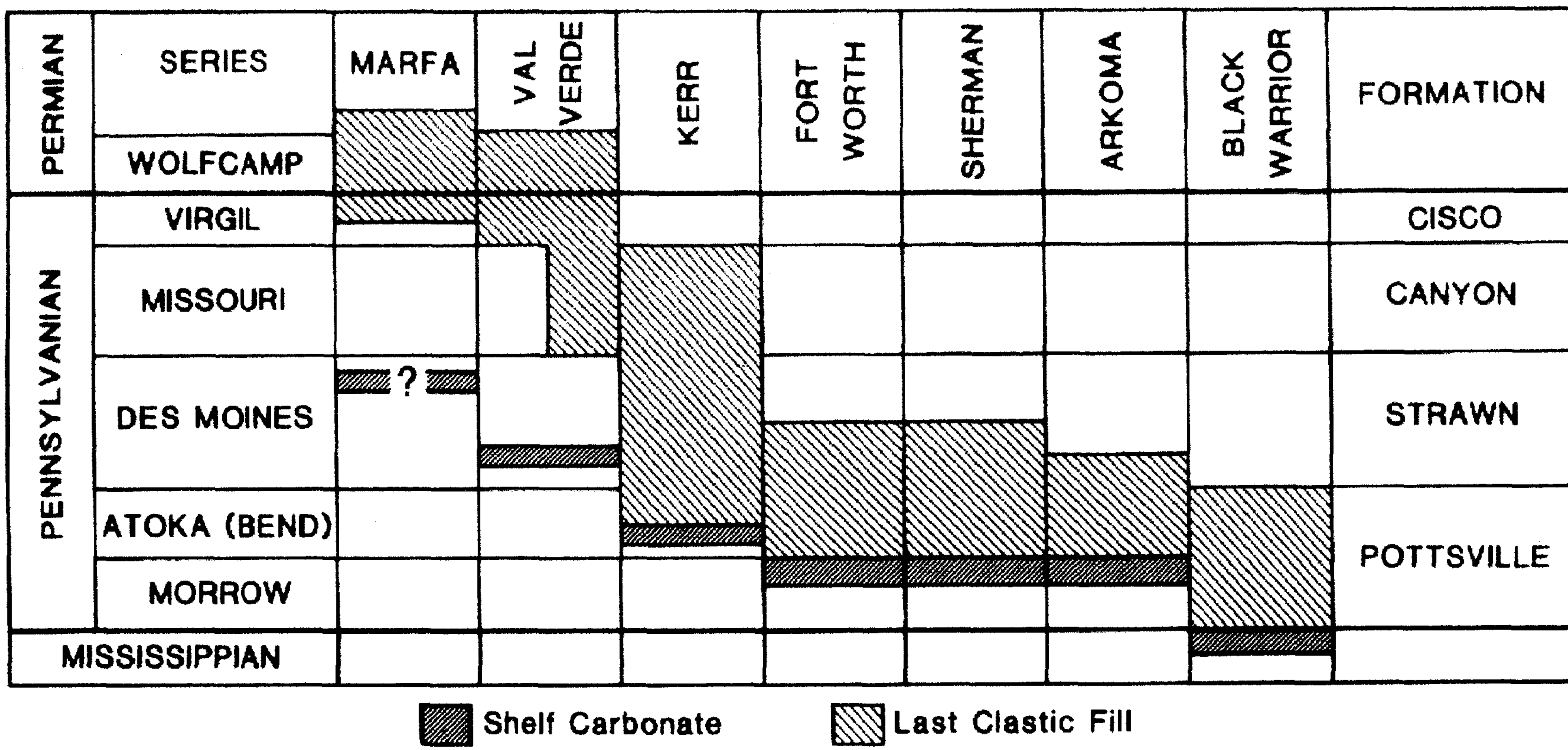


Figure 7. Stratigraphic column showing the change in age of the switch from shelf carbonate deposition to clastic deposition (basin fill). Basins are positioned from east (right) to west (left) along the Ouachita thrust (after Meckel et al., 1992).

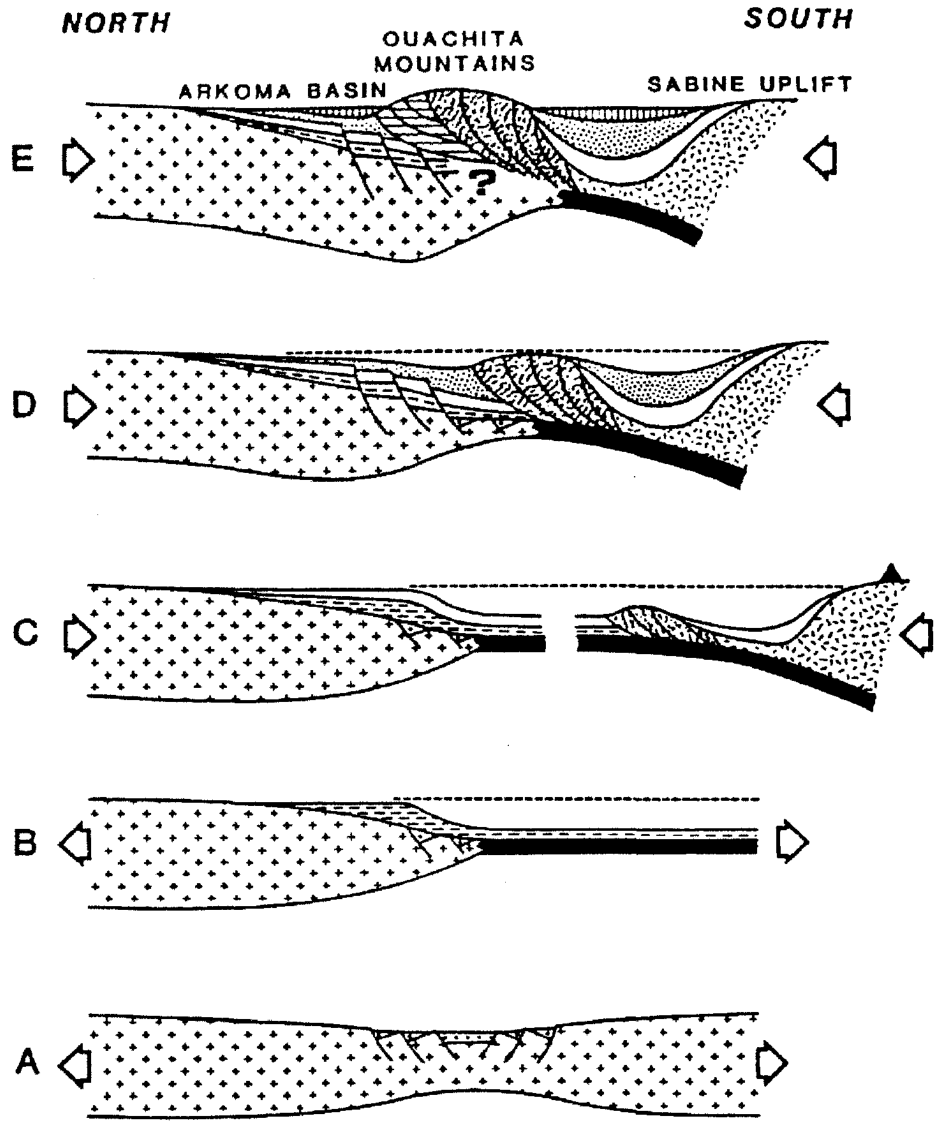


Figure 8. Hypothetical cross sections depicting tectonic evolution of southern margin of North America during (A) late Precambrian-earliest Cambrian, (B) late Cambrian-earliest Mississippian, (C) early Mississippian-earliest Atokan, (D) early-middle Atokan, (E) late Atokan- Desmoinesian. Key to patterns: crosses = continental crust (undifferentiated in A, North American in B-E; straw hachures = `Llanorian' crust; black = oceanic crust; heavy dots = basal Paleozoic strata; horizontal hachures = upper Cambrian-basal Mississippian strata; white = Mississippian-basal Atokam strata; sand stippling = lower-middle Atokan strata; vertical lines = upper Atokan-Desmoinesian strata; mottled = Ouachita accretionary prism; wavy lines = Ouachita foreland thrust belt; black triangle = magmatic arc volcanoes. Figure from Houseknecht (1986).

CHAPTER 2

METHODOLOGY

Well logging tools

The available log curves for this study include conductivity, resistivity, and spontaneous potential logs. Fewer wells have other logging measurements such as gamma ray, density, neutron, photoelectric factor (PEF), and/or sonic logs. The gamma ray log is the most common tool used for well correlations and building sequence stratigraphic models, but in the study area, over one third of the wells do not have gamma ray logs. Careful examination of the available conductivity logs revealed that this log type has many criteria that allow better correlations than gamma ray logs especially in a regional study where shale is the dominant lithology.

The electrical conductivity log is the inverse of the rock resistivity. The units of conductivity measurements are in mmhos, which equals 1000/ohm.m. This measurement is a function of the conductivity of the rock-forming minerals, texture, and the fluids in the pores of the rock (Brie et al., 1985; Schoch, 1989; Doveton, 1994). In clean rocks, which contain small amount of clay minerals, the fluid content within the pore spaces plays the dominant role in determining the conductivity measurements. Figure (9) shows characteristic abrupt high- and low-conductivity zones within the clean rocks, indicating wet and gas-bearing (or very low porosity) intervals, respectively. This character makes it easy to distinguish clean intervals from the adjacent shales in the studied stratigraphic section.

The relationship between conductivity and gamma ray logs is generally the same, for the stratigraphic section from the Union Valley to the Booch interval, in two wells in the shelf and the deep part of the Arkoma Basin. The cross plots of this relationship can be divided into two segments (Fig. 10). In the lower segment of each plot, the conductivity values increase as the gamma ray values increase, or at higher volume of shale assuming that the only radioactive minerals in the studied section are clay minerals. In the upper segment of the plots, or the shale zone, a wide variation in the conductivity values occurs with much less variation in the corresponding gamma ray values indicating the effect of a factor other than the shale volume.

The term "shale" is properly defined by its particle size rather than its mineralogy. Twenhofel (1932) defined it as having particles less than 1/256 mm or 4 μm. Lewan (1978) defined shale rock as containing more than 65% by volume of material smaller than 5 μm. Hunt (1996) mentioned that this <5 μm fraction is thought of as containing mainly clay minerals, but this is not always the case. He listed many shale rocks, in several basins around the world, that are composed of 53-95% quartz and the rest is clay minerals. The size of these quartz grains is very small, even less than 2 μm in some shale rocks. Wong (1969) concluded that the main clay minerals in the Atoka Formation are illite, chlorite, kaolinite, and mixed-layer illite-montomorillonite in order of decreasing abundance. Spotl et al. (1993) mentioned that the mineralogy of the <2 μm fraction of the mudrocks of the Atoka Formation is fairly monotonous and includes quartz as well as the clay minerals mentioned above.

The photoelectric factor log (PEF) is a good indictor of the mineralogy. The PEF value for illite is 3.5-3.8 barns/electron (Schlumberger, 1989). Figure (11) is a plot of the density, PEF, and gamma ray measurements for the T-bar Ranch #2-19 well, on the shelf area of the Arkoma Basin. It shows that the points are clustered in a triangle area leaning toward the sandstone line away from the clay point (the circle in Fig. 11). The end members of this triangle are for the dominant clay mineral, quartz and porosity (lowest density). The clay point, at the highest gamma ray and density values or lowest porosity, indicates that the dominant clay mineral is illite. The lower arrow points toward the quartz matrix (clay-quartz trend line). The upper arrow points toward increasing porosity (clay-porosity trend line). Thus, the shale intervals in the studied section (generally above 85 API units using the gamma ray logs) will behave differently in terms of their log response based on the proportions of the three components (end members).

Since the clay mineralogy in the Atoka Formation is generally uniform, the only remaining factor that may cause the wide variation of the conductivity values in the shale zone presented in Figure (10) is textural variations within the shale rocks. Schoch (1989) stated that textural variations play an extremely important role in determining the conductivity of a particular rock unit. Such textural variations may include changes in the grain size of the quartz in shale intervals, pore size, packing of the quartz fraction, and consequently the compaction of shale rocks and the interconnection between pores. The sonic log is a highly sensitive logging tool for textural variations (Brie et al., 1985). The textural effect on the conductivity measurements in the shale rocks of the studied stratigraphic section is clearly demonstrated by the good correlation between the sonic and conductivity logs. The correlation coefficient is between 0.78-0.9 for the shaly zones in the wells on both the shelf and deep part of the Arkoma Basin (Fig. 12). Detailed examination of the well logs shows that both sonic and conductivity logs perfectly track each other except in wet zones, where the conductivity is much higher, and in condensed sections where the sonic transit time values increase (Fig. 12-14).

The gamma ray log is merely a measure of natural radioactivity level in sedimentary rocks, and consequently, does not detect changes in the grain size or the resulting differential compaction in the shale rocks. Meanwhile, the conductivity log not only can substitute the gamma ray log in distinguishing clean from shaly intervals, it can also distinguish between different shale units, which is an advantage over using the gamma ray log as a correlation tool.

Sequence stratigraphic concepts

Sequence stratigraphy represents a definitive approach to stratigraphic interpretations. It integrates a predictive model in which a series of systems tracts comprising a sequence are deposited in response to a cycle of fall and rise of relative sea level. The repetitive nature of cyclicity in sedimentary rocks is the result of the interaction between tectonics, sediment supply, and eustacy. Each sedimentary basin is highly influenced by tectonic factors in its subsidence and accommodation history (Hubbard, 1988), and by the type and rate of sediments supplied to the basin (Galloway, 1989). The eustatic imprint is superimposed on these tectonic and sedimentary controls (Vail et al., 1991).

Sequence stratigraphic concepts provide powerful tools in the analysis of the evolutionary history of sedimentary basins (Nummedal and Swift, 1987). These tools include: 1) the key stratigraphic surfaces encountered in sedimentary sequences, which include unconformities, first transgressive (marine flooding), and maximum flooding surfaces, and 2) the different patterns of systems stacking above and below these surfaces. This analytical approach allows the subdivision of the sedimentary rocks into genetically related units bounded by surfaces with chronostratigraphic significance. The surfaces provide a framework for correlating and mapping. Interpretation of systems tracts with specific stacking patterns provides a framework to predict facies relationships and different depositional environments within the sequence.

The fundamental unit of sequence stratigraphy is the sequence, which is a relatively conformable succession of genetically related strata bounded by unconformities and their correlative conformities (Mitchum, 1977). A sequence is divided into three depositional systems tracts: lowstand systems tract (LST), transgressive systems tract (TST), and highstand systems tract (HST) in a type 1 sequence (Fig. 15). These abbreviated capitalized letters will be used throughout the text to define each systems tract. In a type 2 sequence, a shelf-margin systems tract substitutes for the lowstand systems tract. A depositional systems tract is a three-dimensional assemblage of lithofacies, which is deposited at a predictable position in the basin and during a specific phase of a cycle of relative change of sea level. In a type 1 sequence, the lowstand systems tract is composed of basin floor and slope fans, and a lowstand wedge. It is deposited during a time of rapid fall followed by a slow rise of relative sea level (Van

Wagoner et al., 1988). A transgressive systems tract is deposited during a rapid rise in relative sea level. A highstand systems tract is deposited during the late part of relative sea level rise, stillstand, and the early part of the fall of relative sea level.

Systems tracts can be defined uniquely by the nature of the bounding surfaces and the geometry of the parasequence stacking patterns within them. Each tract may be composed of one or more parasequence sets. The stacking pattern and geometry of a parasequence set is dependent on the ratio of sediment-supply rate to accommodation rate (S/A ratio) (Van Wagoner et al., 1988). A transgressive systems tract is characterized by retrogradational parasequence sets (S/A<1). A highstand systems tract is characterized by both progradational (S/A>1), and aggradational (S/A=1) parasequence sets (Fig. 16).

Depositional sequences are bounded by unconformities and their correlative surfaces. An unconformity is a surface separating younger from older strata. Along this surface, there is evidence of subaerial exposure or erosional truncation and, in some areas, submarine erosion, with a significant hiatus indicated (Van Wagoner et al., 1988). The other two major surfaces that divide the depositional sequence into systems tracts are the first transgressive and the downlap surfaces (Fig. 17).

The first transgressive surface is produced during a transgression of high-energy nearshore environments across the shelf area of a basin (Loutit et al., 1988). Thus, it forms a boundary between the lowstand systems tract and the overlying transgressive system tract. The downlap surface is a starvation surface that develops during the maximum regional transgression when terrigenous sediments are restricted to landward regions. This surface is also called maximum flooding surface (MFS) associated with, or after, the maximum rate of relative sea level rise. Two criteria mark this surface: 1) the change from retrogradational to aggradational or progradational stacking patterns, and 2) the occurrence of condensed sections.

The condensed section plays a fundamental role in stratigraphic correlation because it regionally extends, as a thin sedimentary unit, from the basin to the shelf in the middle of a depositional sequence. Hence, it represents a physical stratigraphic link between shallow and deep-water sections. It incorporates slowly accumulating sediments laid down in the distal parts of both the transgressive and the highstand deposits consisting of pelagic to hemipelagic sediments characterized by very low sedimentation rates (Fig. 18). Abundant organic matter and authigenic minerals, such as glauconite and phosphorite, make it readily recognizable on well logs. Its characteristic pattern of abnormally high gamma ray and low conductivity values is clearly recognizable in the studied wells (Fig. 9).

Estimates for the time span of the Atokan series differ, but they are generally between 3-6 million years (Fig. 19) (Salvador, 1985; Spotl et al., 1993; Visher, 1996). This time frame implies that the Atokan sediments were deposited within a third-order-cyclic hierarchy, or the sequence/composite sequence time range of 1-10 million years (Fig. 20). Visher (1996), based on his and other workers studies on sandstone facies distribution in the Arkoma Basin, considered the Atokan strata to represent one third-order sequence.

In a comprehensive study of the Atoka Formation in the Arkansas part of the Arkoma Basin, Zachry (1983) divided the formation into lower, middle, and upper intervals based on each interval's response to the basin structural development. His criteria for these divisions were the position and continuity of the sandstone lithostratigraphic units. He stated: " in the southern part of the Arkoma Basin, the upper boundary of the lower Atoka can not be determined in the absence of the sandstone units". This indicates the inadequacy of using sandstones as basis for regional correlations. Yet, the position of sandstone units in the Atokan section has been frequently used to define the divisions within the Atoka.

Throughout the Arkoma Basin in Oklahoma, different geologists and operators assigned different names for sandstone intervals based on local lithostratigraphic correlations that covered a few townships. In my view, this may have resulted in miscorrelations that consequently have led to several misconceptions in building a regional picture for the basin. In addition, regional correlations are difficult because of the dominance of shale lithology throughout the Oklahoma part of the Arkoma Basin and the huge change in thickness of the Atoka Formation. Fig. (21) is an example showing a 10-fold increase in the thickness of the formation from the shelf to the deep part of the basin within a distance of about 40 miles.

As explained earlier, conductivity logs give a better definition of the different shale packages than the gamma ray logs. The correlations made in this study are based on the continuous character of shale packages, which include the less continuous sandstone units within them (Fig. 22). Detailed and regional well log correlations of these shale packages and their bounding surfaces were established using the conductivity logs and sometimes gamma ray logs within a sequence stratigraphic framework. The basic sequence-stratigraphic model (slug model) is two-dimensional, and assumes that sediment supply and accommodation space are in the same direction. Because of the complexity of the stratigraphic evolution of the Arkoma Basin in three dimensions (shelf-to-basin and laterally), and the change of sediment supply directions, the sequence stratigraphic tools were used as building blocks. In other words, the tools of sequence stratigraphy (surfaces and stacking patterns) were identified and traced, and then a regional stratigraphic model was constructed accordingly.

Fudge#1-28 well (10N-20E-28)

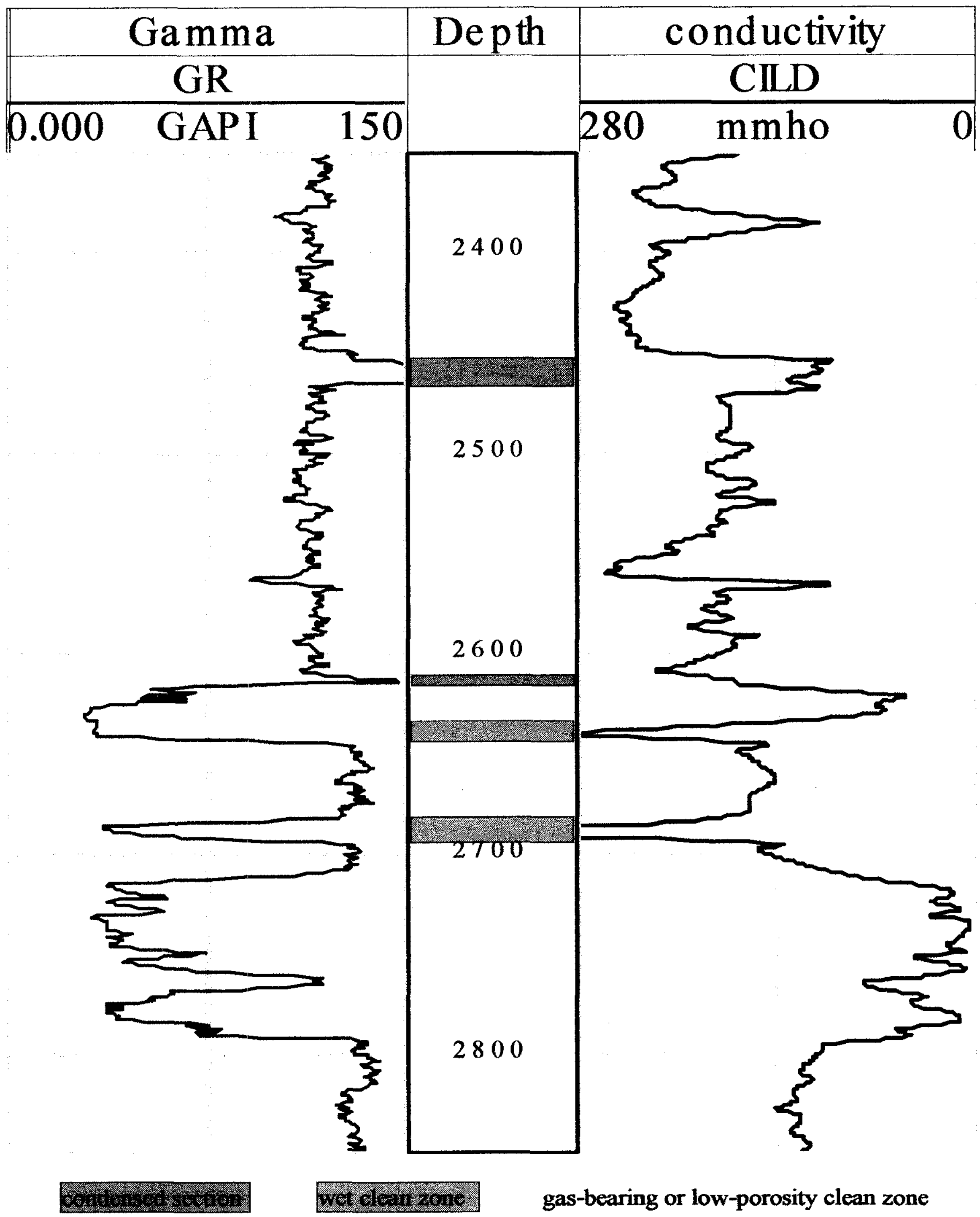


Figure 9. Characteristic signature for rocks on conductivity and gamma ray logs. The unmarked section consists of shale or shaly intervals.

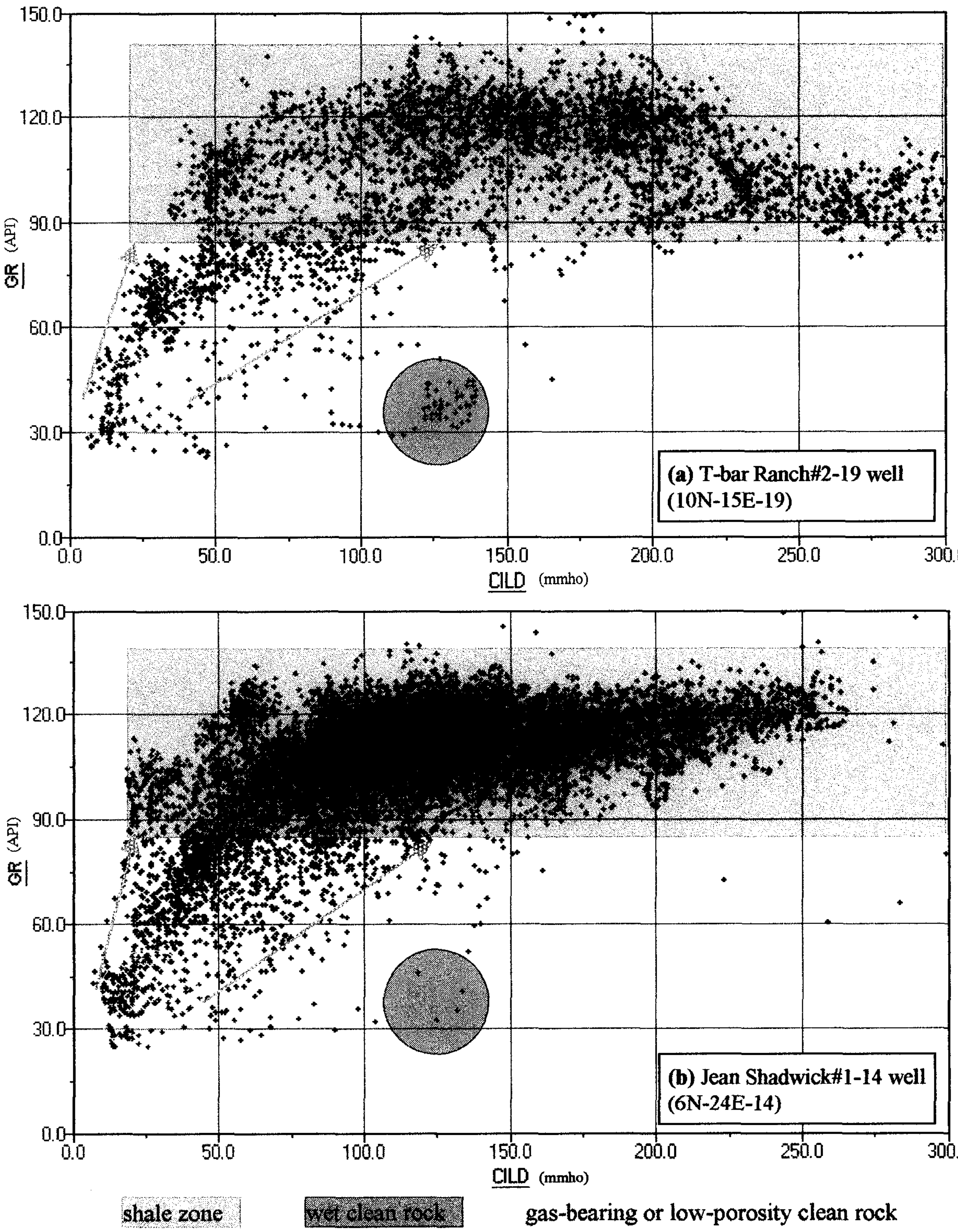


Figure 10. Conductivity (CILD)-gamma ray (GR) cross plot for two wells: (a) on the shelf of Arkoma basin, and (b) in the deep part of the basin. In the lower segment of the plots, the conductivity values increase at higher gamma ray values. In the shale zone, wide variation in the conductivity values occurs indicating the effect of a factor other than the shale volume.

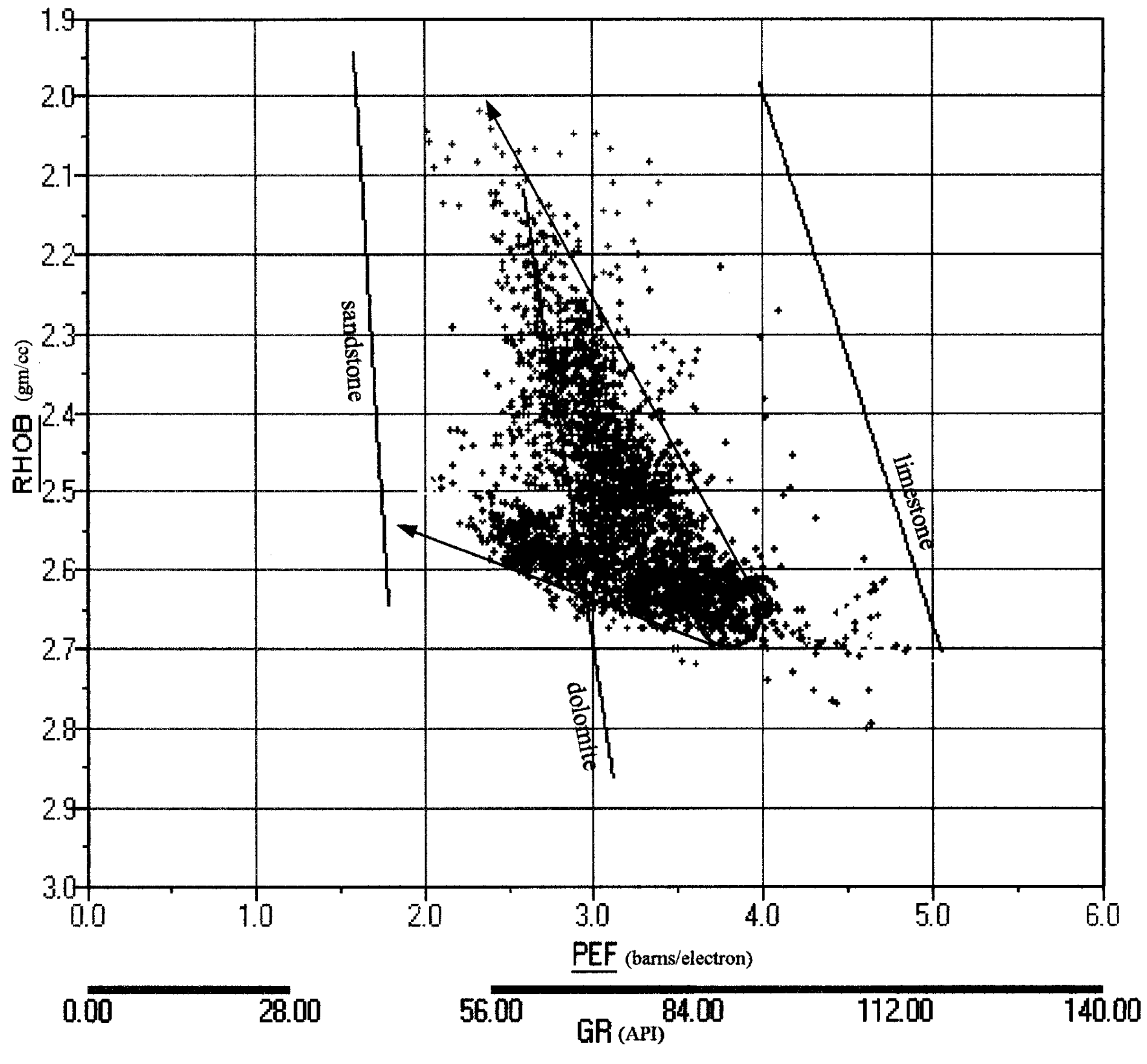
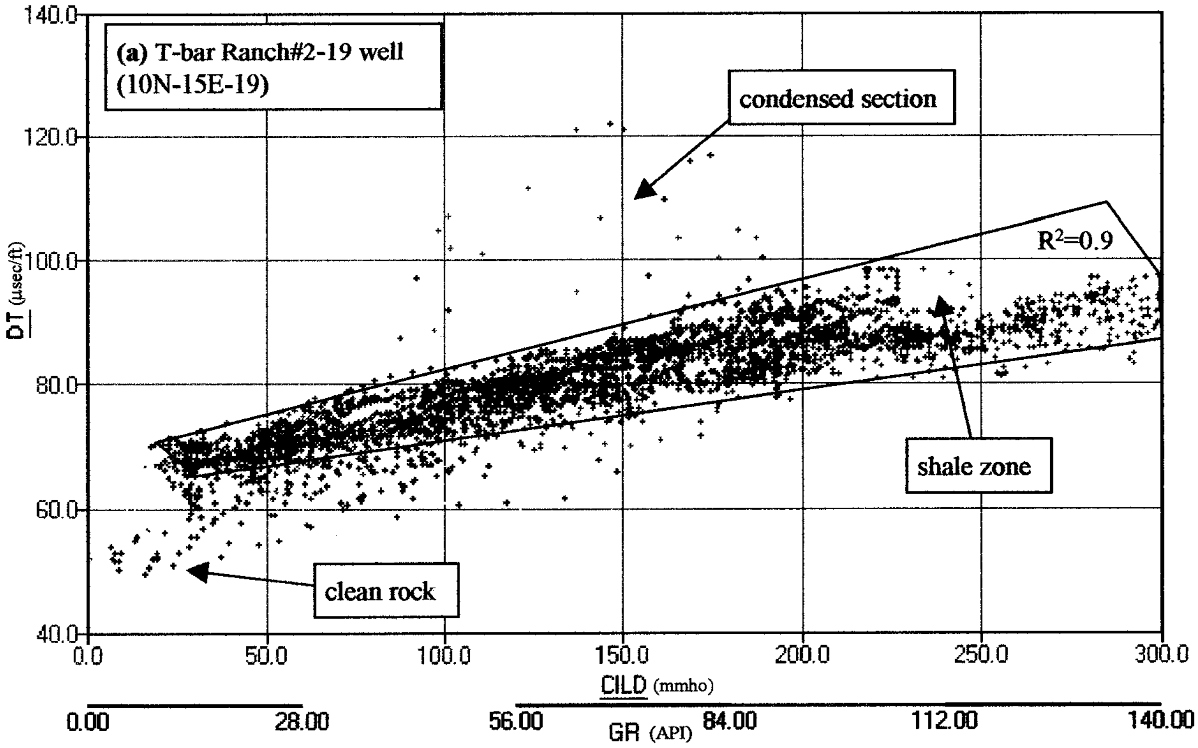


Figure 11. Photoelectric factor (PEF)-density (Rhob)-gamma ray (GR) plot for the T-bar Ranch#2-19 well. Shale is indicated by high gamma ray values. The clay point (black circle) indicates illite mineralogy (3.5-3.8 barns/electron). The points are clustered in a triangle area leaning toward the sandstone line away from the clay point. The lower arrow points toward the quartz matrix (clay-quartz trend line). The upper arrow points toward increasing porosity (clay-porosity trend line).



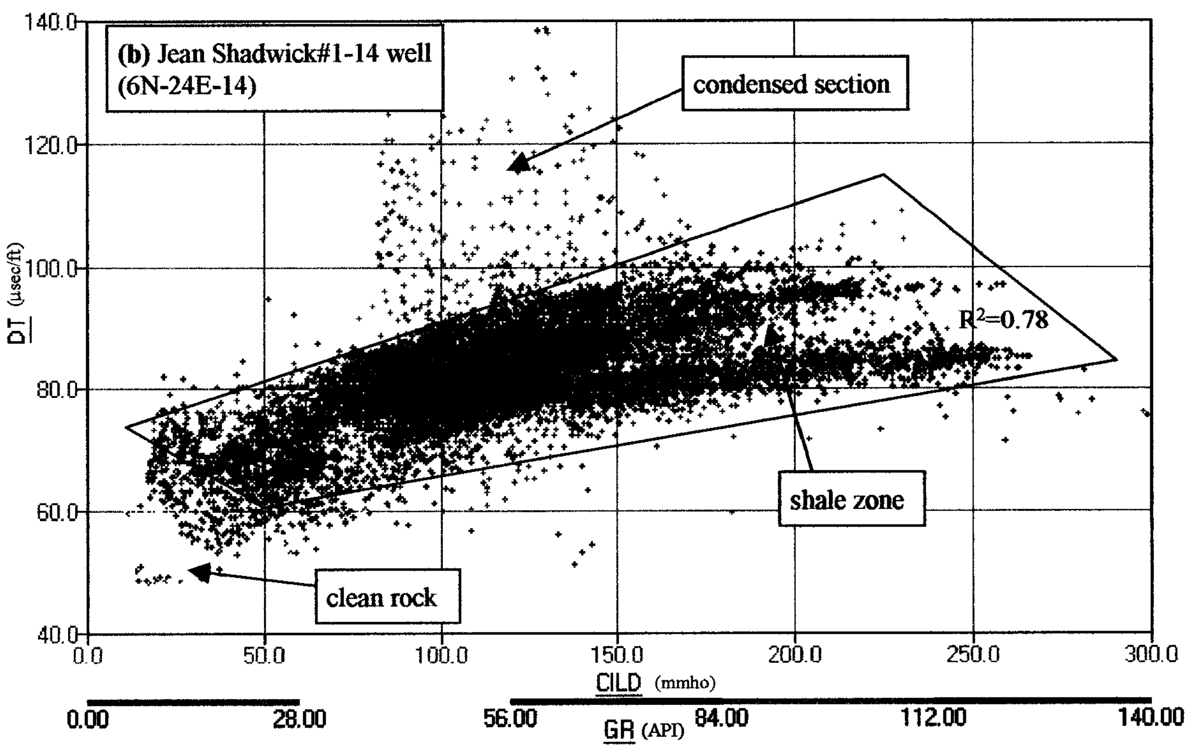


Figure 12. Conductivity (CILD)-sonic (DT)- Gamma (GR) plot for two wells: (a) on the shelf of Arkoma basin, and (b) in the deep part of the basin. The plots show good correlation between the conductivity and sonic measurements for the shaly zones (R^2 =0.78-0.9) indicating the conductivity log sensitivity to textural variations.

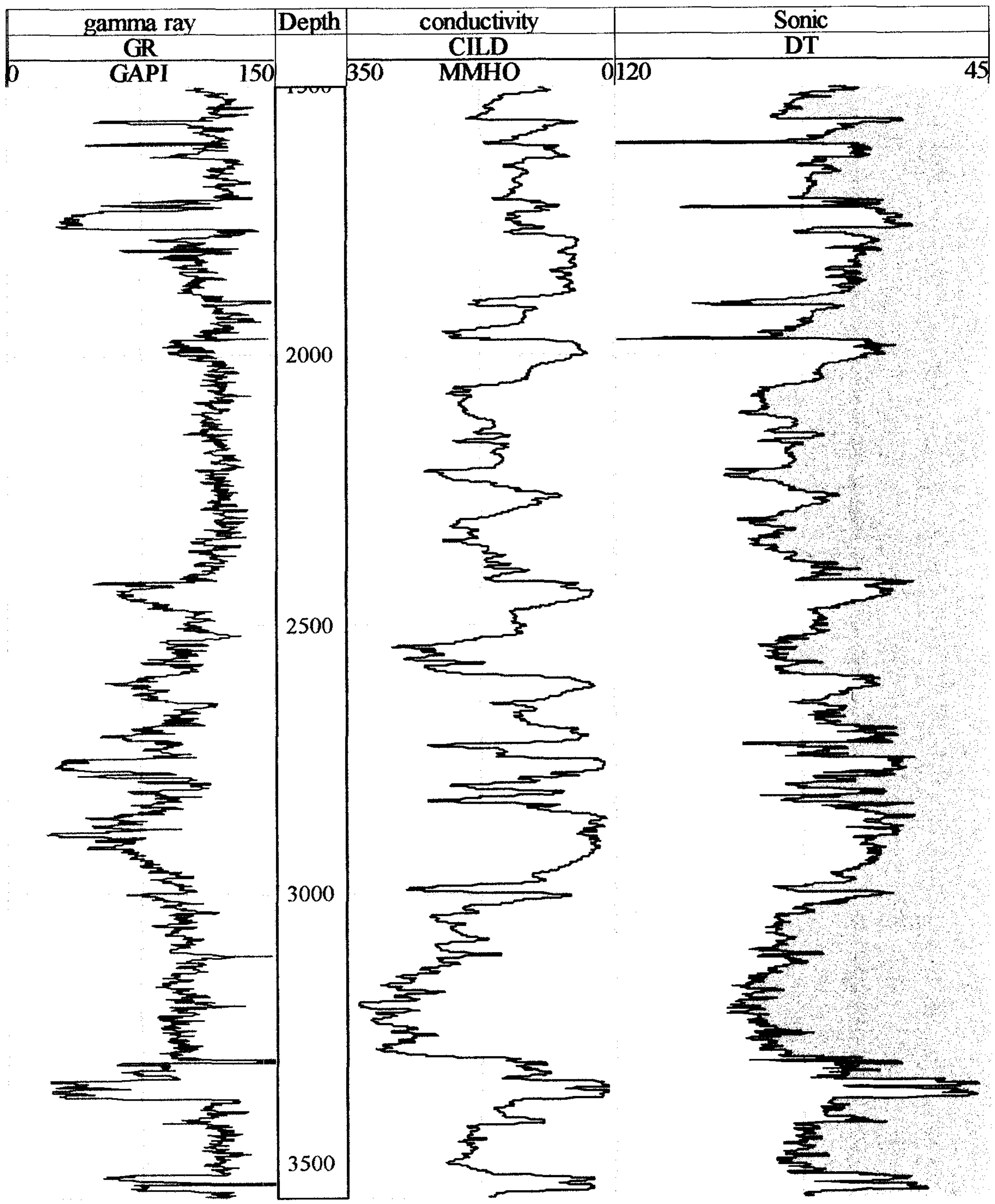


Figure 13. Log curves for T-bar Ranch#2-19 well (10N-15E-11). The conductivity and sonic logs show very similar patterns throughout the studied stratigraphic section on the shelf of Arkoma basin.

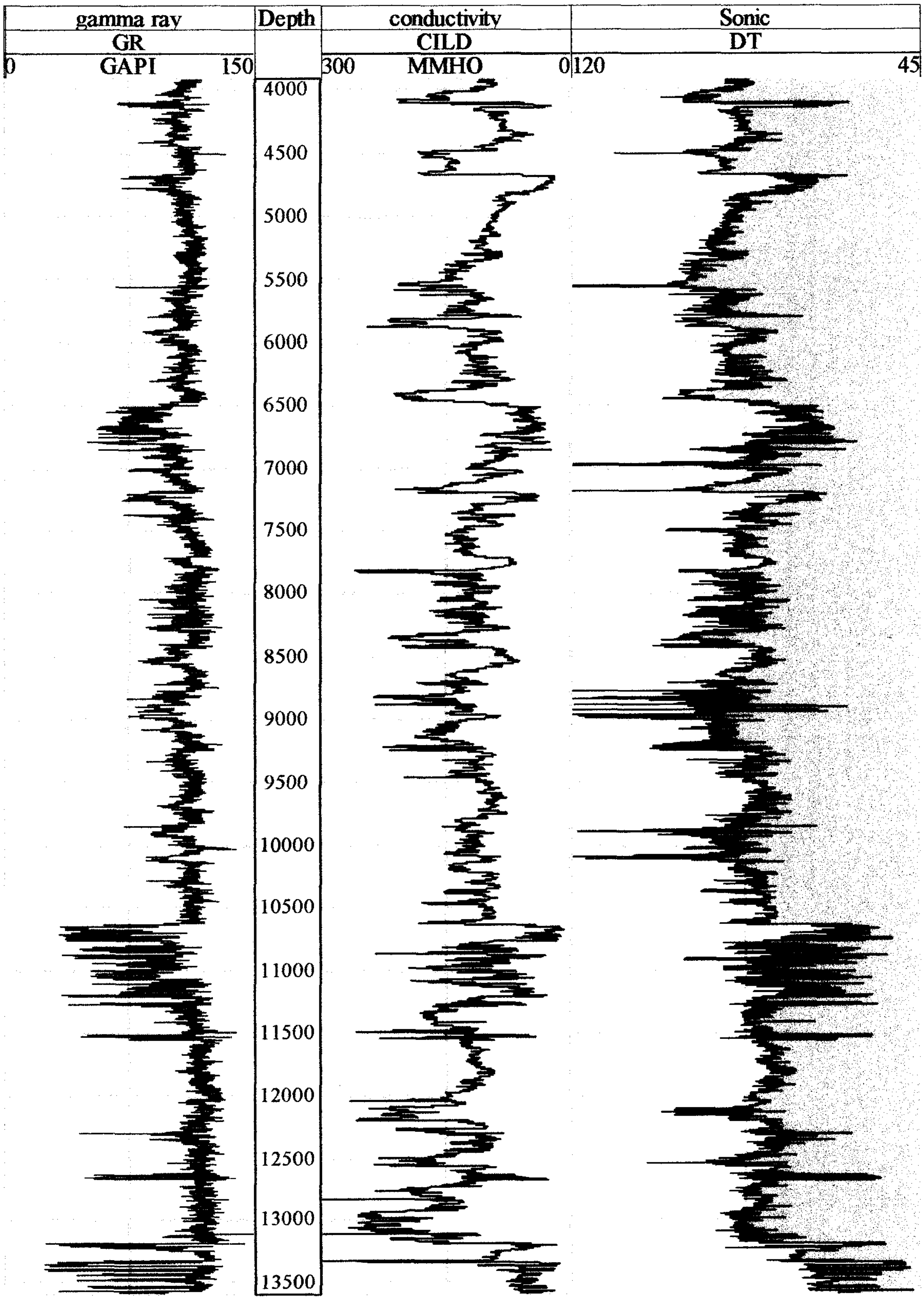


Figure 14. Log curves for Jean Shadwick#1-14 well (6N-24E-14). The conductivity and sonic logs show very similar patterns throughout the studied stratigraphic section in the deep part of Arkoma basin.

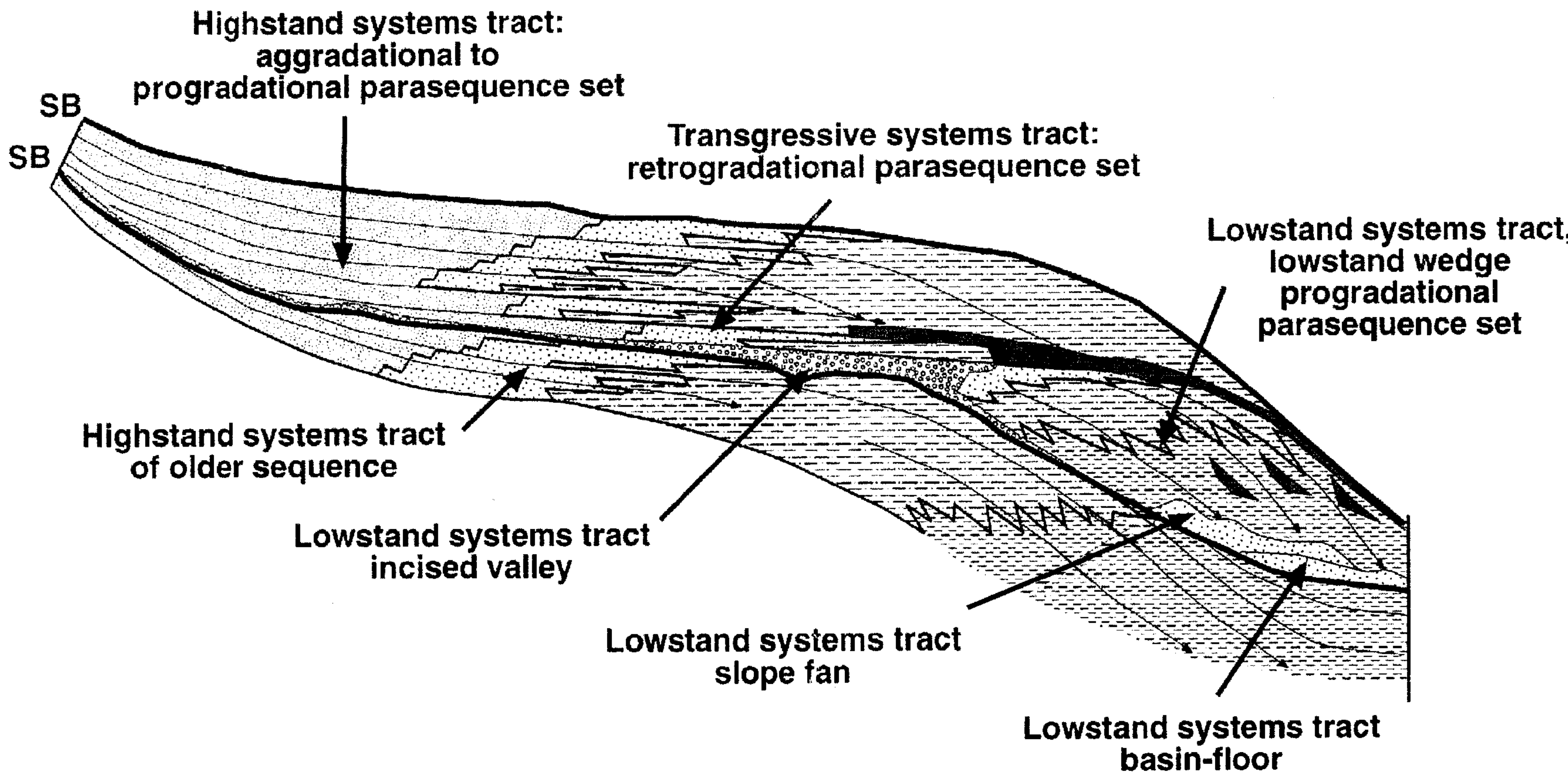


Figure 15. The sequence stratigraphic model showing the three main components of type 1 sequence in a basin with shelf break: lowstand systems tract, transgressive systems tract, and highstand systems tract (modified after Kerans and Tinker, 1997).

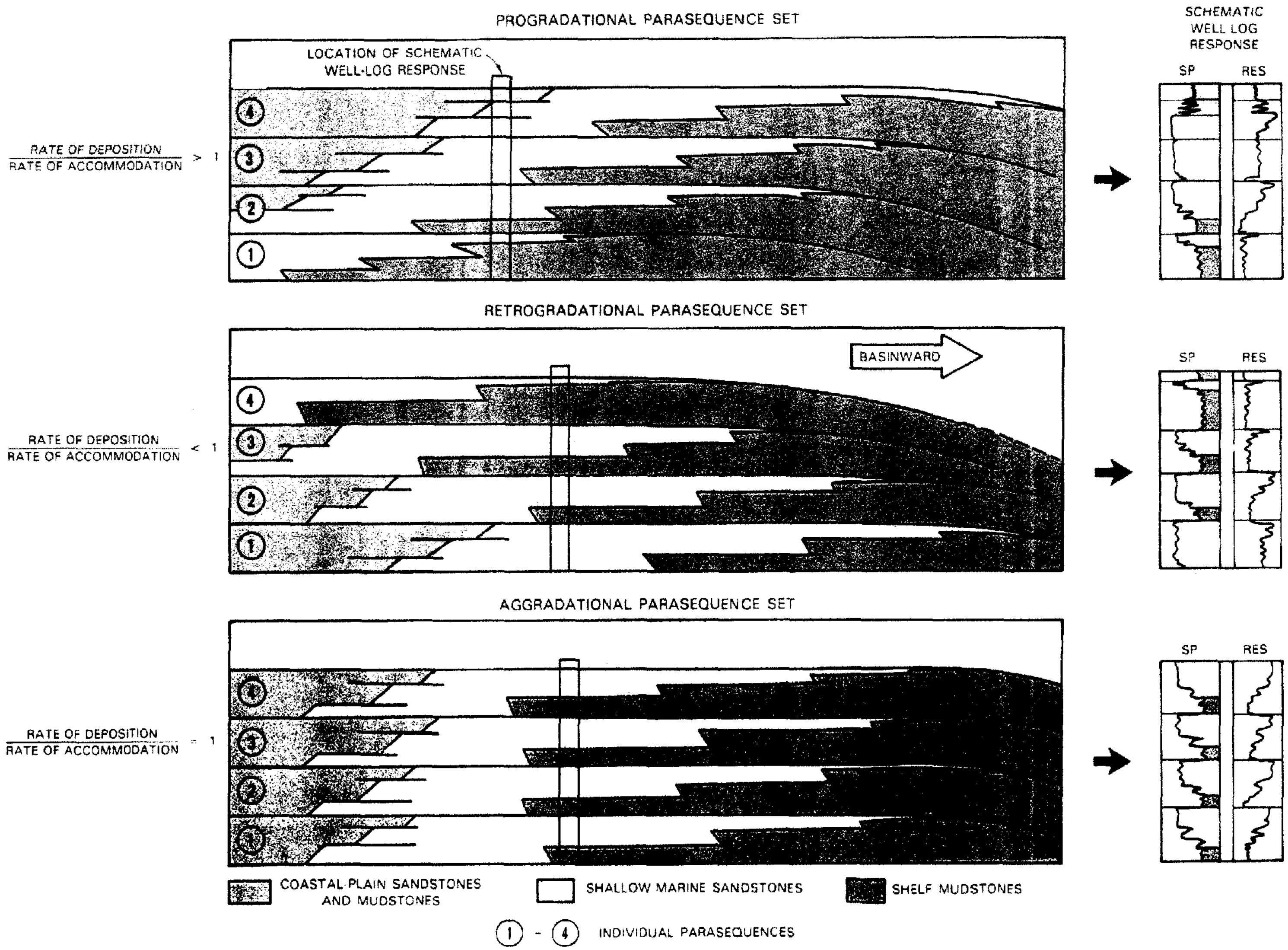


Figure 16. Stacking patterns of parasequence sets are progradational, retrogradational,or aggradational depending upon the ratio of deposition rate (sediment supply) to accommodation rate (after Van Wagoner et al., 1988).

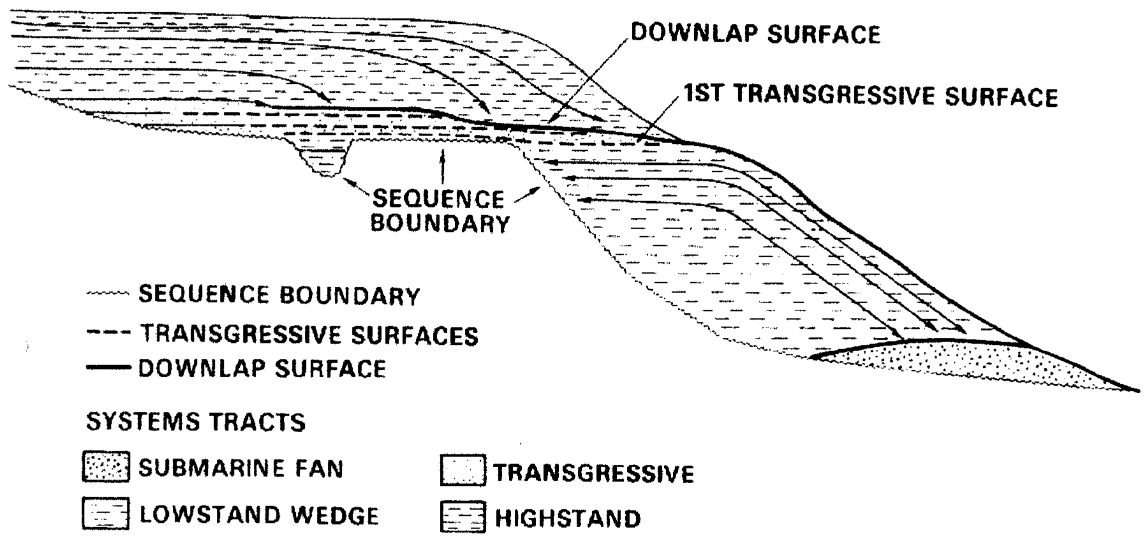


Figure 17. Schematic diagram showing the stratigraphic relations of the key correlation surfaces within a sequence: sequence boundary (unconformity), first transgressive surface, and downlap surface (maximum flooding surface) (after Loutit et al., 1988).

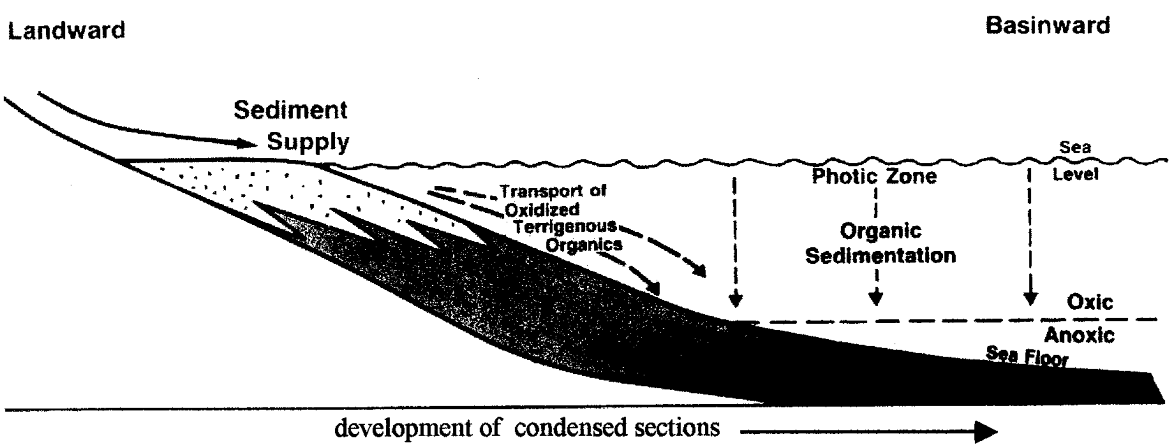


Figure 18. Condensed section incorporates slowly accumulating sediments laid down in the distal parts of both the transgressive and highstand deposits. This thin section is characterized by its wide extension across the basin, and abundance of organic matter and authigenic minerals showing on a gamma ray log as hot shale (modified after Creaney and Allan, 1992).

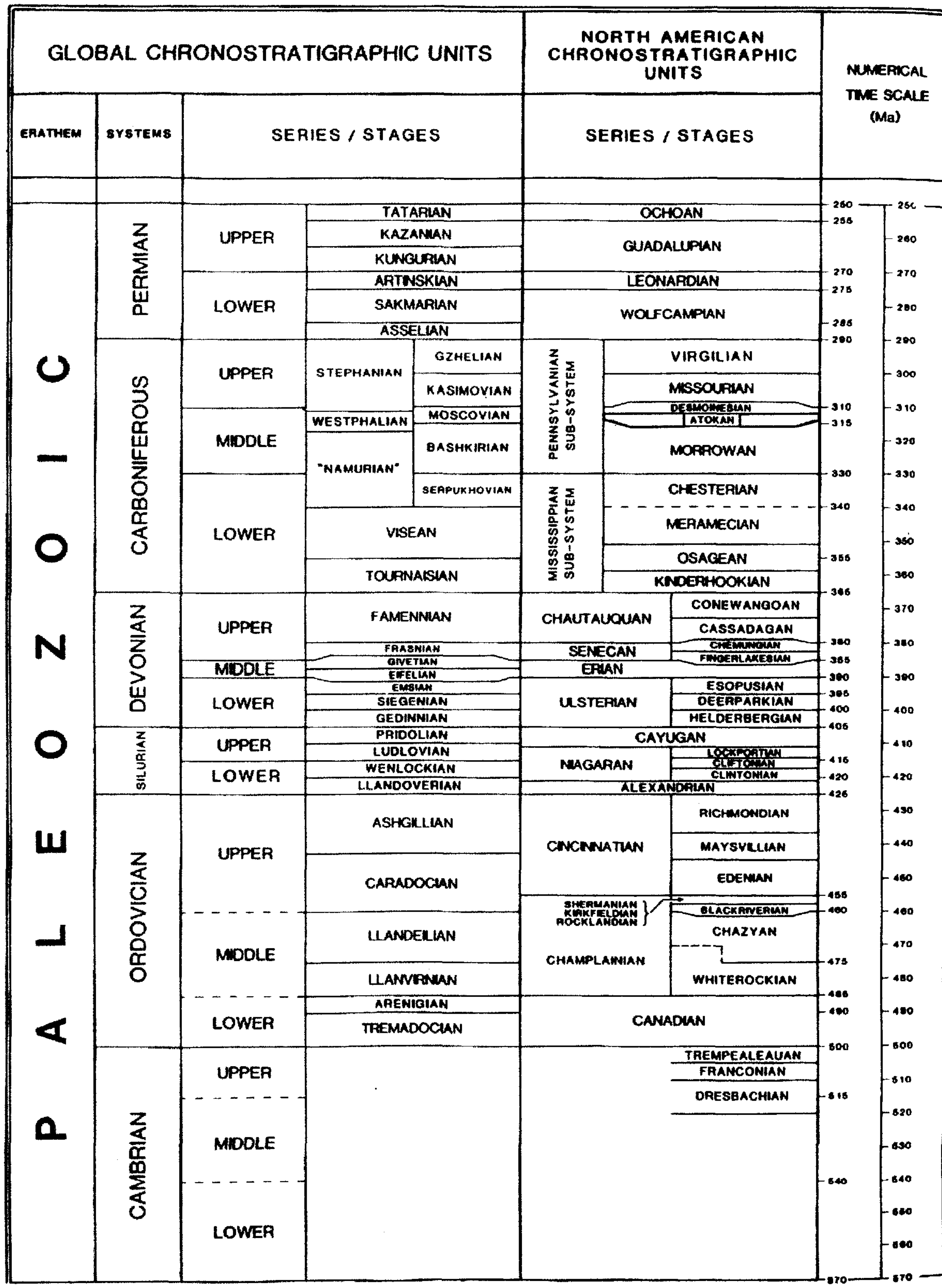


Figure 19. Chronostratigraphic scale for the Paleozoic Erathem showing the time span for the Atokan Series marked with yellow color (after, Salvador, 1985).

Tectono-Eustatic/ Eustatic Cycle Order	Sequence Stratigraphic Unit	Duration (my)	Relative Sea Level Amplitude (m)	Relative Sea Level Rise/Fall Rate (cm/1,000 yr)
First		>100		<1
Second	Supersequence	10-100	50-100	1-3
Third	Depositional Sequence Composite Sequence	1-10	50-100	1-10
Fourth	High Frequency Sequence, Parasequence and Cylce Set	0.1-1	1-150	40-500
Fifth	Parasequence, High-Frequency Cycle	0.01-0.1	1-150	60-700

Figure 20.Terminology of cycle hierarchies and orders of cyclicity (after Kerans and Tinker, 1997).

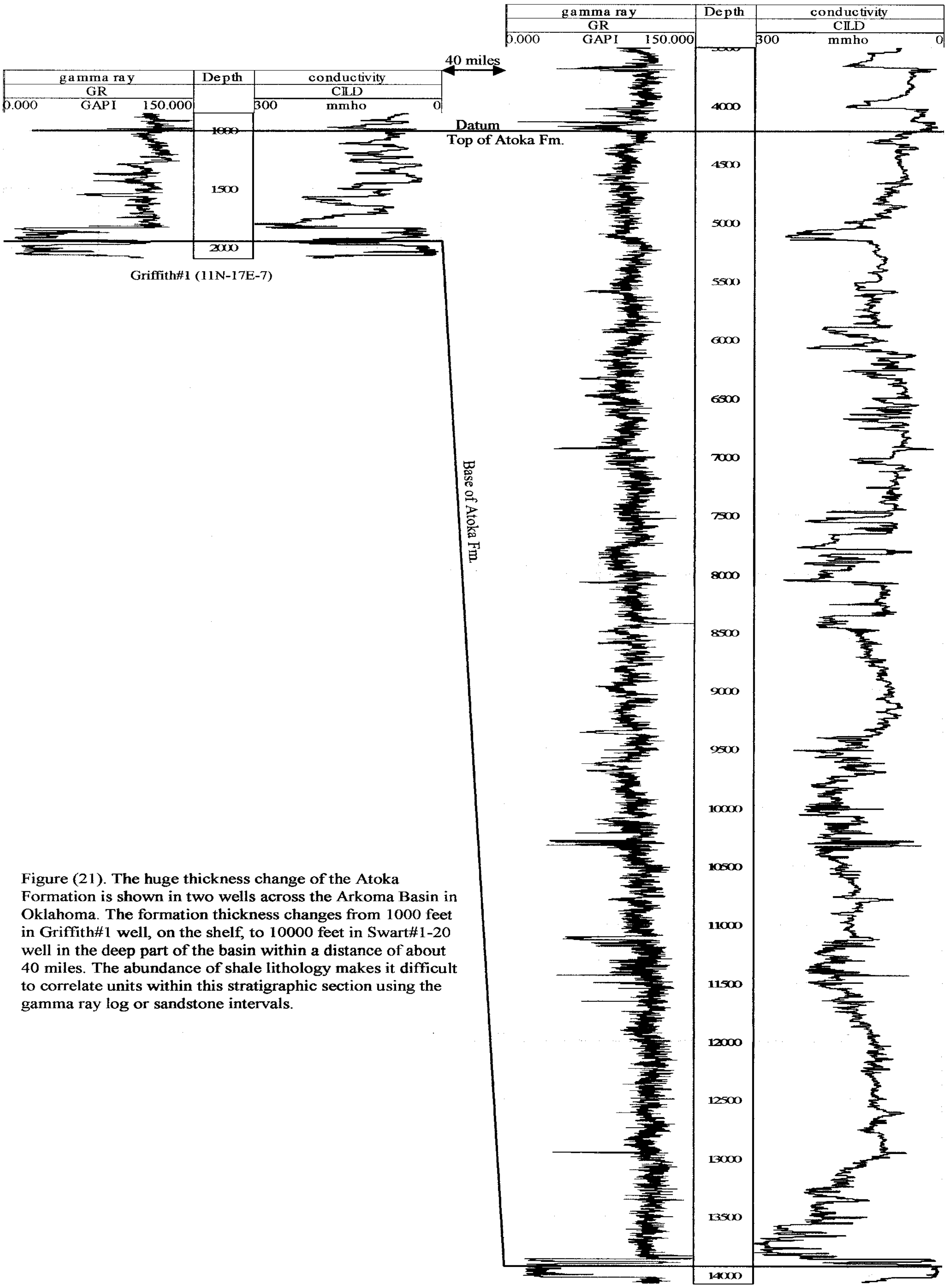


Figure (21). The huge thickness change of the Atoka Formation is shown in two wells across the Arkoma Basin in Oklahoma. The formation thickness changes from 1000 feet in Griffith#1 well, on the shelf, to 10000 feet in Swart#1-20 well in the deep part of the basin within a distance of about 40 miles. The abundance of shale lithology makes it difficult to correlate units within this stratigraphic section using the gamma ray log or sandstone intervals.

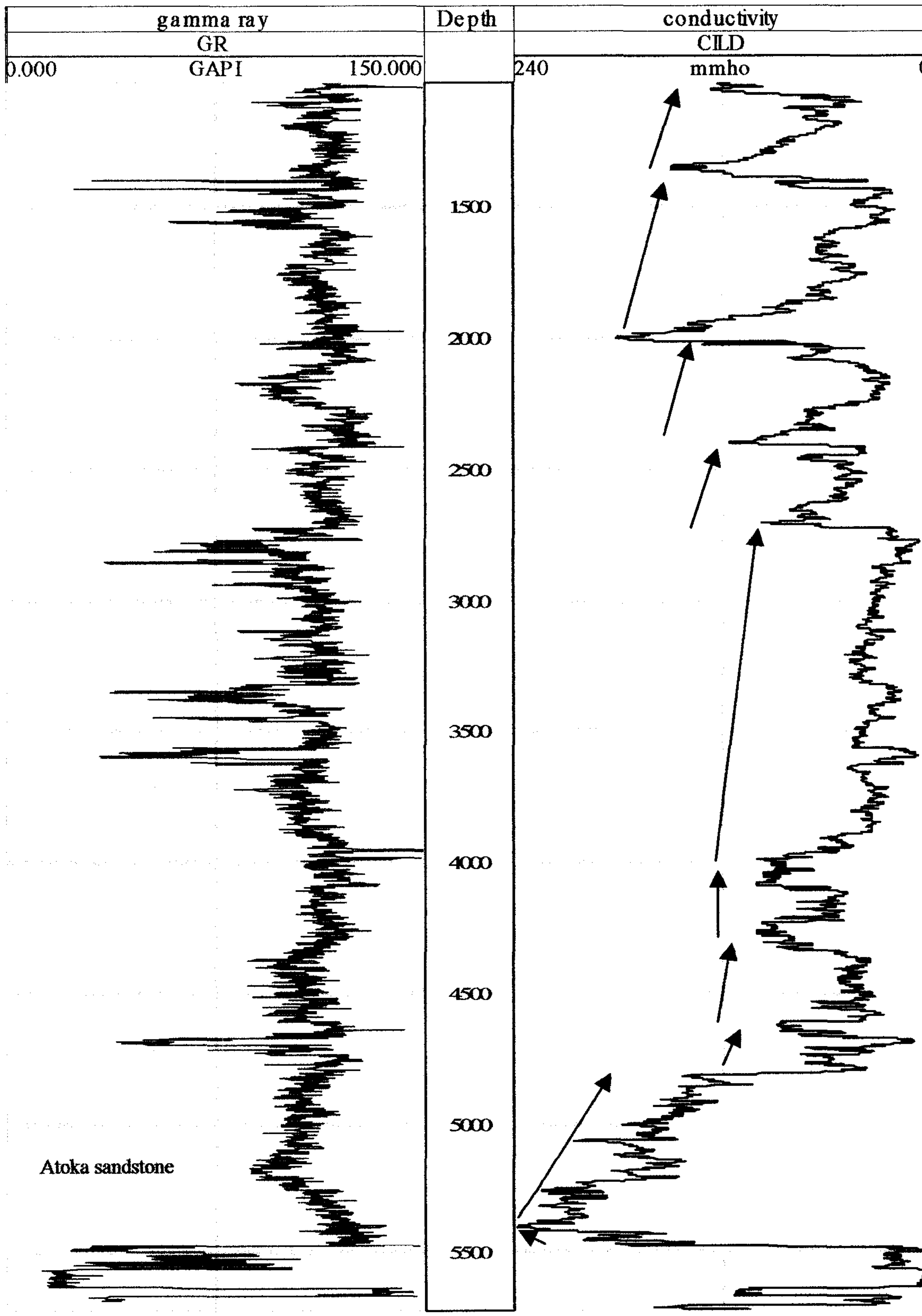


Figure 22. Conductivity log shows good definition of the stacking pattern for the shale packages in MaCafferty Unit#2 well (8N-22E-26). Such packages are much more continuous than the sandstone intervals that occur within them.

CHAPTER 3

UNION VALLEY - BASAL ATOKA

This chapter deals with the stratigraphic interval from the Morrowan Union Valley at the base to the basal Atoka strata, which are defined in this work to include the Foster sandstone, sub-Spiro shale, Spiro sandstone, and Cecil sandstone respectively from base to top. This interval is one of the most heavily studied sections in both the Arkoma Basin and the frontal Ouachitas, and includes the contact between the Atoka Formation and the underlying Morrowan strata. Several paleontological studies have been conducted on this section using conodonts and fusulinids (Grayson, 1980, 1984 and 1990; Douglass and Nestell, 1984; Groves and Grayson, 1984). Yet, the nature and the placement of this contact are still controversial both in outcrops and subsurface. Groves and Grayson (1984), in their study to identify the position of the Morrowan/Atokan boundary in the frontal Ouachitas, concluded that the precise faunal correlations to the type areas at the boundary level are impossible.

The Morrowan strata in the Arkoma Basin in Oklahoma consist of the Cromwell sandstone, the Union Valley and Wapanucka limestones respectively from base to top (Fig. 2). The Cromwell sandstone was deposited as channel-fill sandstones in the erosional valleys of the Mississippian/Pennsylvanian regional unconformity (Visher, 1996). The Cromwell interval overlies a thinner sandstone beds informally called the Jefferson sandstone, which is considered "lower Cromwell" by some geologists (Andrews, 2003). Overlying the Cromwell sandstone, the Union Valley (called alternatively Union Valley "shale" or "limestone") consists primarily of gray shales and an upper limestone unit (French, 1994). Grayson (1980) divided the overlying Wapanucka Formation in the frontal Ouachitas into four members: chickachoc chert, the lower limestone, middle shale, and the upper sandstone-limestone members. Grayson and Sutherland (1988) mentioned that this formation has traditionally been included entirely within the Morrowan Series, but studies on conodont faunas showed that the uppermost unit is Atokan in age and represents the lateral equivalent of the lower Atokan Spiro sandstone in the subsurface Arkoma Basin (Fig. 23). Jordan (1957) was the first to use the term " Spiro sandstone" as an official lithostratigraphic term, noting its regional persistence at the base of the Atokan section across the Oklahoma part of the Arkoma Basin. Lumsden et al. (1971) separated the Spiro sandstone into two stratigraphic units, the lower Foster sandstone, and the upper Spiro sandstone. Following the work of Grayson (1980), Frost (1983) subdivided the Wapanucka Formation in the Arkoma Basin into the lower limestone, middle shale (or sub-Spiro shale), Foster sandstone, and Spiro sandstone.

There is relatively general agreement on the presence of a regional unconformity between the Morrowan and Atokan sections in most of the Arkoma Basin. Several authors suggested that the relationship becomes conformable in the extreme southern part of the Arkoma Basin and the frontal Ouachitas (Zachry and Sutherland, 1984; Johnson et al., 1989; Mauldin, 2000). Previous workers suggested the placement of the unconformity at the base of the Spiro and the Foster (channel) sandstones and above the sub-Spiro shale (Lumsden et al. 1971; Frost, 1983, Horn 1997). Others suggested the placement of the unconformity at the base of the sub-Spiro shale and above the Wapanucka limestone (Hooker, 1988; Choh and Lock, 1997). Moreover, some workers suggested the presence of two unconformities, above and below the sub-Spiro shale (Fritz and Hooker, 1994; Gross et al., 1995).

The controversy in defining the boundary between the Morrowan and Atokan strata can be attributed to three reasons: 1) fossils are generally absent in both the surface outcrops and subsurface cores of the sub-Spiro shale (Frost, 1983; Sutherland and Manger, 1984). 2) different interpretations of the stratigraphic relationships of sub-Spiro shale, Spiro and Foster sandstones. 3) limited attention has been given to the distribution of both the Wapanucka and Union Valley intervals in the subsurface Arkoma Basin.

The mineralogical composition of the Union Valley-basal Atoka stratigraphic interval includes both quartz and calcite minerals. In addition to the conductivity and gamma ray logs, both the density and PEF logs were incorporated, where available, for clear lithological identification. Quartz has a very low PEF log value of 1.81 barns/electron, in contrast to the high PEF value of a calcite matrix (5.08 barns/electron). Also, quartz has a lower density (2.65 gm/cc) than that of calcite (2.71 gm/cc) (Schlumberger, 1989). Fig. (24) shows the characteristic pattern of the logs used to delineate the stratigraphic relationships within the Union Valley-basal Atoka section. Regional cross sections were constructed to show the overall picture of the studied stratigraphic section. Additionally, detailed cross sections were created, covering a few townships and incorporating both the gamma ray and PEF logs, to clearly demonstrate the stratigraphic relationships.

The Union Valley interval in the west and south of the Arkoma Basin is dominated by shale that exhibits a characteristic conductivity pattern. The overlying Wapanucka limestone is characterized by a sharp base and top on both the gamma ray and conductivity logs (Fig. 24). The thickest Wapanucka limestone occurs in the area between ranges 12 to 18 in the southern part of the Arkoma Basin, where it reaches over 200 feet in thickness, north of the Choctaw fault. It thins both to the east and the west of this area as a result of erosion, with an increase of intercalating shale beds within the limestone interval to the east (Fig. 25). A N-S cross section in the western part of the Arkoma Basin, demonstrates that Wapanucka limestone was also progressively eroded from south to north (Fig. 26). It was completely eroded in the northwestern part of the Arkoma Basin where a transgressive Atokan sandstone overlies the Union Valley shale in Grayson#1-22 well (Fig. 26).

Both in the literature and the well scout tickets, the top limestone of the Morrowan section in the entire Arkoma Basin is always identified as the Wapanucka limestone. Fig (27) shows in detail that thin limestone layers within the Union Valley shale thicken to the north and east and become the limestone underlying the Foster sandstone in the Wren#1-a well. The thick Wapanucka limestone was gradually eroded to the northeast, and once it was truncated, thick Foster sandstone develops to the east. On a regional scale, the major part of the limestone underlying the Atokan section in the northeastern part of Arkoma Basin is Union Valley limestone (Figs. 28, 29, and 30). This suggests that the unconformity lies at the top of the Union Valley limestone in the northeastern part of the Arkoma Basin (Fig. 30), and at the top of the Wapanucka limestone farther south and west (Fig. 26).

Fig. (31) is a detailed correlation using the PEF log, for clear lithological identification, showing the same stratigraphic relationships described in Fig. (26), but instead of the development of the Foster sandstone to the east of the truncated Wapanucka limestone, thick sub-Spiro shale was developed. Gross et al. (1995) reported that rip-up clasts of the older Wapanucka limestone were reworked into the overlying sub-Spiro shale. They identified this contact as an unconformity. Based on detailed correlations, both Foster sandstone and sub-Spiro shale are time equivalent and they represent a facies change as shown in Fig. (32). The Foster sandstone has been interpreted as fluvial channel deposits (Frost, 1983; Sutherland; 1988; Houseknecht and McGilvery, 1990). Hooker (1988) suggested that the channels were created by subaerial incision and filled in an estuarine setting or nearshore marine environment. Her shallow marine interpretation was based primarily on the presence of chamosite pellets and skeletal fragments.

A thin sporadic sandstone interval lies beneath the sub-Spiro shale in different parts of the Arkoma Basin. It directly overlies the Morrowan Wapanucka or the Union Valley limestones and can be hardly recognized without using the PEF log (Fig. 33). Horn (1997) identified this thin sandstone in the Red Oak Field as Wapanucka sandstone and assigned it to the Wapanucka Formation. Conversely, in this study, this discontinuous basal sandstone is interpreted as Atokan in age, as it occurs locally at the base of the Atokan section marking the Morrowan/Atokan unconformity surface (Fig. 33).

The Spiro sandstone overlies both the Foster sandstone and sub-Spiro shale. Houseknecht (1987) mentioned that the Spiro was deposited in a broad, tidally swept, coastal environment. Grayson and Hinde (1993) proposed a shelf bar model and concluded that the Spiro in the Arkoma Basin primarily represents offshore shelf bars. Gross et al. (1995) interpreted the Spiro sandstones as barrier islands and tidal channel facies in the area north and south of the Choctaw fault. Forgotson et al. (2000) concluded that the Spiro sandstone in the frontal Ouachitas was deposited in a near shore marine environment. A common criterion in all these interpretations is that the Spiro sandstone was deposited during a transgressive phase of sea level. Unlike the Foster sandstone, the Spiro sandstone represents a widespread stratigraphic unit that thickens to the east and south within the Arkoma Basin (Figs. 25 and 30). Yet it does not form a sheet-like geometry that covers the entire Arkoma Basin. It is mainly composed of laterally stacked sandstone units that become very thin within a few miles. Closely spaced well log correlations illustrate this thinning geometry (Fig. 34). This figure also shows that the Spiro sandstone is partially cutting into the underlying sub-Spiro shale. The surface between the Spiro sandstone and the underlying sub-Spiro shale, or the Foster sandstone, can be interpreted as a diastem rather than an unconformity surface. Nummedal and Swift

(1987) define diastems as short interruptions of sedimentation that are associated with a marine transgression, and can be grouped as transgressive surfaces.

The interval above the Spiro sandstone is considered the top of the transgressive system tract (TST). This interval is generally marked by at the top by a condensed section, indicating a maximum flooding surface (MFS) (Fig. 35). Tracking this condensed section (hot shale marker) shows that the shaly interval above the Spiro, in the deep part of Arkoma Basin, is equivalent to both the Cecil and Pope Chapel sandstones on the shelf (Figs. 29 and 35). These two latter lithostratigraphic sandstone units are time equivalent and represent the upper transgressive sandstones that occur above the Spiro interval in the northeastern part of the Arkoma Basin in Oklahoma (Fig. 29, 30, and 35). A log pattern of slightly lower conductivity characterizes this interval where it becomes shaly to the south and west (Ward#C-1, Bowers#1-23, and White#2 wells in Fig. 35). This pattern helps to define the top of TST where gamma ray logs are not available, or where the condensed section becomes too thin to be detected on the gamma ray log.

A stratigraphic model for the Union Valley-basal Atoka stratigraphic section is presented in Fig. (36). Both the Wapanucka limestone and the Union Valley intervals represent a Morrowan carbonate shelf prograding from northeast to southwest. By the end of Morrowan time, a bulge may have formed in the northwestern part of the Arkoma Basin. This is indicated by the progressive erosion of the Wapanucka limestone to the north, until it was completely eroded in the northwestern part of Arkoma Basin (Fig. 37). This erosional surface is termed throughout this study as the Morrowan/Atokan unconformity, and represents a third-order sequence boundary. Differential erosion resulted in the development of strike valleys in the eastern part of the Arkoma Basin in Oklahoma, where beds of the Union Valley shale were exposed within the forebulge area (Fig. 36). The presence of a bulge as an integral part of the evolution of the Arkoma foreland basin will be discussed in Chapter 8.

The basal Atokan is composed of two systems tracts: the lowstand and transgressive systems tracts. The LST consists of the sub-Spiro shale and its time equivalent the Foster sandstone. Foster sandstones were deposited in the strike valleys adjacent to scarps of the Wapanucka limestone. The limit of the strike valleys to the west is the last scarp of the Wapanucka limestone. This may explain the NW-SE trend of the Foster sandstones unconformably overlying the Union Valley limestone where the Wapanucka limestone had been eroded (Fig. 37). Farther east, thick sub-Spiro shale was deposited (Fig. 36). South of township 8N, these Foster sandstones may overly the last Wapanucka scarp, as the Morrowan shelf dips to the south (Fig. 37). This figure shows the approximate areal position for the development of the strike valleys. Sporadic basal Atokan sandstone was deposited locally in areas where the Foster sandstone was not developed. It may represent the time equivalent of the lowermost part of the Foster sandstone.

Willis (1997) suggested two models for valley-fill evolution: flood-based, and flood-capped models. The thick sub-Spiro shale, in the east, and Foster sandstones may have been deposited as flood-based fills in an estuarine environment where valleys were flooded by marine water during the rise in sea level. This affirms Hooker's (1988) interpretation of an estuarine environment for the deposition of Foster sandstones. Thinner sub-Spiro shale was deposited west of these valleys (Fig. 36).

The transgressive system tract includes both the Spiro and Cecil sandstones. The TST is separated from the underlying LST by a marine flooding or transgressive surface along which the Spiro sandstones were deposited covering almost the entire shelf of the Arkoma Basin in the form of laterally stacked sandstone units (Fig. 36). Carbonates are more abundant than quartz within the Spiro sandstone interval toward the west and southwest. As relative sea level rose, the Cecil sandstone developed farther north and east (Fig. 36). To the south a condensed section caps this transgressive systems tract. The location of the cross sections presented in this chapter is shown in Fig. (37).

The Morrowan/Atokan unconformity surface, in the northeastern part of the Arkoma Basin, drops toward the south from depths above sea level to more than 15000 feet below sea level within a distance of less than 50 miles. The reason for the substantial structural relief across the Arkoma Basin is shown in Fig (38). This figure shows a first derivative map of the structure on the unconformity surface, as a measure for the rate of change in the surface slope. The high rates of slope change represent the trends of the Mulberry, Stonewall, Kinta, and San Bois faults that displaced the unconformity surface and contributed significantly to the structural relief across the basin. These faults were active during the deposition of the middle Atoka and the overlying intervals in Oklahoma part of the Arkoma Basin.

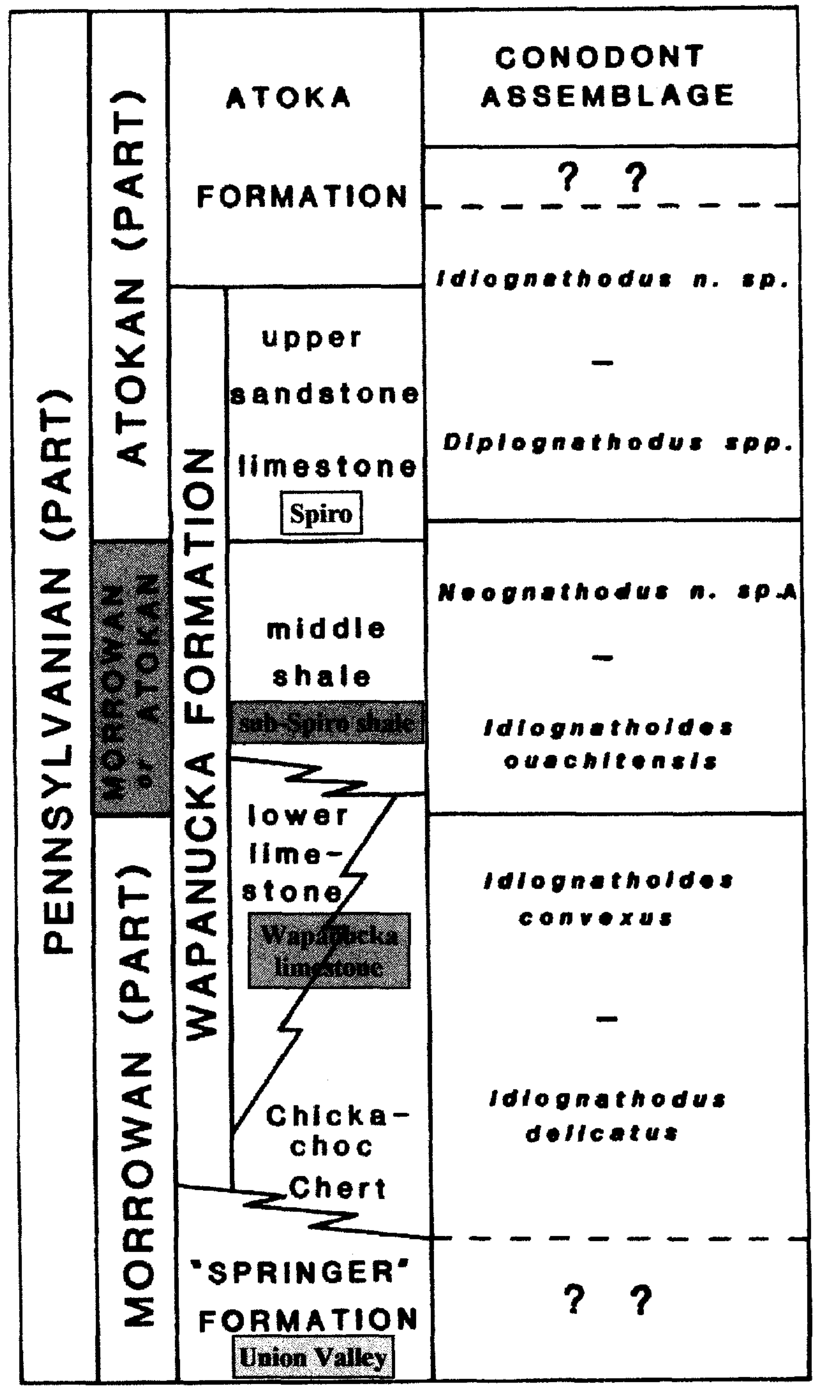


Figure 23. Lithostratigraphic and biostratigraphic subdivisions of the Wapanucka Formation and conodont assemblages, frontal Ouachita mountains (after Groves and Grayson, 1984). The equivalent lithostratigraphic nomenclature of these subdivisions in the Arkoma basin are presented in boxes. Different suggestions have been proposed for the nature and position of the Morrowan/Atokan boundary above and below the sub-Spiro shale (green color).

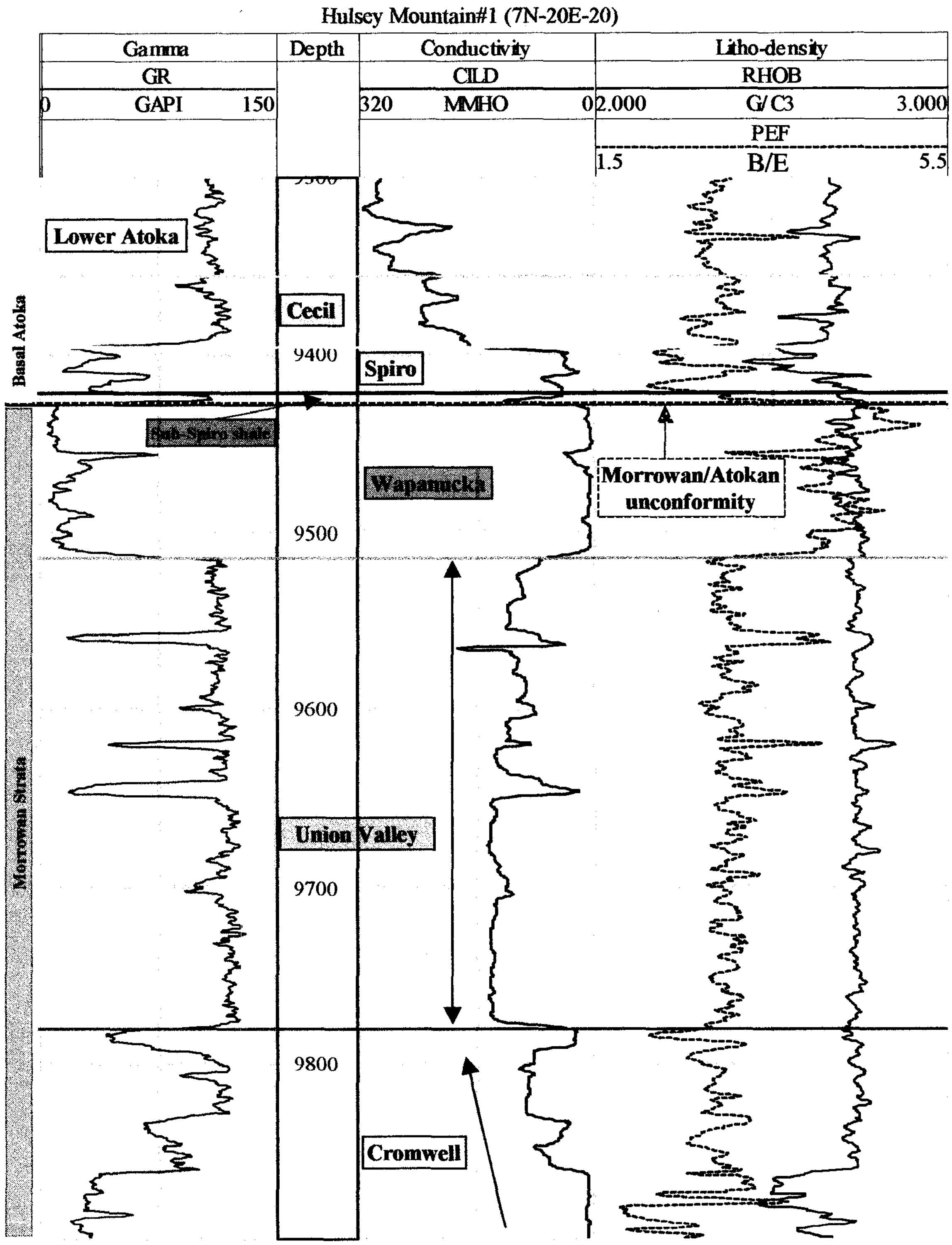


Figure 24. Characteristic log patterns for the Union Valley-basal Atoka section. The Union Valley shale is characterized by a blocky conductivity pattern. The Wapanucka limestone has sharp top and base on both the conductivity and gamma ray logs. The Spiro sandstone is readily distinguished from the underlying Wapanucka limestone by the contrast in both of the PEF and bulk density values, and the presence of the sub-Spiro shale between them. The Cecil interval shows a relatively lower conductivity than the overlying lower Atoka.

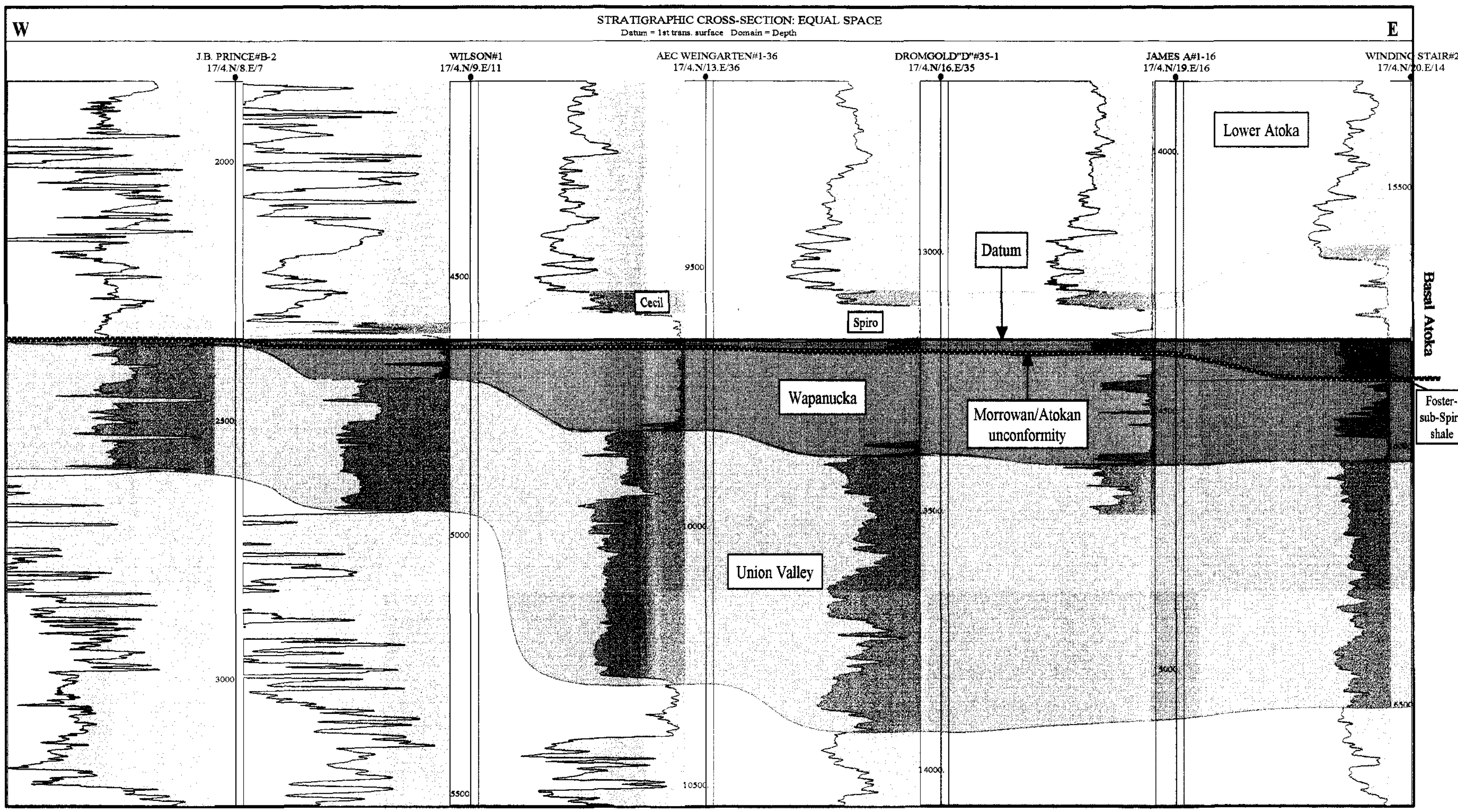


Figure 25. E-W regional stratigraphic cross section for the Union Valley-basal Atoka in the southern part of the Arkoma Basin using conductivity logs. The entire stratigraphic section thins to the west. The Morrowan Wapanucka limestone thins to the east and west with increase of shale beds within the limestone interval to the east. Note the start of extensive erosion of the Wapanucka limestone towards the west in the Wilson#1 well. The Atokan transgressive Spiro sandstone thickens to the east. The cross section datum is the transgressive surface at the base of Spiro sandstone (marine flooding surface). For location, see Fig. (37).

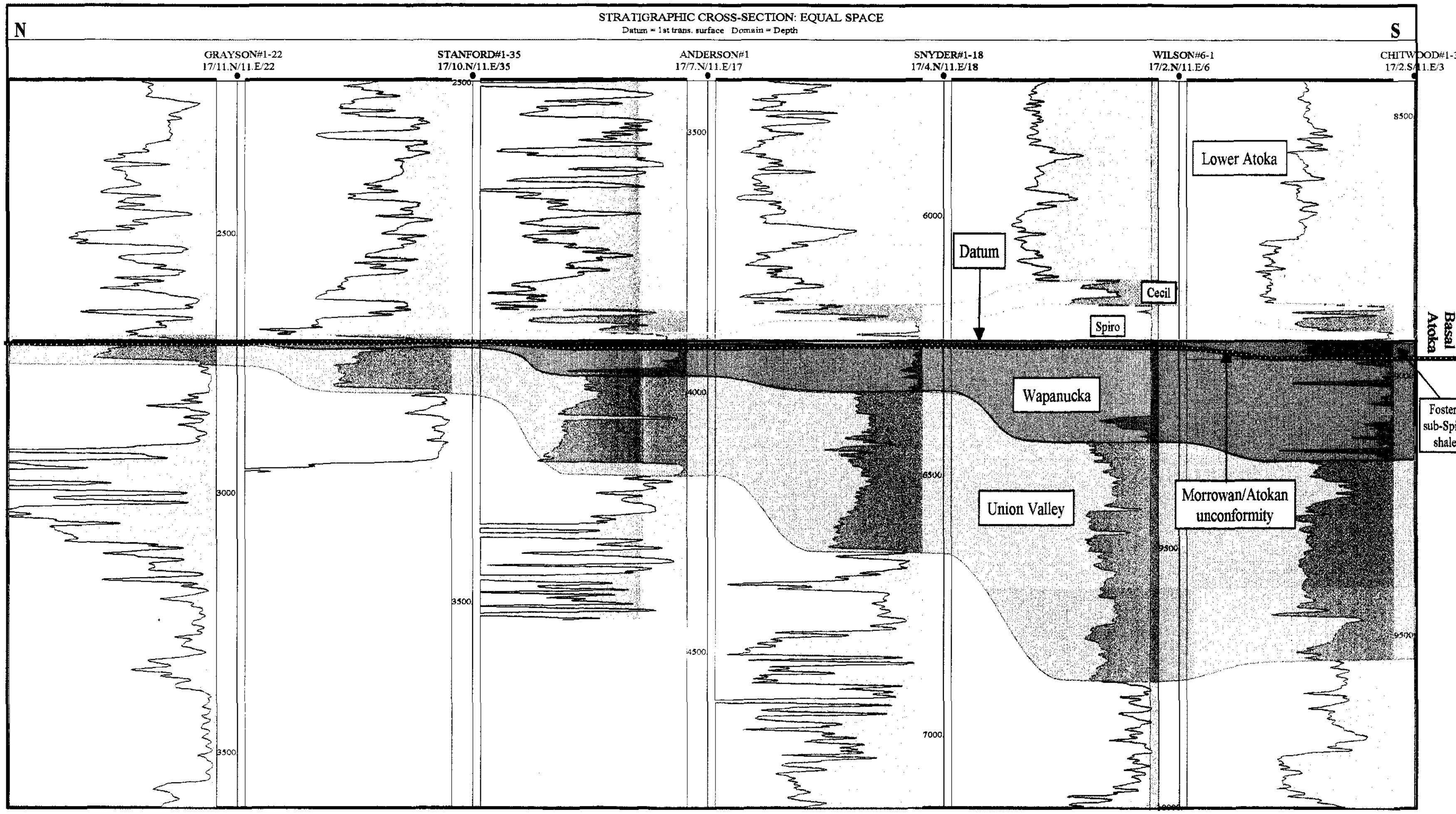


Figure 26. N-S regional stratigraphic cross section in the western part of the Arkoma Basin using conductivity logs. The thick Wapanucka limestone in the south of the Arkoma Basin was progressively eroded northward starting from the Snyder#1-18 well. It was completely eroded in the northwestern part of the basin where the Atokan transgressive Cecil sandstone unconformably overlies the Union Valley shale in Grayson#1-22 well. The cross section datum is the transgressive surface at the base of Spiro sandstone (marine flooding surface). For location, see Fig. (37).

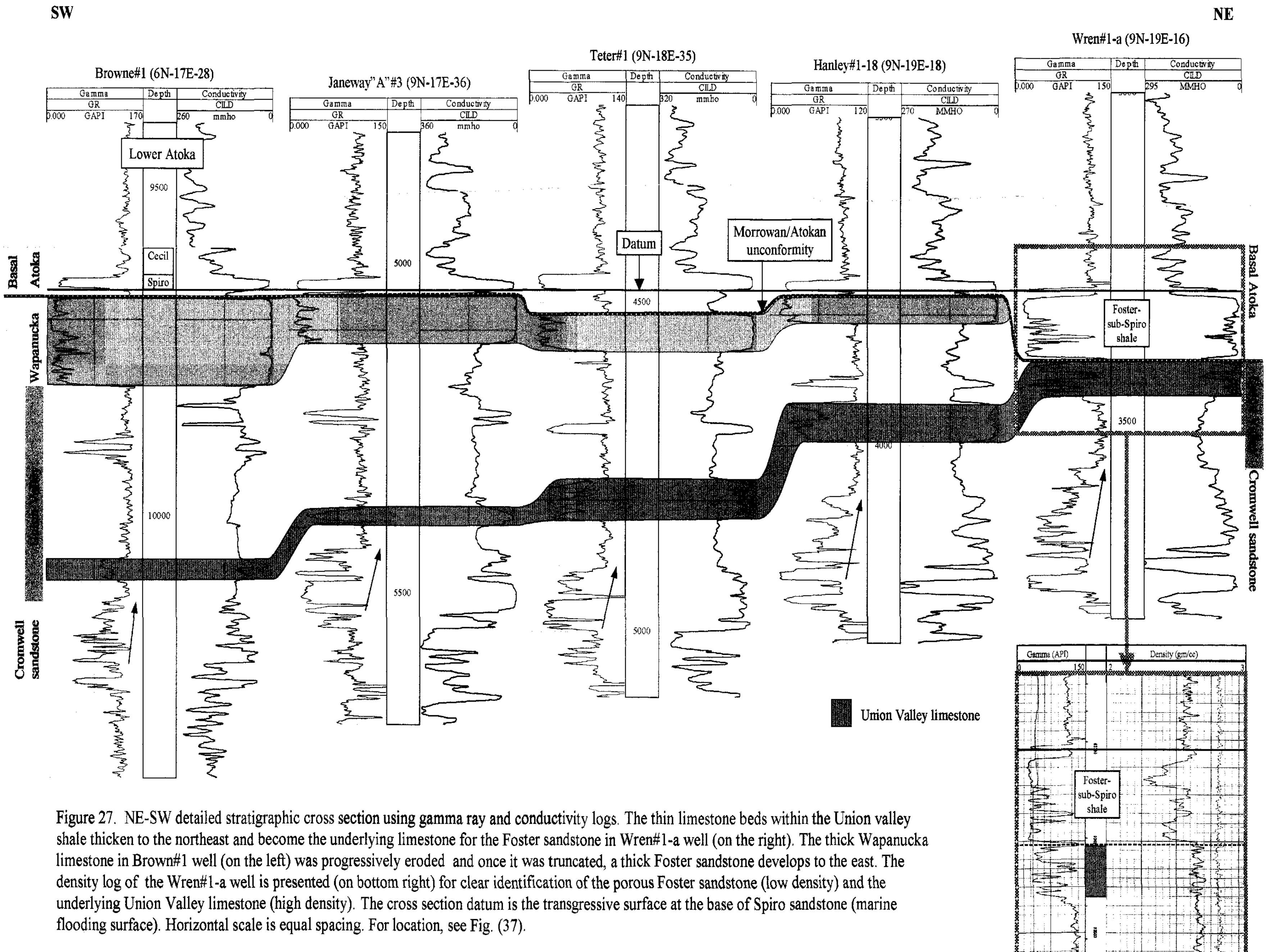


Figure 27. NE-SW detailed stratigraphic cross section using gamma ray and conductivity logs. The thin limestone beds within the Union valley shale thicken to the northeast and become the underlying limestone for the Foster sandstone in Wren#1-a well (on the right). The thick Wapanucka limestone in Brown#1 well (on the left) was progressively eroded and once it was truncated, a thick Foster sandstone develops to the east. The density log of the Wren#1-a well is presented (on bottom right) for clear identification of the porous Foster sandstone (low density) and the underlying Union Valley limestone (high density). The cross section datum is the transgressive surface at the base of Spiro sandstone (marine flooding surface). Horizontal scale is equal spacing. For location, see Fig. (37).

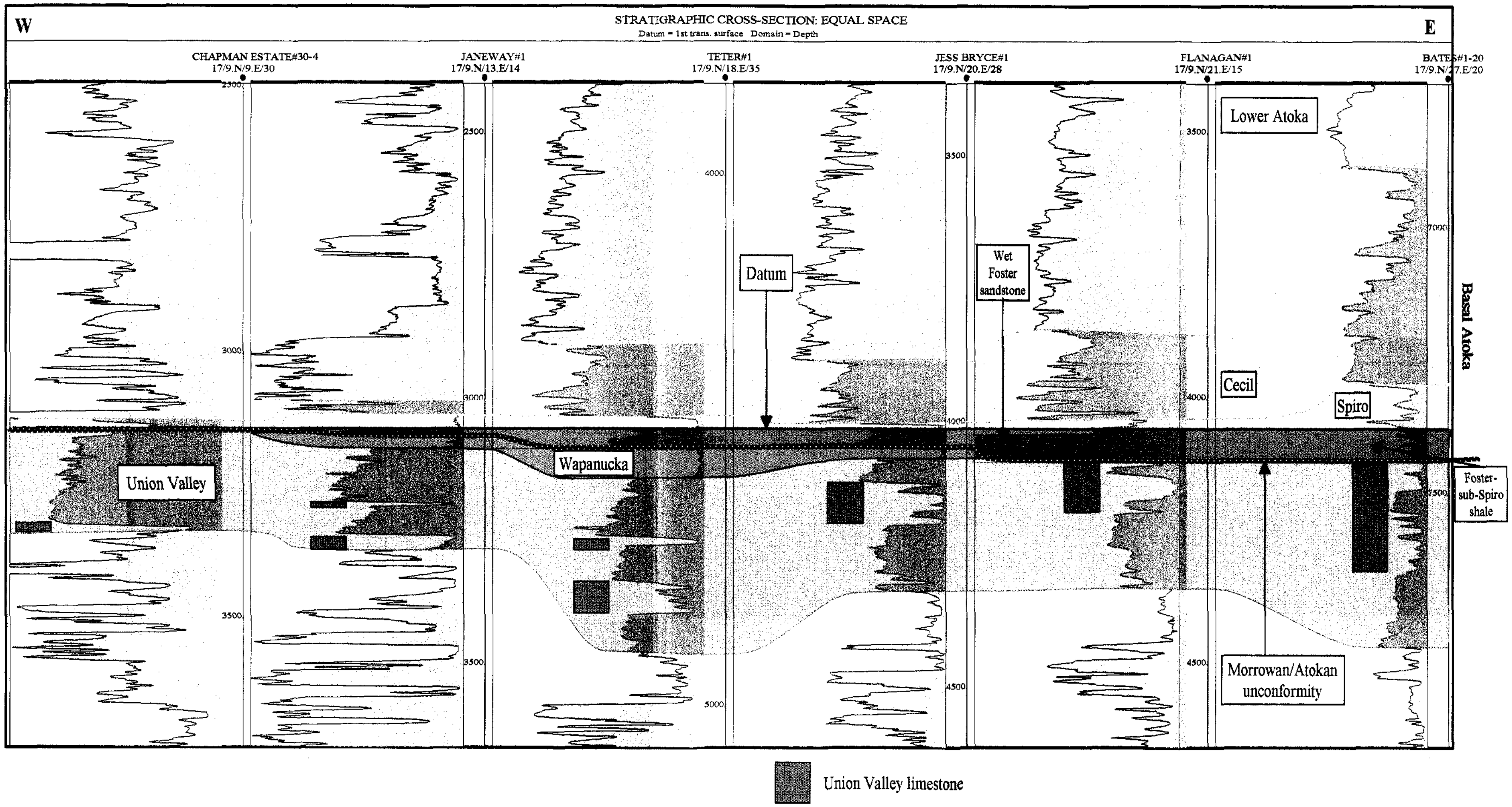


Figure 28. E-W regional stratigraphic cross section in the central part of the Arkoma Basin using conductivity logs. The Wapanucka limestone was completely eroded both to east and west. The Atokan transgressive Cecil sandstone unconformably overlies the Union Valley shale in Chapman Estate#30-4 well (on the left). The Foster sandstone develops to the east of the eroded Wapanucka scarp, where it overlies the Union Valley limestone in Flanagan#1 well. The Foster sandstone in this well is wet (highly-conductive zone). The entire basal Atoka stratigraphic section thickens to the east. The cross section datum is the transgressive surface at the base of Spiro sandstone (marine flooding surface). For location, see Fig. (37).

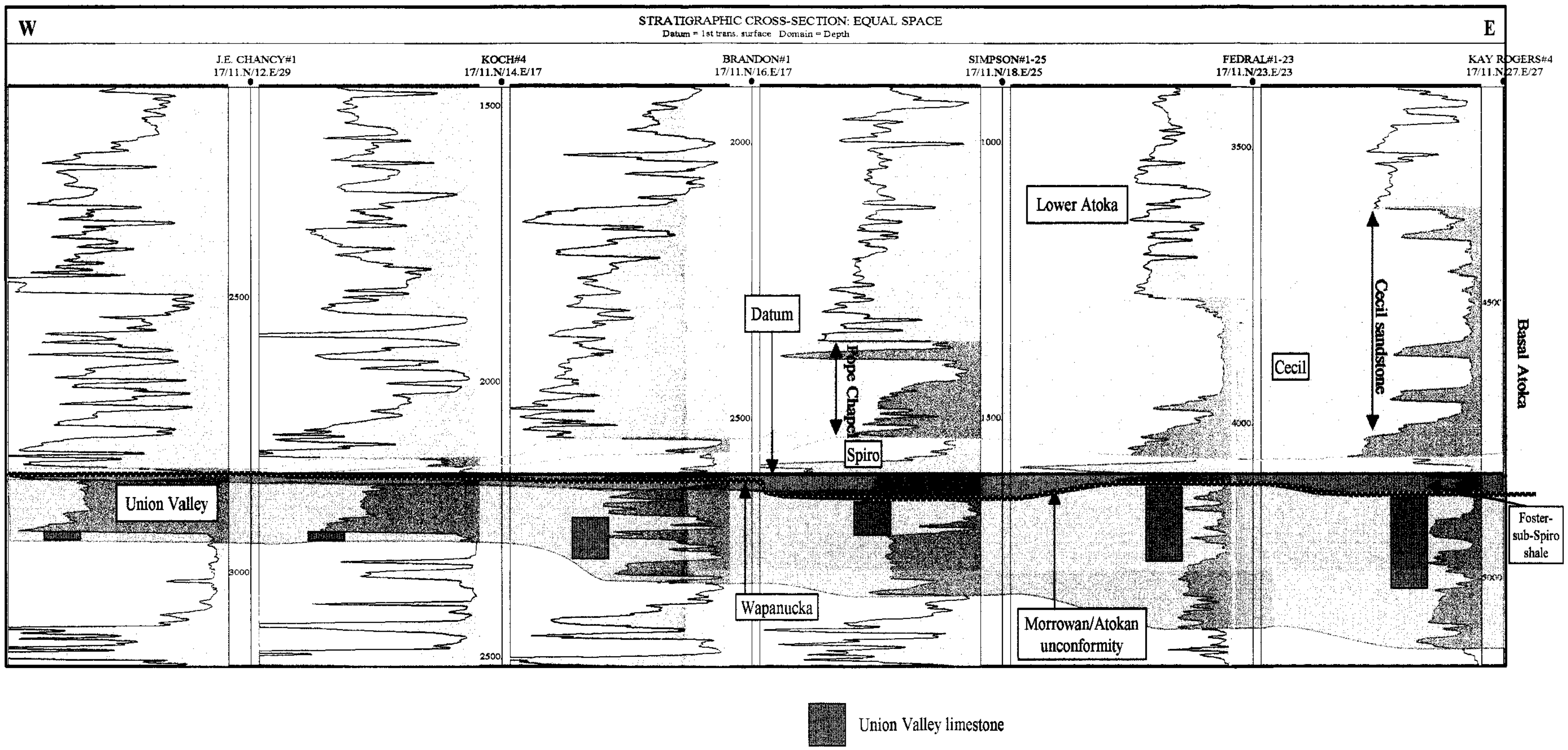


Figure 29. E-W regional stratigraphic cross section in the northern part of the Arkoma Basin using conductivity logs. The Wapanucka limestone is very thin and was completely eroded in the eastern half of Arkoma basin. Meanwhile, the limestone in Union valley is well-developed. The Morrowan/Atokan unconformity lies at the top of the Union Valley limestone in the east, and at the top of Wapanucka limestone to the west. The sub-Spiro shale thickens to the east once the Wapanucka scarp is eroded . The Cecil sandstone in Kay Rogers#4 well (on the right) is time-equivalent for the Pope Chapel sandstone in Simpson#1-25 well to the west. Both sandstones represent the upper transgressive interval of the basal Atoka stratigraphic section. The cross section datum is the transgressive surface at the base of Spiro sandstone (marine flooding surface). For location, see Fig. (37).

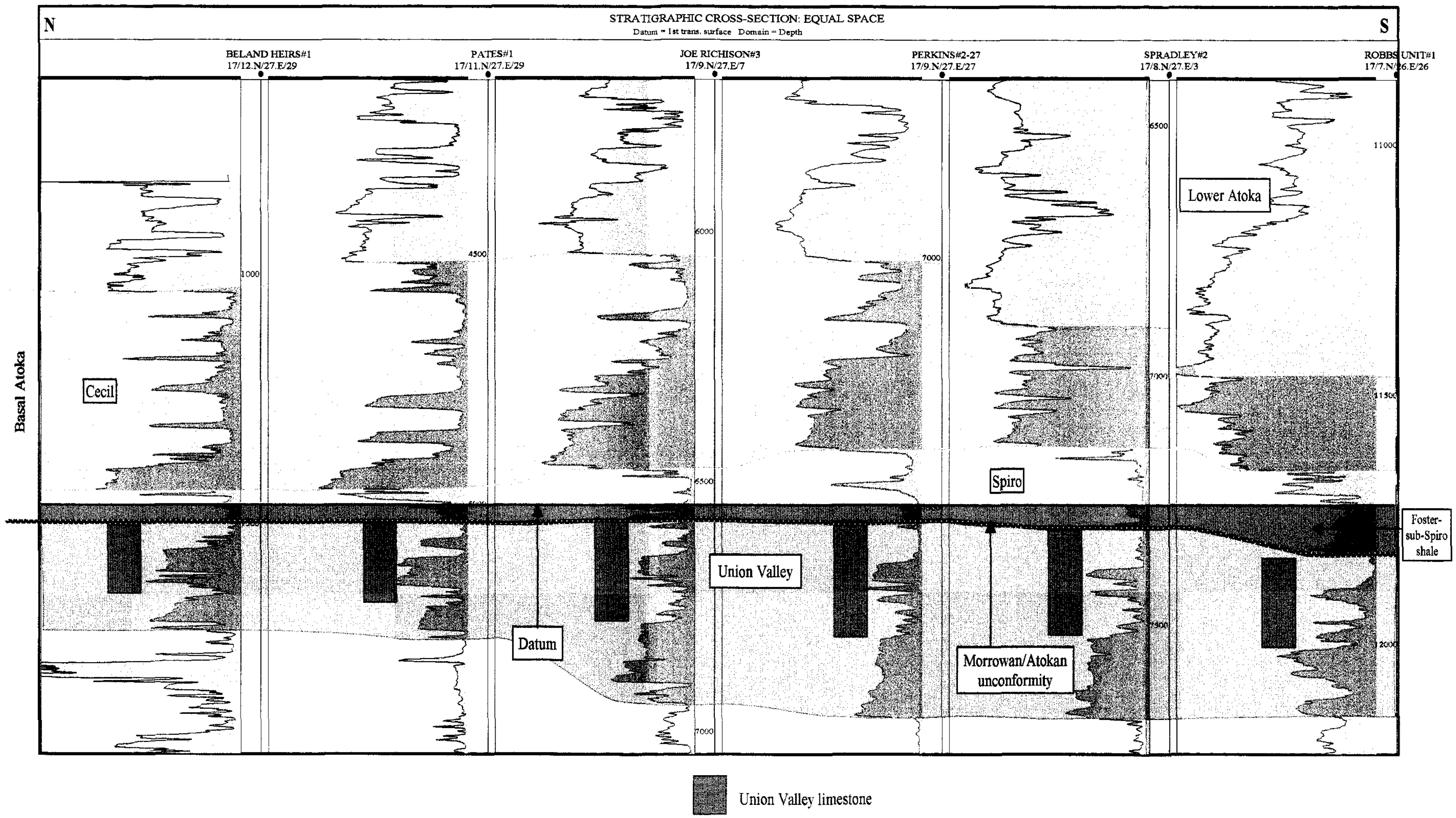


Figure 30. N-S regional stratigraphic cross section in the eastern part of the Arkoma Basin using conductivity logs. The union Valley limestone is well-developed and underlies the basal Atoka section in all the wells. The cross section shows the thickness trends of sandstones composing the transgressive system tract of the basal Atoka section. The Spiro sandstone is thicker in the south. Meanwhile, the Cecil sandstone thickens to the north indicating rise in relative sea level. The cross section datum is the transgressive surface at the base of Spiro sandstone (marine flooding surface). For location, see Fig. (37).

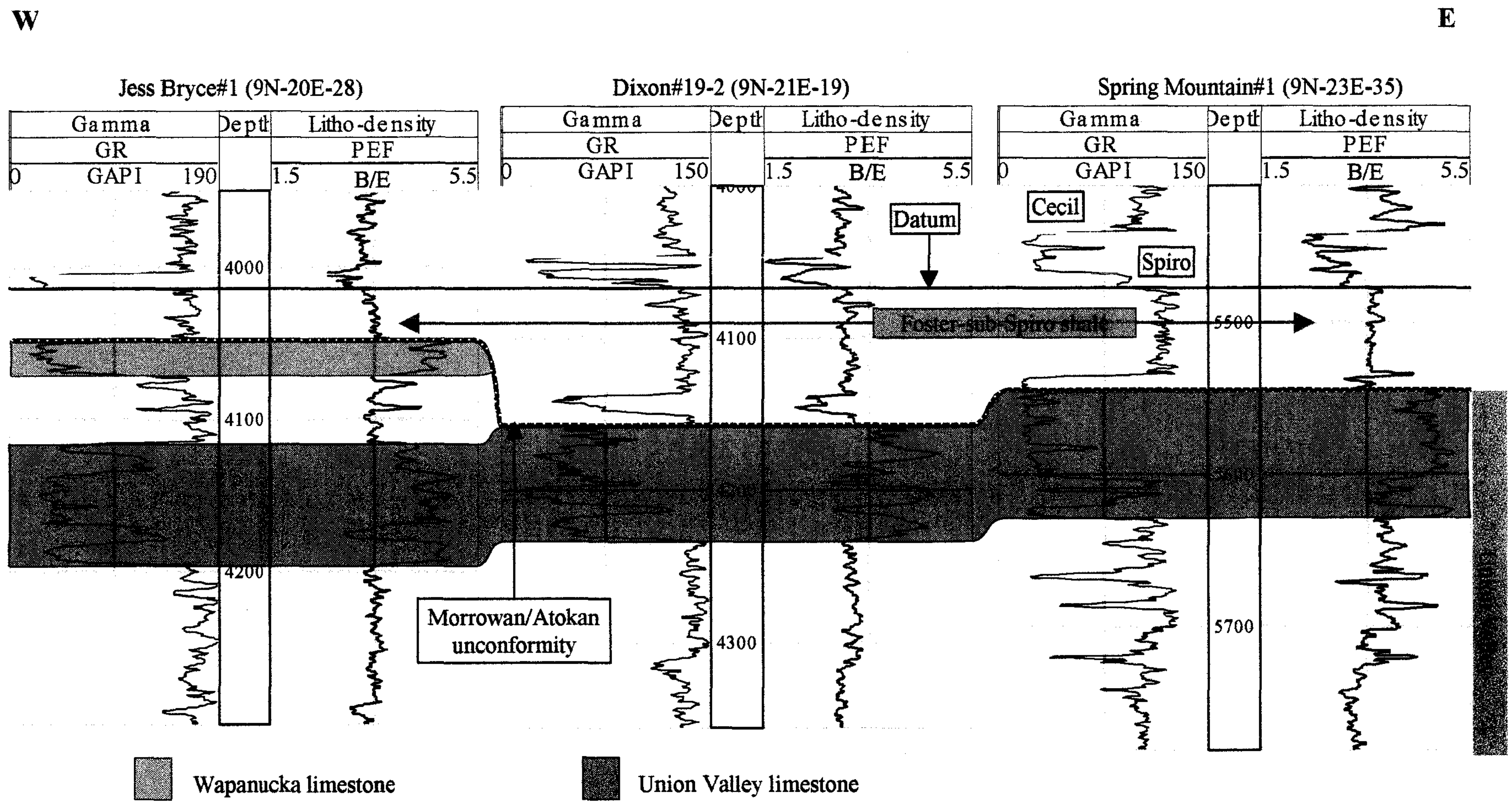


Figure 31. E-W detailed stratigraphic cross section using gamma ray and PEF logs for clear lithologic identification. A thick sub-Spiro shale develops to the east once the Wapanucka limestone scarp is eroded. Note the thin basal sandstone interval at the base of the sub-Spiro shale. The cross section datum is the transgressive surface at the base of Spiro sandstone (marine flooding surface). Horizontal scale is equal spacing. For location, see Fig. (37).

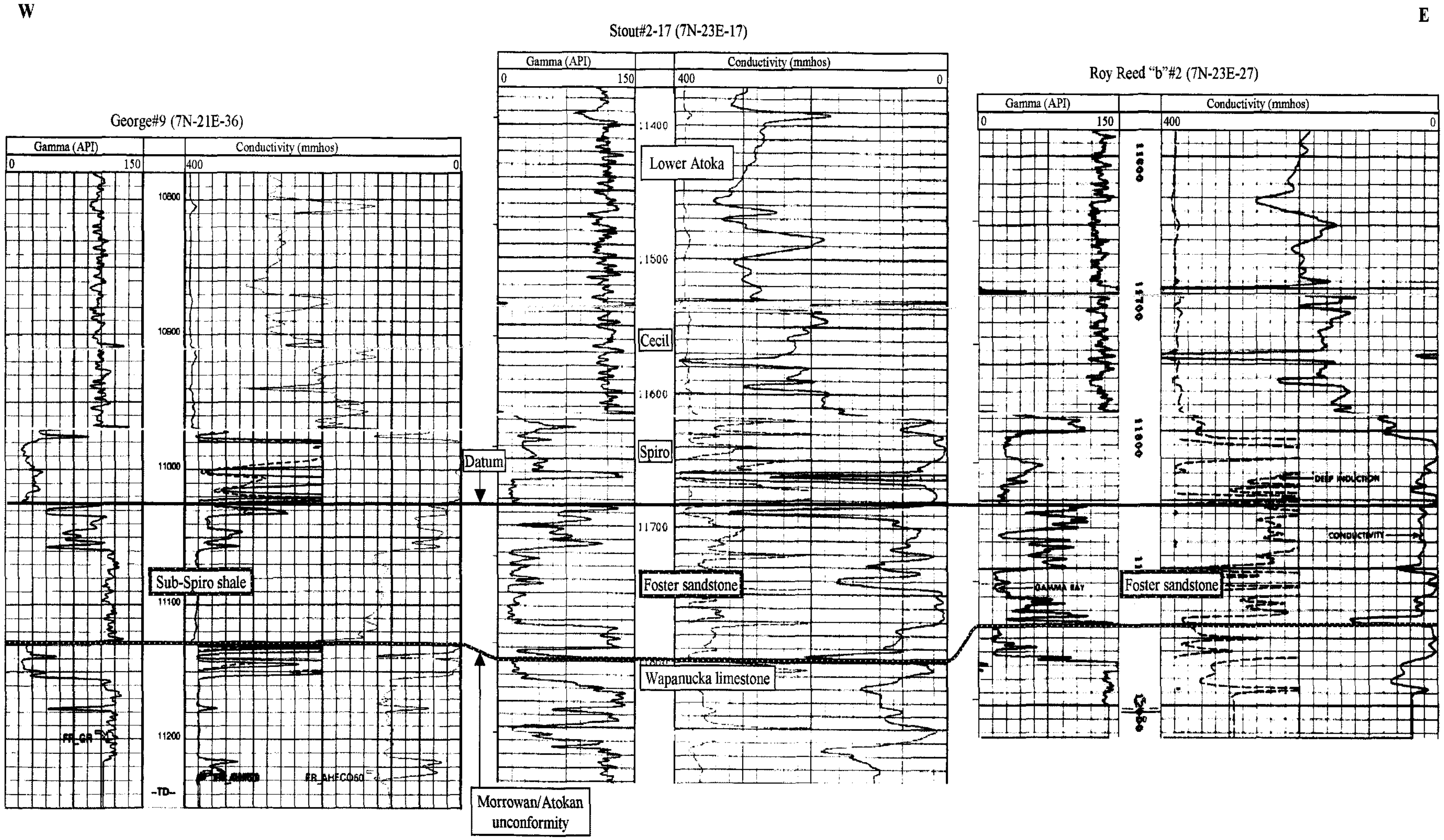


Figure 32. E-W detailed stratigraphic cross section using gamma ray and conductivity logs. It shows the facies change of the sub-Spiro shale in George#9 well (on the left) to the Foster sandstone in Stout#2-17 well (in the middle). Farther east, the foster sandstone becomes more shaly in Roy Reed "b"#2 well (on the right). The cross section datum is the transgressive surface at the base of Spiro sandstone (marine flooding surface). Horizontal scale is equal spacing. For location, see Fig. (37).

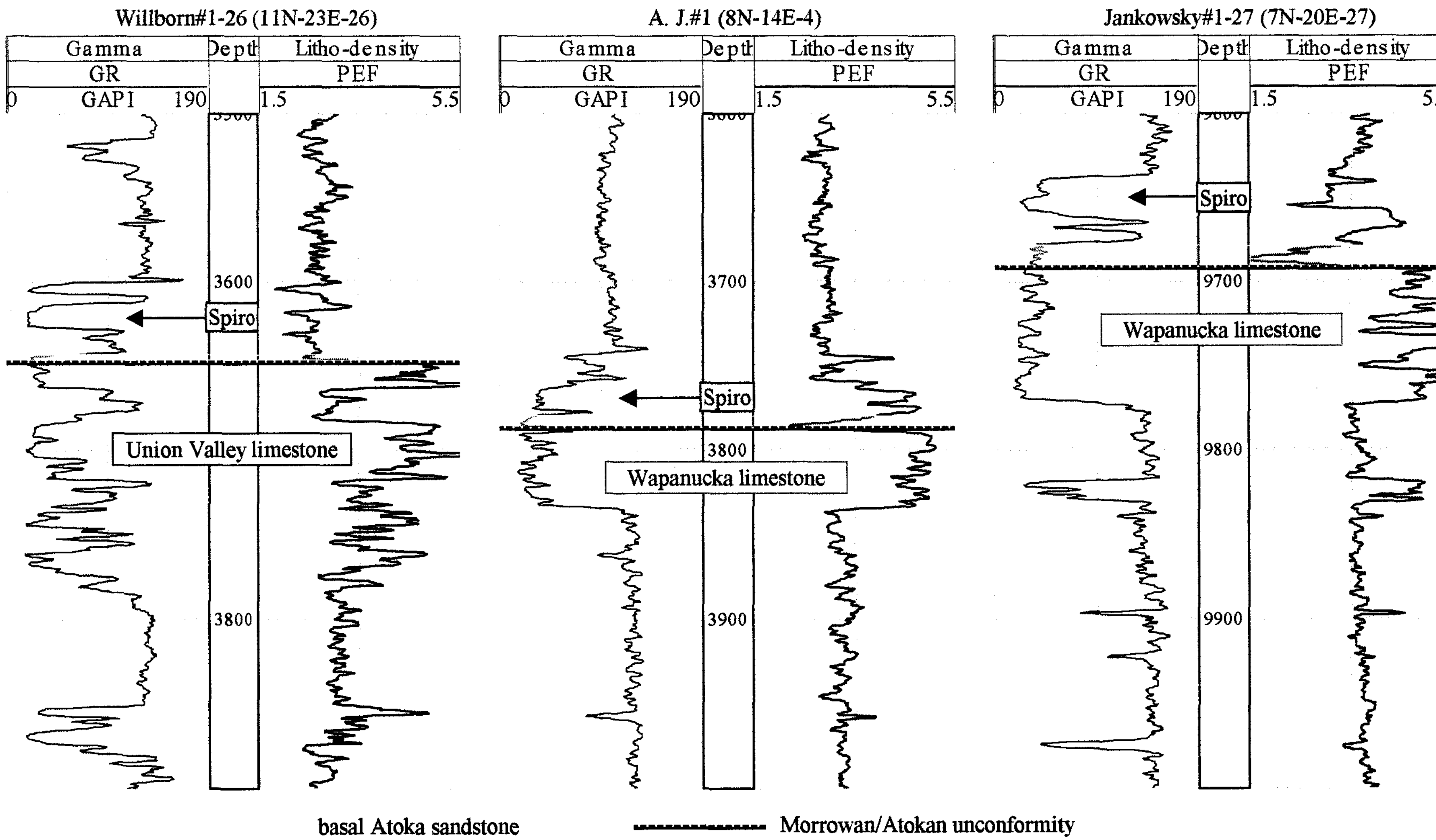


Figure 33. Thin basal sandstone interval overlies the unconformity surface in wells at different parts of the Arkoma Basin. Its thickness does not exceed 20 feet. It can be hardly recognized without using PEF log as clearly demonstrated by the contrast between PEF values for this basal sandstone and the underlying limestone. It may represent the time equivalent of the lowermost part of the Foster sandstone outside the strike valley areas.

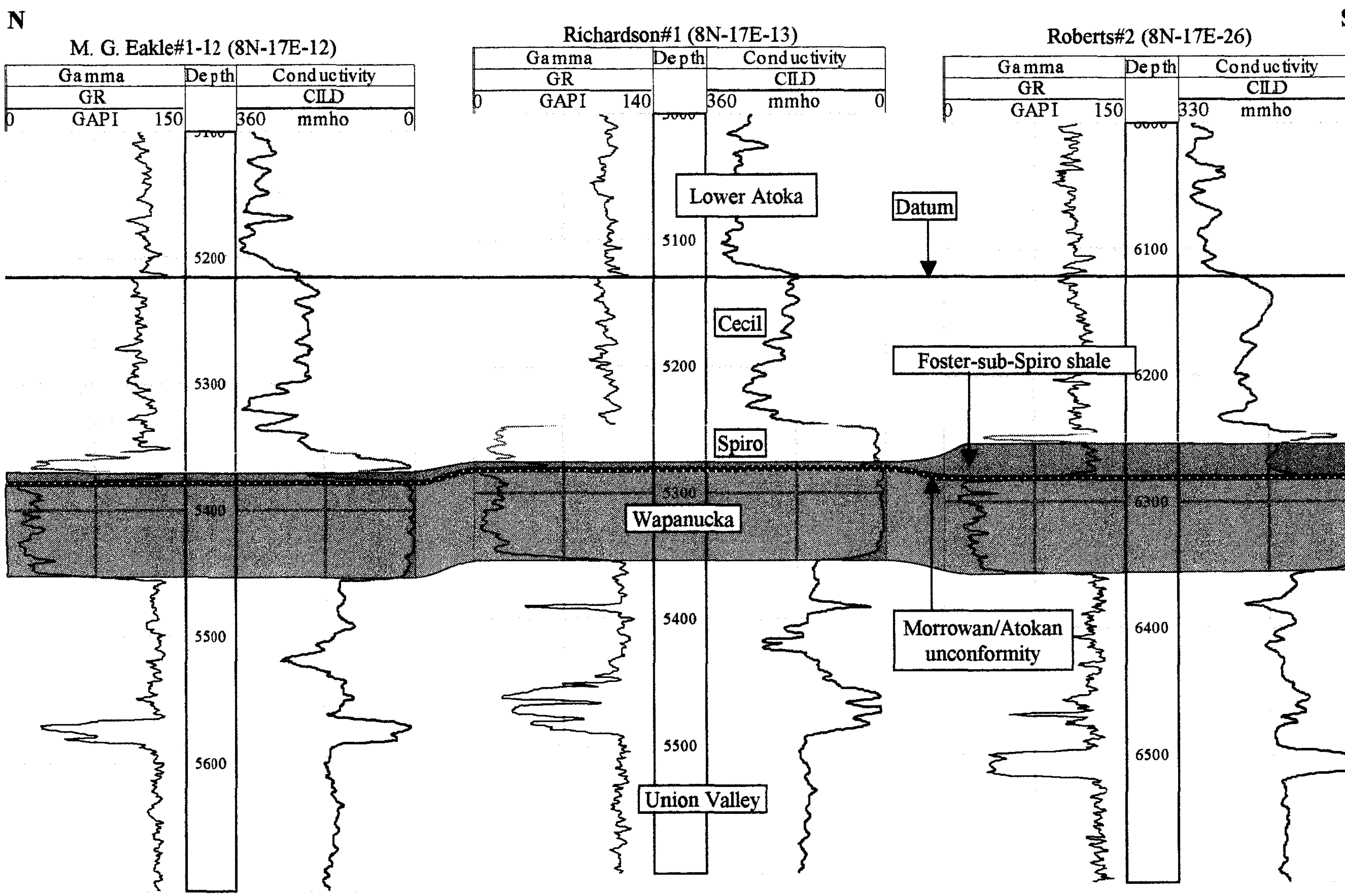


Figure 34. N-S detailed stratigraphic cross section showing that individual Spiro sandstone bar pinches out to the north and south in a closely-spaced wells (Within 4 miles). It also cuts into the underlying sub-Spiro shale. The datum is the top of TST. Horizontal scale is equal spacing. For location, see Fig. (37).

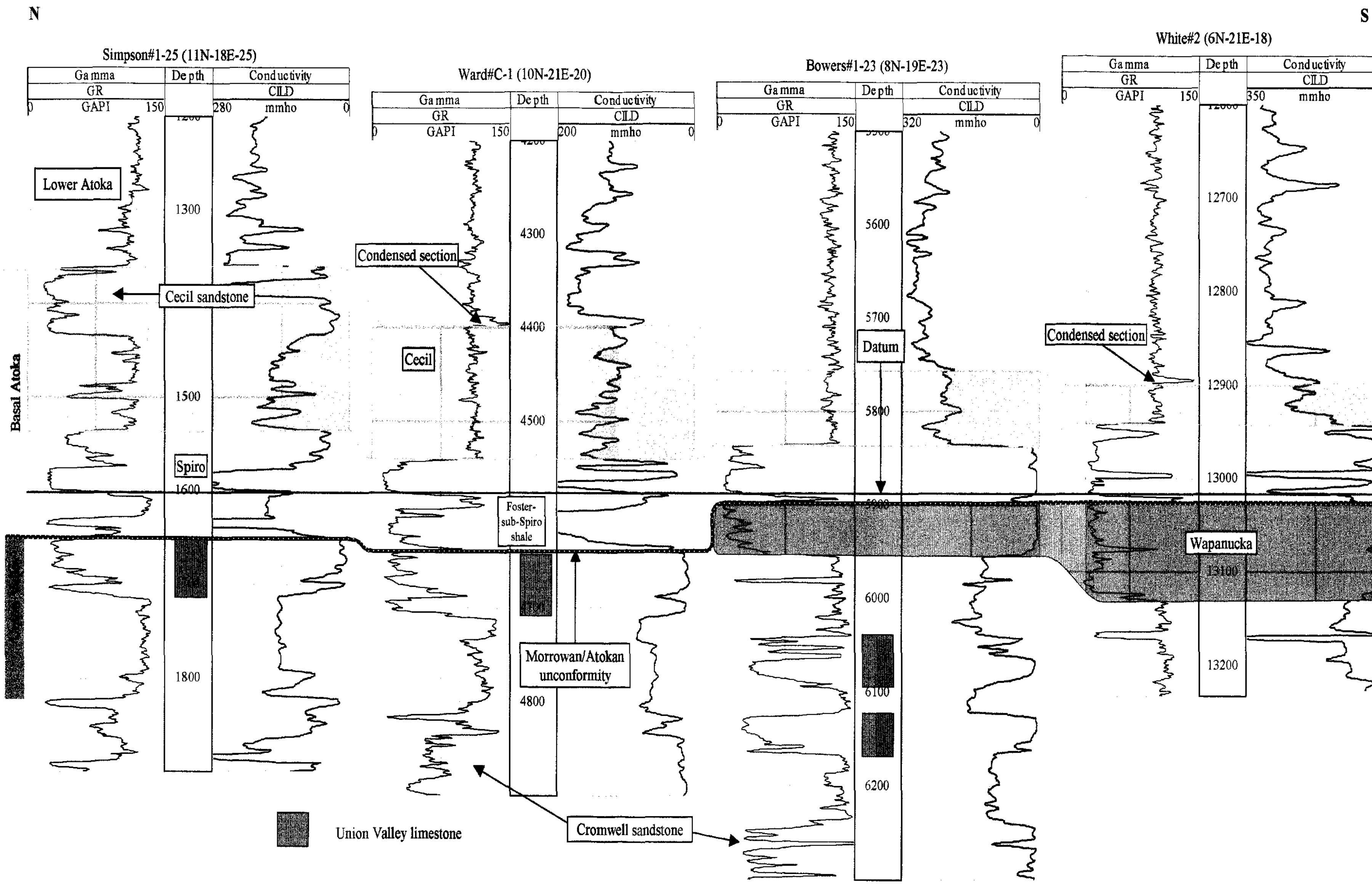
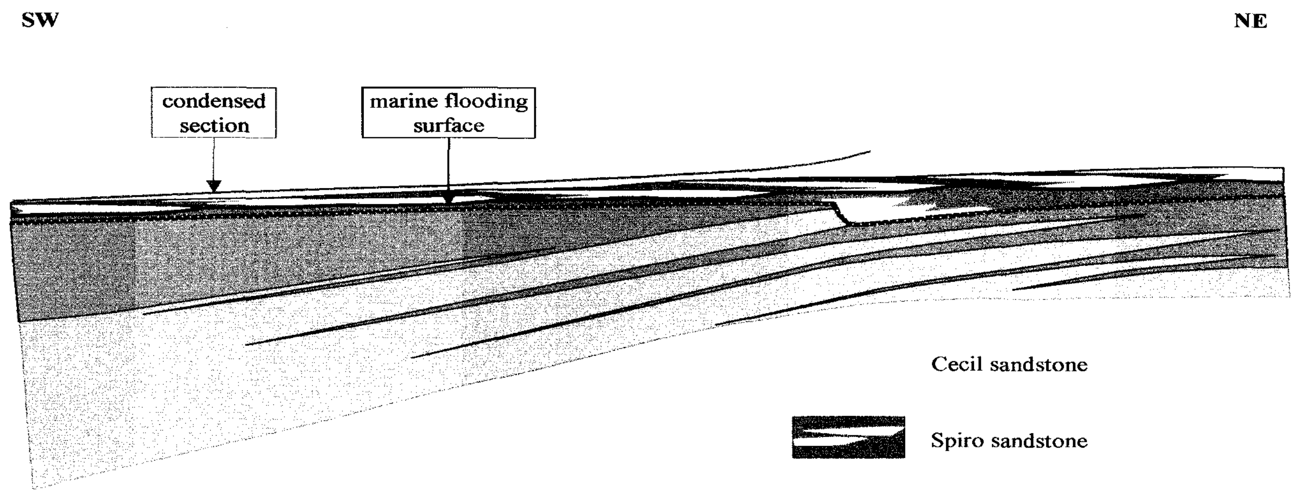
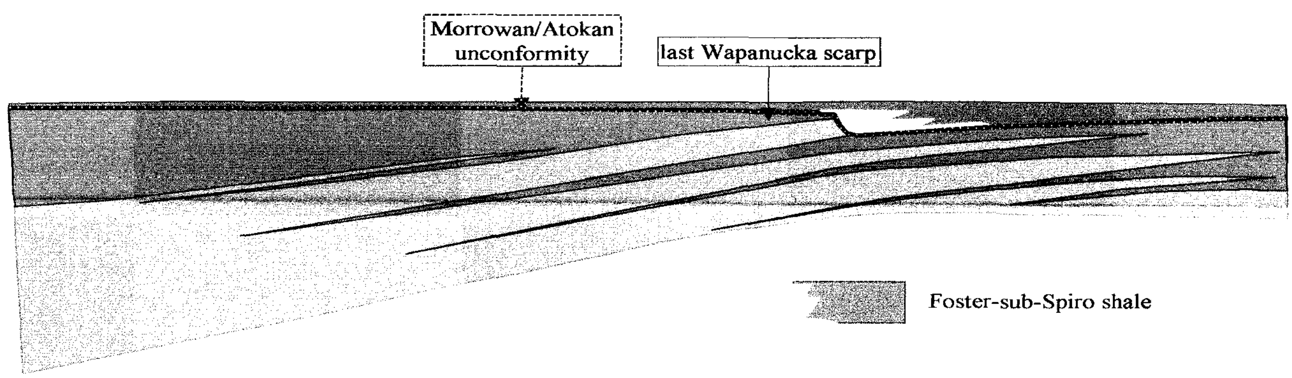


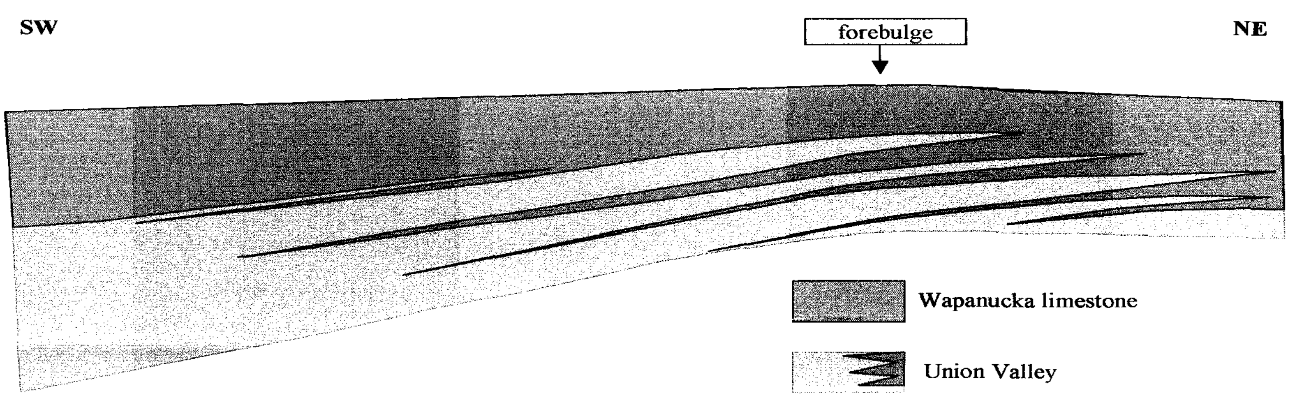
Figure 35. N-S stratigraphic cross section using gamma ray and conductivity logs. The upper transgressive Cecil sandstone in Simpson#1-25 well changes to shale to the south. A log pattern of slightly lower conductivity characterizes this interval when it becomes shaly. A condensed section marks the top of this interval indicating a maximum flooding surface, which separates the basal Atoka TST from the overlying lower Atoka HST. Note the development of Foster sandstone in Ward#C-1 well to the north of the eroded Wapanucka scarp . The cross section datum is the transgressive surface at the base of Spiro sandstone (marine flooding surface). Horizontal scale is equal spacing. For location, see Fig. (37).



(c) Deposition of the basal Atoka TST: marine flooding resulted in the deposition of laterally-stacked transgressive Spiro sandstones covering the entire Arkoma shelf. As the relative sea level rose, the Cecil sandstone developed farther northeast. To the south condensed section caps this transgressive systems tract.



(b) Deposition of the basal Atoka LST: differential erosion along the Morrowan/Atokan unconformity surface resulted in the development of strike valleys in the eastern part of Arkoma Basin where beds of the Union Valley shale were exposed at the forebulge area. Foster sandstones were deposited in these strike valleys across scarps of the Wapanucka limestone. Note that only the last Wapanucka scarp to the west is presented in the figure, and other scarps may be present farther east. Outside these strike valleys, sub-Spiro shale was deposited.



(a) Both of the Wapanucka limestone and Union Valley intervals represent a carbonate shelf prograding from NE to SW. By the end of Morrowan time, a bulge may have formed in the northwestern part of Arkoma Basin, with a forebulge to the east.

Figure 36. Stratigraphic model for the evolution of the Union Valley-basal Atoka sedimentary section along NE-SW trend in the Arkoma Basin in Oklahoma. Different green shades are shales, yellow is sandstone, blue is limestone. For location, see Fig. (37).

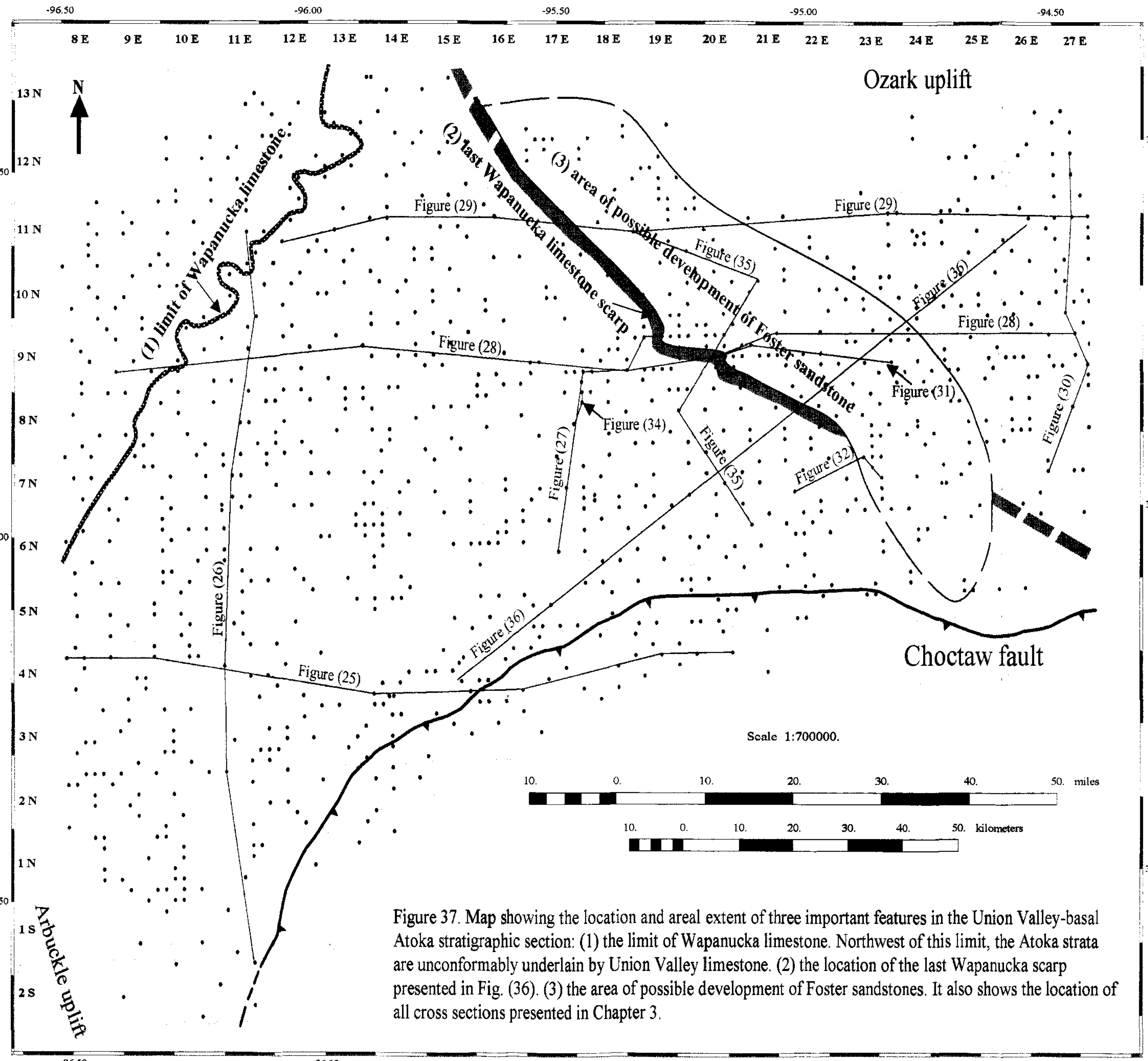


Figure 37. Map showing the location and areal extent of three important features in the Union Valley-basal Atoka stratigraphic section: (1) the limit of Wapanucka limestone. Northwest of this limit, the Atoka strata are unconformably underlain by Union Valley limestone. (2) the location of the last Wapanucka scarp presented in Fig. (36). (3) the area of possible development of Foster sandstones. It also shows the location of all cross sections presented in Chapter 3.

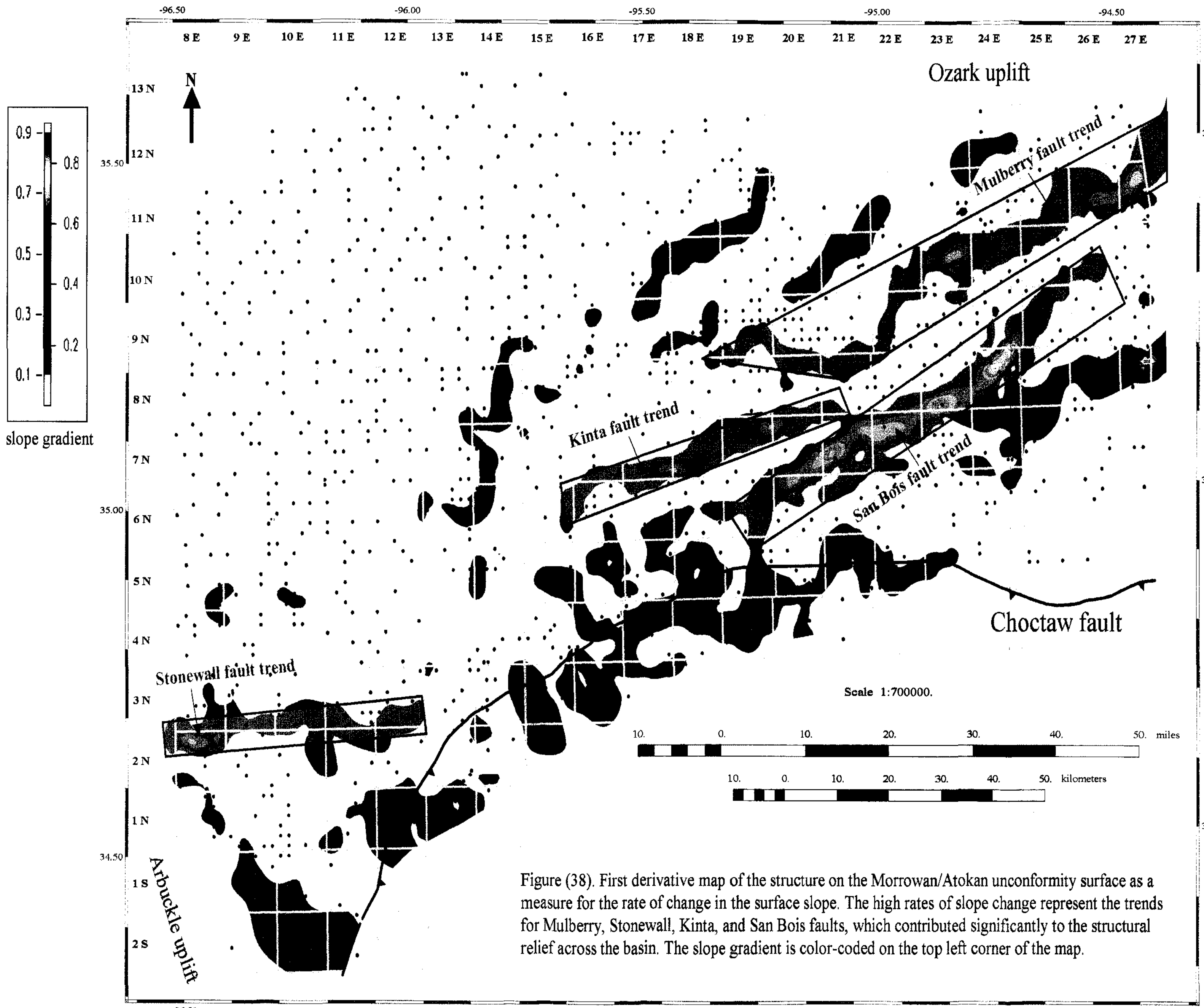


Figure (38). First derivative map of the structure on the Morrowan/Atokan unconformity surface as a measure for the rate of change in the surface slope. The high rates of slope change represent the trends for Mulberry, Stonewall, Kinta, and San Bois faults, which contributed significantly to the structural relief across the basin. The slope gradient is color-coded on the top left corner of the map.

CHAPTER 4

LOWER ATOKA

This stratigraphic interval is the least understood in the Atoka Formation in the Oklahoma part of Arkoma Basin. Based on this study, many of the sandstone units on the shelf, in the northern and western parts of the basin, are within the lower Atoka section. The vague understanding of the stratigraphy of this section may be because most of the studies conducted on the Atoka Formation in Oklahoma were on outcrops of the frontal Ouachitas, where the lower Atokan section is relatively thin and shaly. This is in contrast to the Arkansas part of the Arkoma Basin, where the lower Atoka sandstones crop out. Zachry and Sutherland (1984) stated that in the absence of correlatable sandstone units above the Spiro in Oklahoma, the upper boundary of the lower Atoka interval occurs within a shale succession and is poorly defined.

Zachry (1983) mentioned that the lower Atokan section in the Arkansas part of the Arkoma Basin is composed of 7 to 8 sandstone units separated by intervals of shale. These units are relatively thin and persistent throughout the northern and central parts of the Arkoma Basin in Arkansas. In outcrops, the thin sandstone beds grade upward into intervals of medium to thick-bedded sandstones that suggest progradational sequences. To the south, these sandstone units above the basal Spiro sandstone become thinner and are replaced by shale. He distinguished the lower and middle Atokan sections using the thickness change across growth faults (Fig. 39), and occurrence of metamorphic rock fragments in the middle Atokan sandstones. Johnson et al. (1989) mentioned that the lower Atokan sandstones above the Spiro in the Arkansas part of the Arkoma Basin are replaced by shale westward in Oklahoma. Houseknecht (1987) stated that typically a 100 to 200 meter thick dark shale immediately overlies the Spiro throughout the basin. He interpreted this shale section as the stratal equivalent of expanded sections downthrown to major faults. Visher (1996) mentioned that lower Atokan strata are not present on the Oklahoma platform. Several authors acknowledge the presence of a lower Atokan section in Oklahoma, but the name is frequently used as synonymous with the Spiro sandstone.

The lower Atoka shale section above the basal Atoka transgressive systems tract has a very characteristic conductivity log pattern that can be tracked throughout the Arkoma Basin. Fig. (40) shows a stacking pattern of decreasing conductivity values from the base to the top of the lower Atoka section in five wells in different parts of the Arkoma Basin. Within the overall decreasing-conductivity pattern, which is clearly shown in the Waycott#1-3 well, low-conductivity sandstone units are stacked in a series of parasequences in the Brown#1 and Skinner-davis#1 wells (Fig. 40). Each parasequence starts with relatively high conductivity log values that decrease upward towards the sandy facies at the top of the parasequence.

The gamma ray log response shows no clear change corresponding to the gradual vertical decrease of the conductivity values in the lower Atoka section, except where sandstone units occur (Zehnder#1 and Fudge#1-28 wells in Fig. 41). This could be attributed to the high sensitivity of the conductivity log to changes in the grain size of clastics, which should increase upward in a prograding delta (coarsening-upward pattern).

On the other hand, the gamma ray log is merely a measure of radioactivity level in sedimentary rocks, and consequently, does not detect changes in the grain size as shown in the Kent Unit#2 well in Fig. (41).

The deltaic interpretation for the lower Atoka section is supported by the facies changes from shale in the south (prodelta facies) to the development of aggrading and prograding sandstone units in the north and west (delta front facies). The stacking pattern of the aggradational and progradational systems tracts is shown in Fig. (16). Fig. (42) shows that, in some areas on the shelf, the vertical stacking pattern of some sandstone intervals even changes to a retrogradational pattern but within the overall progradation or coarsening-upward pattern characteristic of the lower Atoka delta system. This is attributable to changes in the sediment supply to accommodation space ratio (S/A) along the shelf of the Arkoma Basin, implying autocyclic factors or higher order relative-sea-level cyclicity.

The lower bounding surface of the lower Atoka delta system is the top of the basal Atoka transgressive systems tract. This surface is distinguished by a condensed section, or the low-conductivity pattern that is characteristic of the shale in the basal Atoka TST discussed in the previous chapter. The upper bounding surface is an unconformity marked by an abrupt change in the conductivity pattern. In the deep part of the Arkoma Basin, thin lower Atoka prodelta shale is overlain by middle Atoka turbidites showing indications of the occurrence of submarine erosion (Short Unit#1 and Graham#1 wells in Fig. 40, and Kent Unit#2 well in Fig. 41). On the shelf, the unconformity is marked by: 1) extensive truncation, which could be indicative of subaerial erosion as in the McCafferty Unit#2 well in Fig. (41). 2) presence of the basal transgressive sandstone of the upper Atoka section (McCafferty Unit#2, Zehnder#1 and Fudge#1-28 wells in Fig. 41). Thus, in terms of sequence stratigraphy this lower Atoka deltaic system represents a highstand systems tract. The stratal pattern of HST setting, in landward direction, will usually show aggradation as the space between the sea floor and the base level is filled, whereas the basinward limit of progradation is a function of sediment supply and basin margin geometry (Posamentier et al. 1988).

The thickest lower Atoka sandstones occur in a delta system in the northeastern part of Arkoma Basin that grades to prodelta shale to the south and west (Figs. 43 and 44). Fig. (44) shows that along the northern edge of the Arkoma Basin, another sandstone units appear to the west indicative of the development of another thin and broad delta system. In the northwestern edge of the Arkoma Basin, the lower Atoka section was completely eroded where the upper Atoka strata overlie the Union Valley shale (Rife-Reed Trust#1 in Fig. 44, and Phillips#1 in Fig. 45).

Fig (45) is an east-west cross section in the west central part of Arkoma Basin showing that the sandy intervals of the lower Atoka prograding delta grade eastward to prodelta shale. The same pattern is observed in a N-S direction across the central and western parts of the Arkoma Basin (Fig. 46 and 47 respectively). The deltaic sandstones, in the north and west, grade to prodelta shale to the south where sandstone intervals of the middle Atoka LST unconformably overly the lower Atoka HST.

The lower Atoka highstand systems tract is characterized by substantial development of deltas in the shelf areas of the Arkoma Basin. Delta systems prograded from the northeast, northwest, and west, across the shelf where prodelta shale extended well into the southern parts of the modern structural basin (Fig. 48). The sandstones within these delta systems display different geometries in different parts of the basin inferred to variable tidal and fluvial influences, which require further detailed study. Sandstone intervals occur at the top of each parasequence within the lower Atoka HST in the northeastern part of the Arkoma Basin in Oklahoma, which may represent a part of a major delta system centered in western Arkansas (Fig. 43, and Brown#1 well in Fig. 40). The sandstones carry the Arkansas nomenclature such as Dunn (A through C), Jenkins, and Sells. These lithostratigraphic units are time equivalent to the deltaic sandstones of the Dutcher and the majority of Gilcrease sandstones in the northern and western parts of the Arkoma Basin (Fig. 44). This interpretation is different from that of Suneson and Hemish (1994) and Visher (1996). Suneson and Hemish (1994) included all Gilcrease sandstones within the upper Atoka section. Visher (1996) included both Gilcrease and Dutcher sandstones in the middle and upper Atoka sections.

Both of the basal Atoka (LST and TST) and lower Atoka HST systems tracts compose a third-order sequence referred to here as the lower Atoka sequence throughout this study. This sequence is bounded by the Morrowan/Atokan unconformity at its base, and by the middle Atoka unconformity at its top. An isopach map shows an axis trending NE-SW for the thickest part of the sequence (Fig. 49). The maximum thickness (over 3000 feet) occurs in the northeastern part of the Arkoma Basin, where the sandstones in both the TST and HST are best developed. In the central parts of the basin, the thickness of the lower Atoka sequence is between 1500-2000 feet. It thins dramatically to the northwest, and becomes completely absent in the extreme northwestern part of the basin due to both thinning and erosion (Fig. 49). Submarine erosion, along the unconformity surface on the top of the sequence, may have contributed to its thinning in the southern area of the Arkoma Basin where middle Atoka turbidites were later deposited.

An interesting area in the isopach map shows a trend of anomalous thinning close to the southern margin of the Arkoma Basin (Fig. 49). This area coincides with the NE-SW trend of the San Bois fault, which is inferred from the first derivative map of the structure on the top of the sequence (Fig. 48). A cross section trending NE-SW shows that the lower Atoka HST is truncated along this trend, with over 1000 feet of section having been eroded in some wells (Fig. 50). The truncated section is on the upthrown side of the San Bois syndepositional fault that was active during the middle Atokan time. It may represent an area of subaerial erosion on the shelf edge. On the downthrown side of this fault, thick middle Atoka turbidites were deposited to the south. This is in contrast to Houseknecht (1987) who stated that despite the thickness increase of over 1000 meters across the syndepositional faults in the Arkoma Basin in Oklahoma, there is absolutely no evidence of erosion of the Spiro sandstone or the overlying strata on the upthrown sides of the faults. All cross section locations and important features discussed in this chapter are shown on Fig. (48).

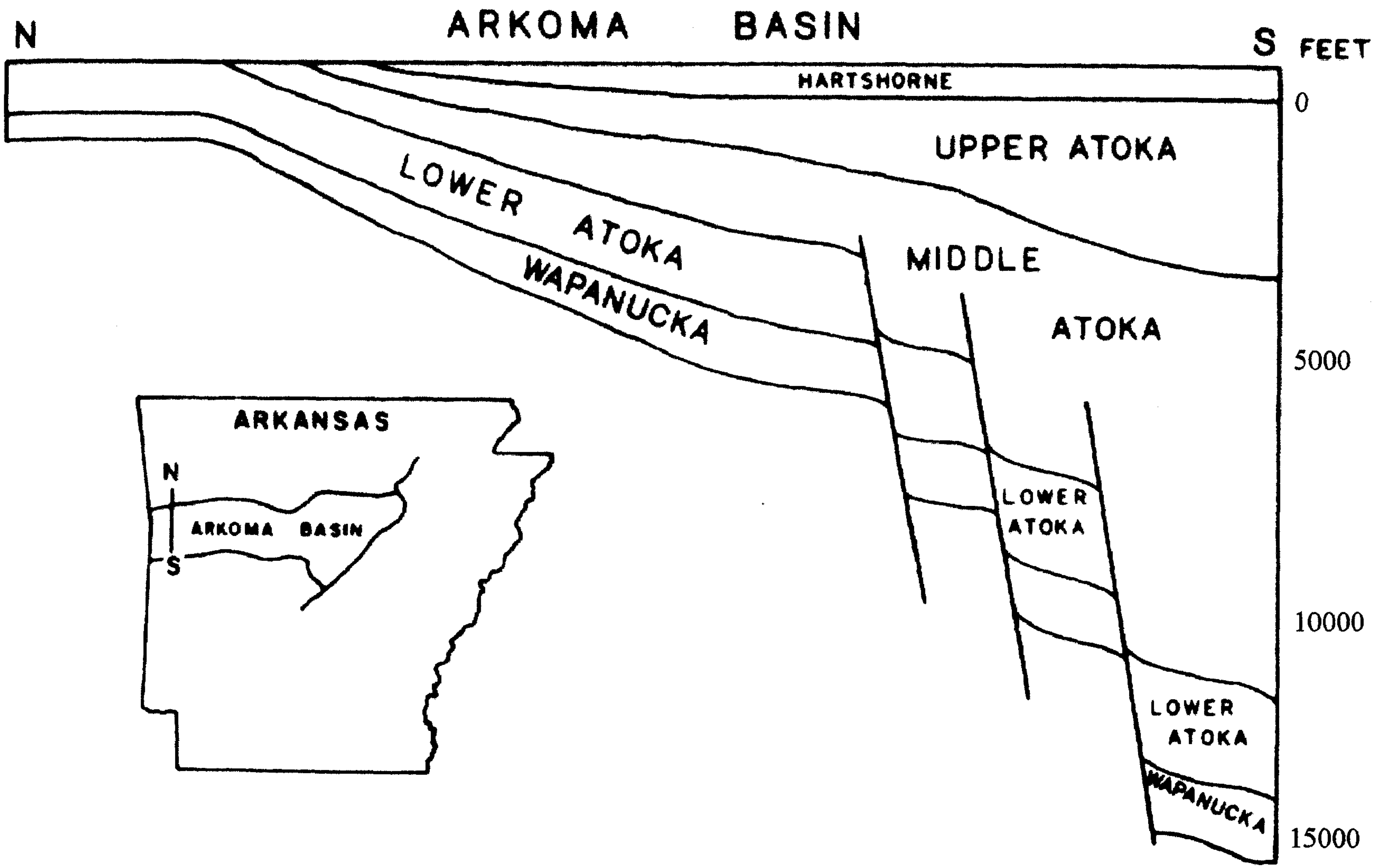


Figure 39. N-S section across the Arkoma Basin in Arkansas depicting the Atoka sedimentary section and the adjacent strata. Changes in thickness across syndepositional faults and sandstone distribution were used to define the divisions of the Atoka Formation into lower, middle and upper units (modified after Johnson et al., 1989).

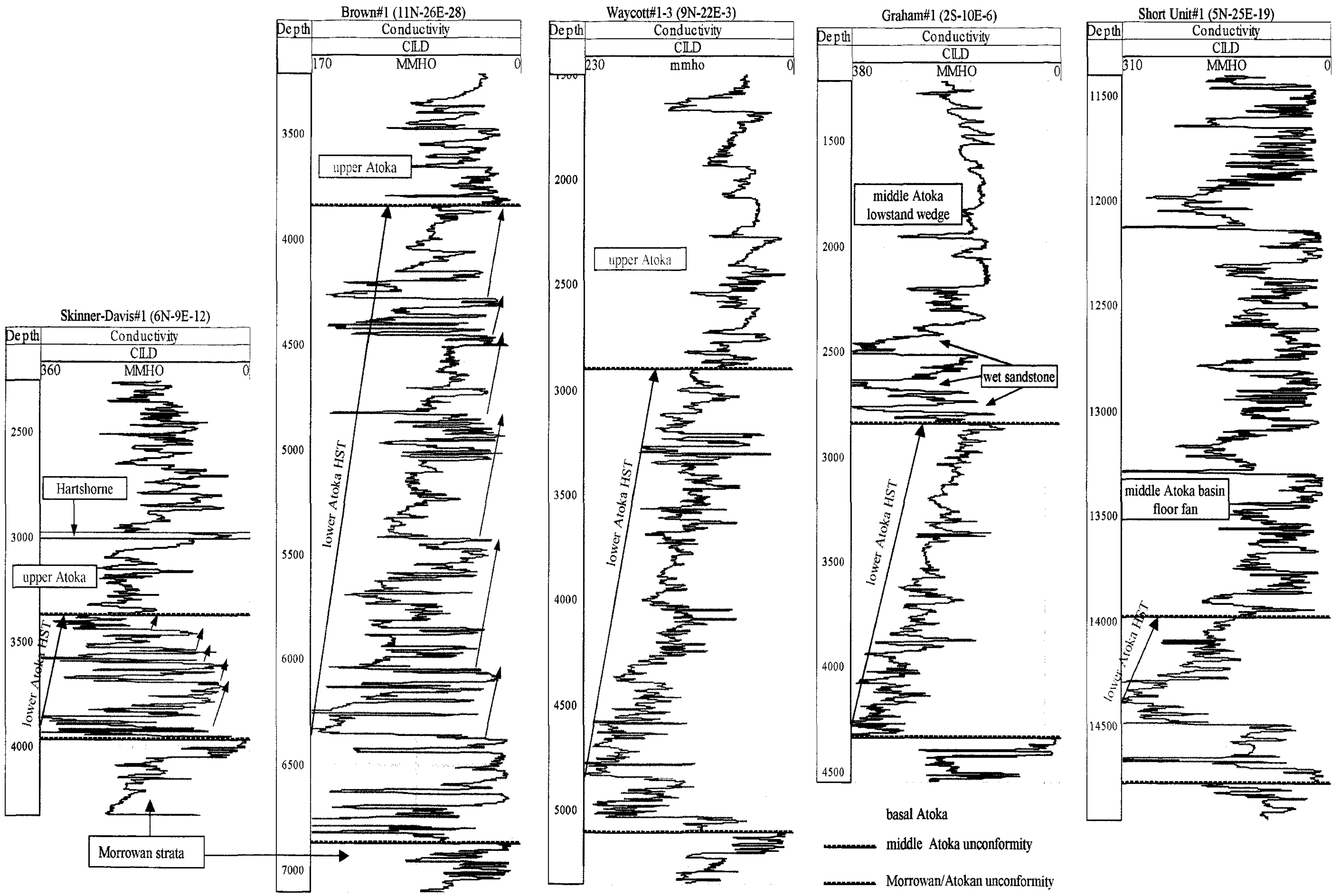


Figure 40. Examples from wells in different parts of the Arkoma Basin in Oklahoma showing the characteristic decreasing-conductivity pattern of the lower Atoka HST. The section in the two wells on the right is composed of prodelta shale, with indication of submarine erosion where middle Atoka basin floor fan and lowstand wedge unconformably overly the prodelta shale. The lower Atoka HST in the two wells on the left shows two different delta fronts composed of several parasequences (blue arrows). Each parasequence starts with relatively high conductivity log values that decrease upward as it approaches sandy facies at the top of the parasequence.

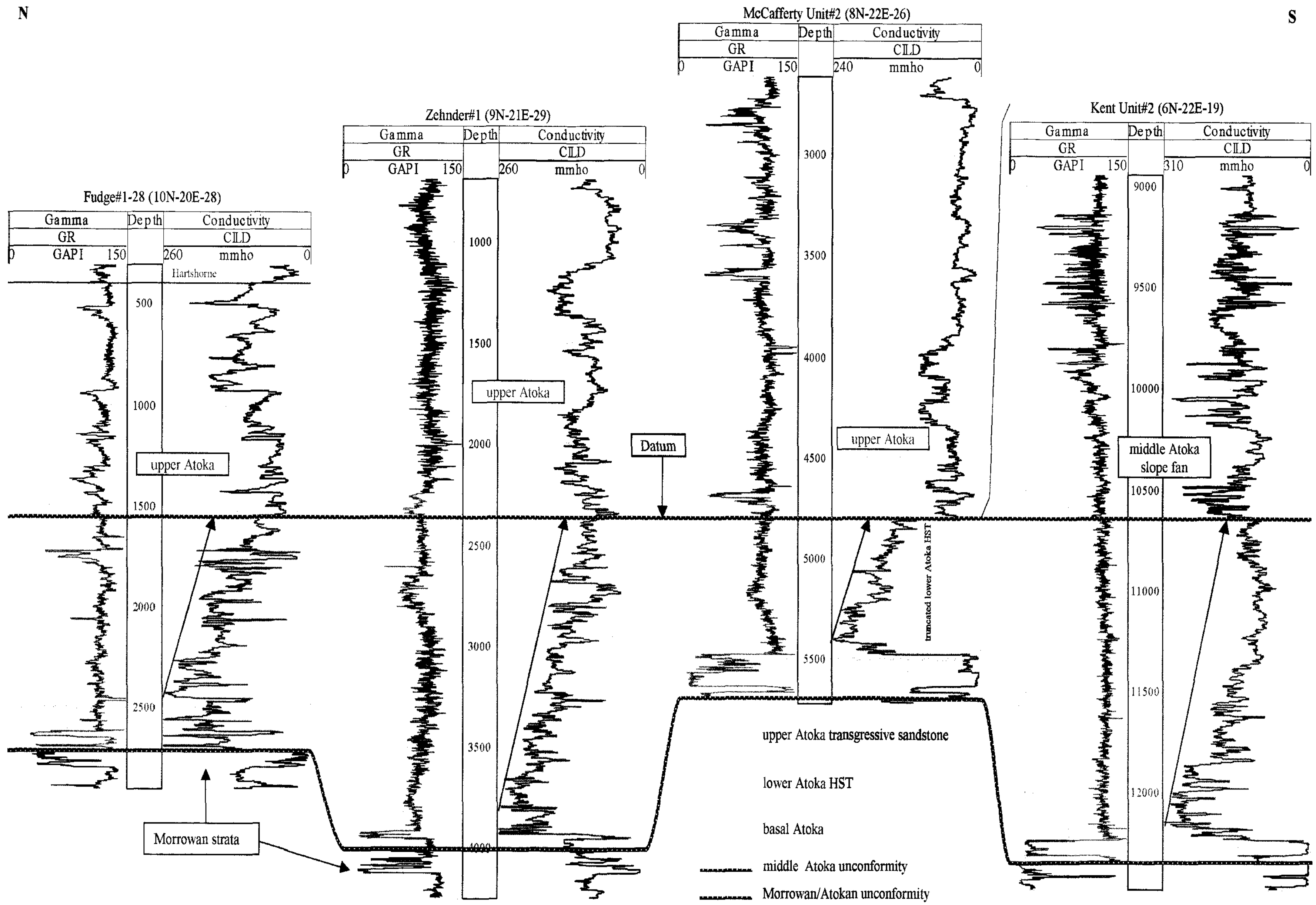


Figure 41. N-S cross section using gamma ray and conductivity logs. The gamma ray log shows no clear change that corresponds to the gradual vertical decrease of the conductivity values in the lower Atoka section, except where sandstone units occur. This can be attributed to the high sensitivity of the conductivity log to changes in clastics grain size, which should increase upward in a prograding delta (coarsening-upward pattern). The unconformity surface at the top of lower Atoka is marked by middle Atoka turbidites in the deep part of Arkoma Basin (Kent Unit#2 well), truncation of the lower Atoka section and deposition of the upper Atoka basal transgressive sandstone on the shelf. The cross section datum is the middle Atoka unconformity. Horizontal scale is equal spacing. For location, see Fig. (48).

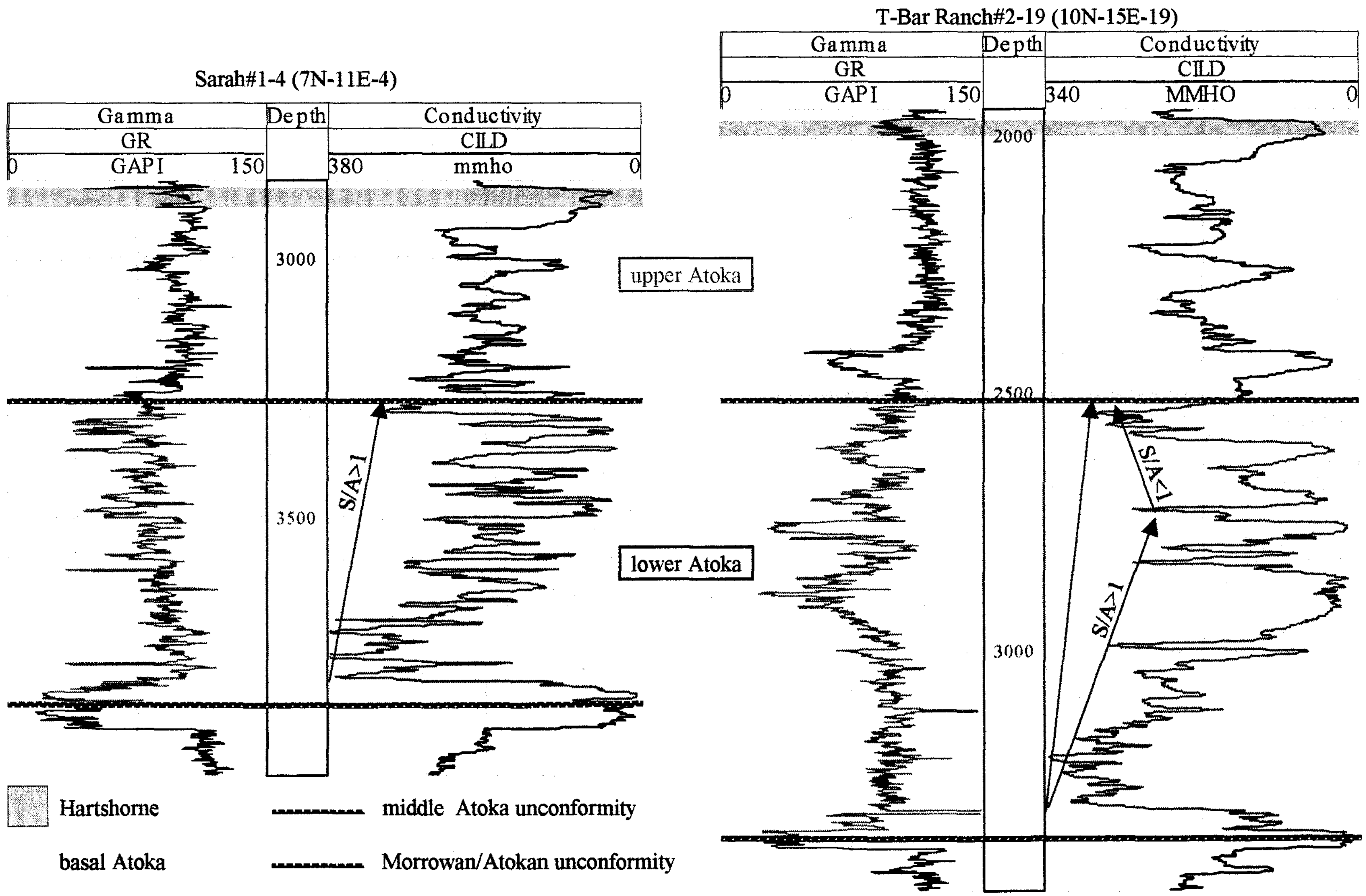


Figure 42. The decreasing-conductivity pattern is shown in two wells on the shelf of Arkoma Basin. Within this overall pattern, changes in sediment supply to accommodation rate (S/A) led to higher cyclicity as shown in T-Bar Ranch#2-19 well where delta-front clean sandstones in the middle of the lower Atoka HST are overlain by shaly sandstones and marine shales. The gamma log pattern is included to affirm this interpretation.

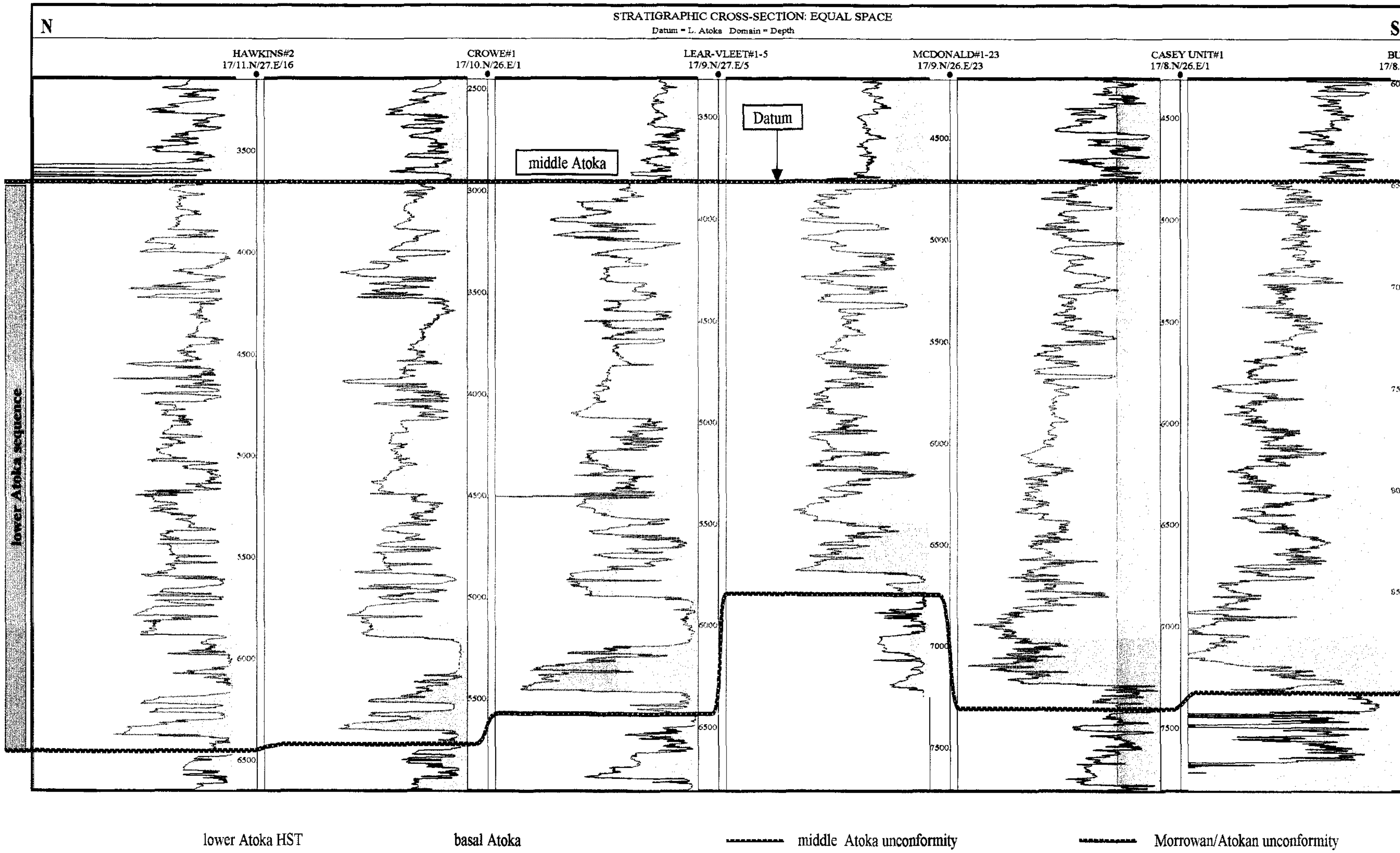
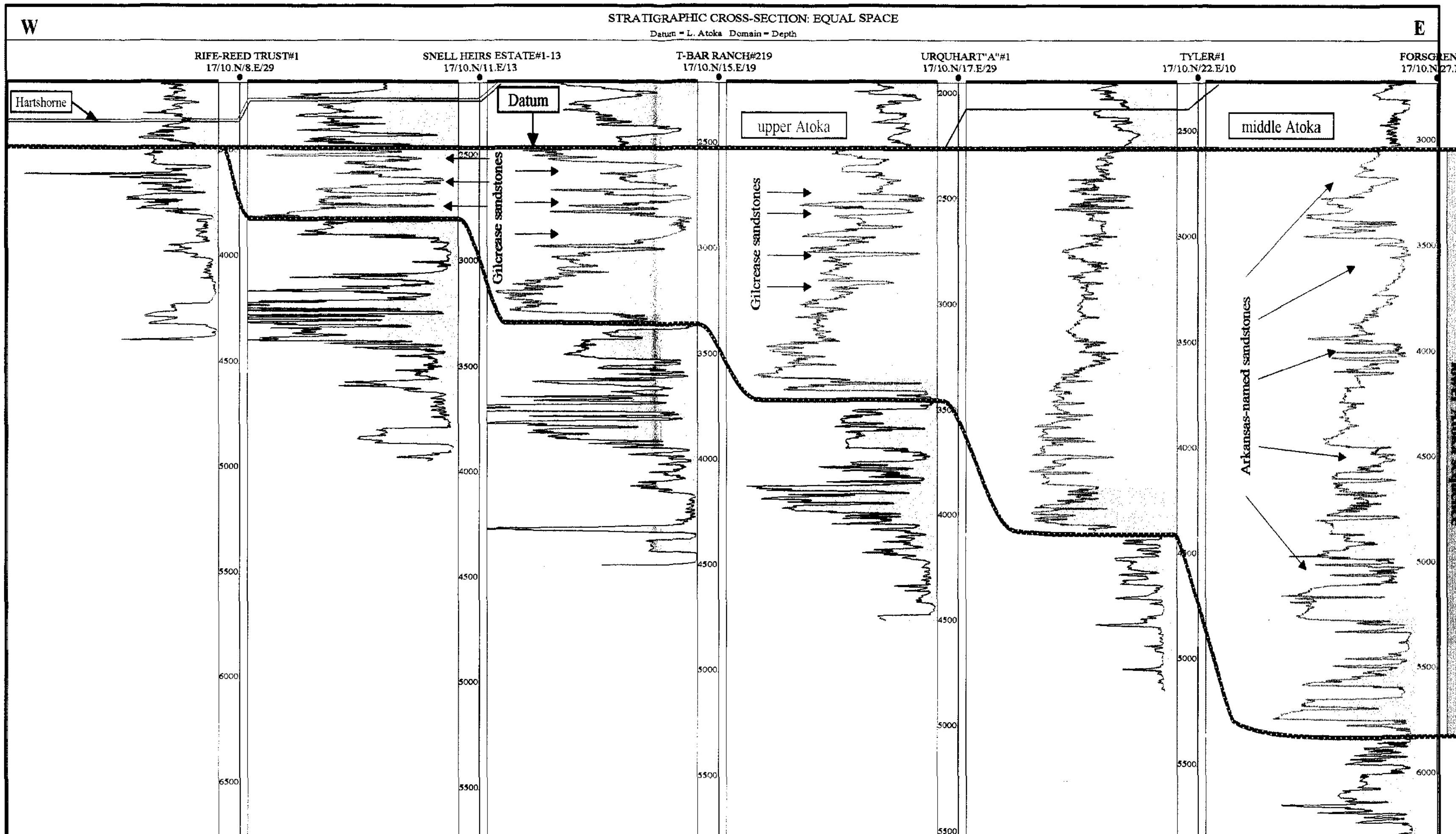
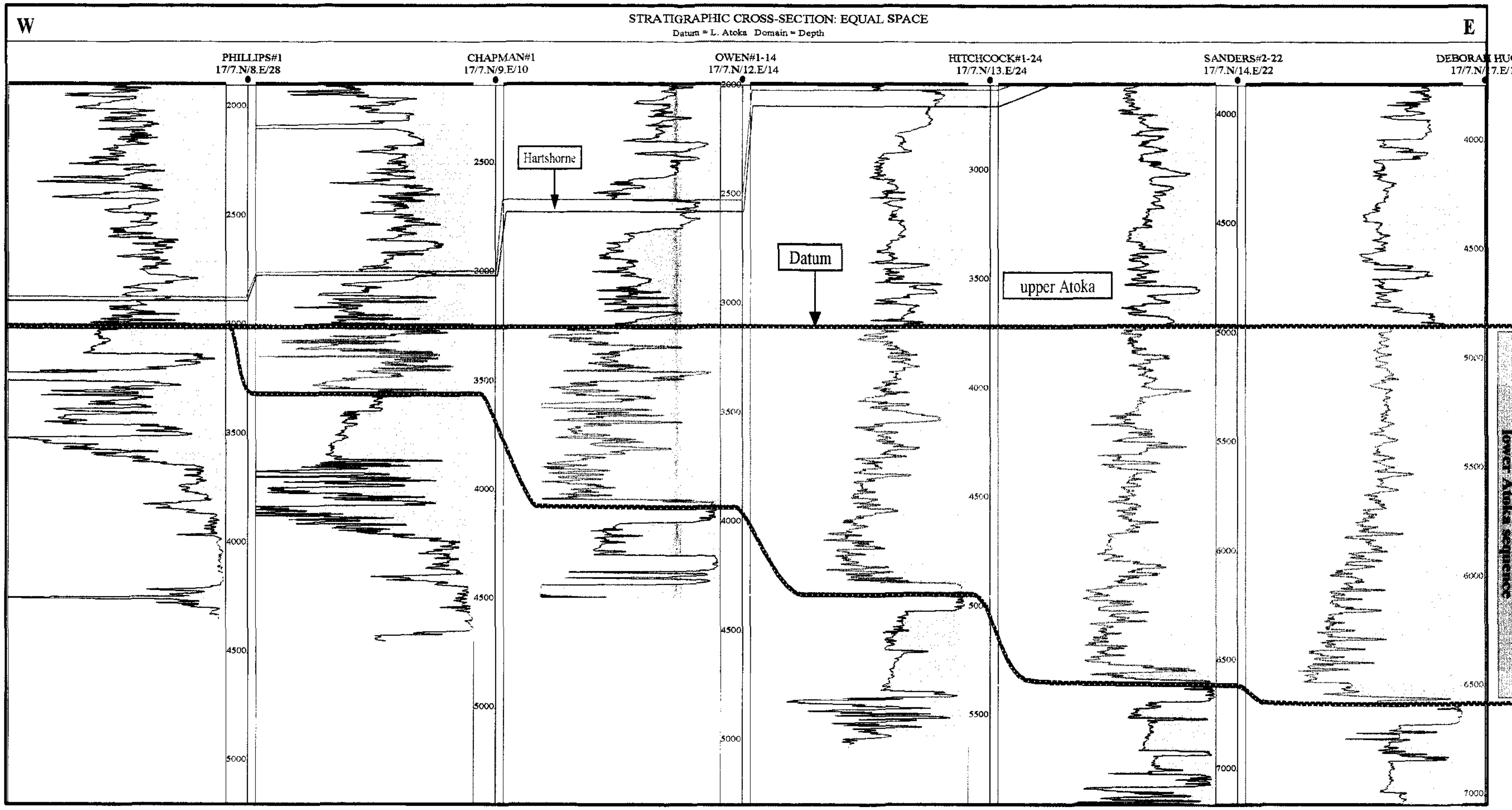


Figure 43. N-S regional stratigraphic cross section in the eastern part of the Arkoma basin using conductivity logs. The thickest delta system in the lower Atoka HST occurs in this part of the basin. In the north, the section is composed of several parasequences stacked in a delta front, which grades to prodelta shale toward the south. The lower Atoka HST is unconformably overlain by middle Atoka LST in this part of the basin. The cross section datum is the middle Atoka unconformity. For location, see Fig. (48).



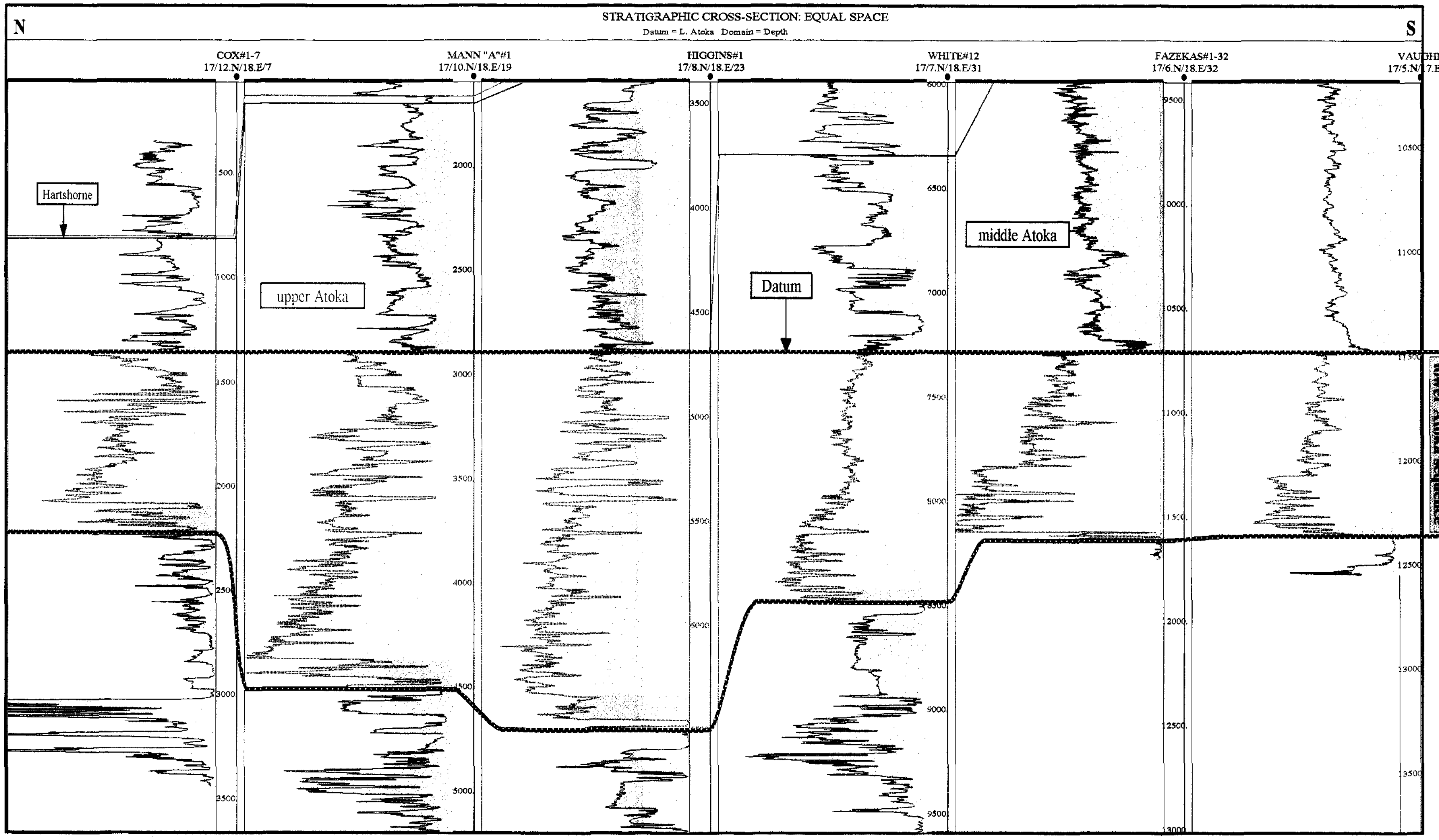
lower Atoka HST basal Atoka middle Atoka unconformity Morrowan/Atokan unconformity

Figure 44. E-W regional stratigraphic cross section in the northern part of the Arkoma Basin using conductivity logs. Along the shelf of the basin, the sandstone-topped parasequences of the lower Atoka delta front in the east grade to shale to the west (Tyler#1 well), then another delta front sandstones appear farther west. The lithostratigraphic sandstone units in the east carry Arkansas nomenclature. Yet, they are time equivalent to the Dutcher and most of the Gilcrease sandstones in the western part of the Arkoma Basin. The lower Atoka section was completely eroded in the Rife-Reed Trust#1 well in the extreme northwestern part of the basin, where the upper Atoka strata overlie the Union Valley shale. The cross section datum is the middle Atoka unconformity. For location, see Fig. (48).



lower Atoka HST   basal Atoka   middle Atoka unconformity   Morrowan/Atokan unconformity

Figure 45. E-W regional stratigraphic cross section in the west central part of the Arkoma Basin using conductivity logs. It shows the deltaic sandstones of lower Atoka in the west grade to prodelta shale to the east. Note the thinning of the section to the west due to both depositional thinning and erosion. The lower Atoka section was completely eroded in Phillips#1 well, where the upper Atoka strata overlie the Union Valley shale. The cross section datum is the middle Atoka unconformity. For location, see Fig. (48).



lower Atoka HST basal Atoka middle Atoka unconformity Morrowan/Atokan unconformity

Figure 46. N-S regional stratigraphic cross section in the central part of the Arkoma Basin using conductivity logs. Thick lower Atoka HST occurs in the central part of the basin. To the south, the section is partially eroded and sandstones of the middle Atoka LST unconformably overly the lower Atoka prodelta shale. To the north, the section thins and delta front sandstones appear, as it is unconformably overlain by the upper Atoka section. The cross section datum is the middle Atoka unconformity. For location, see Fig. (48).

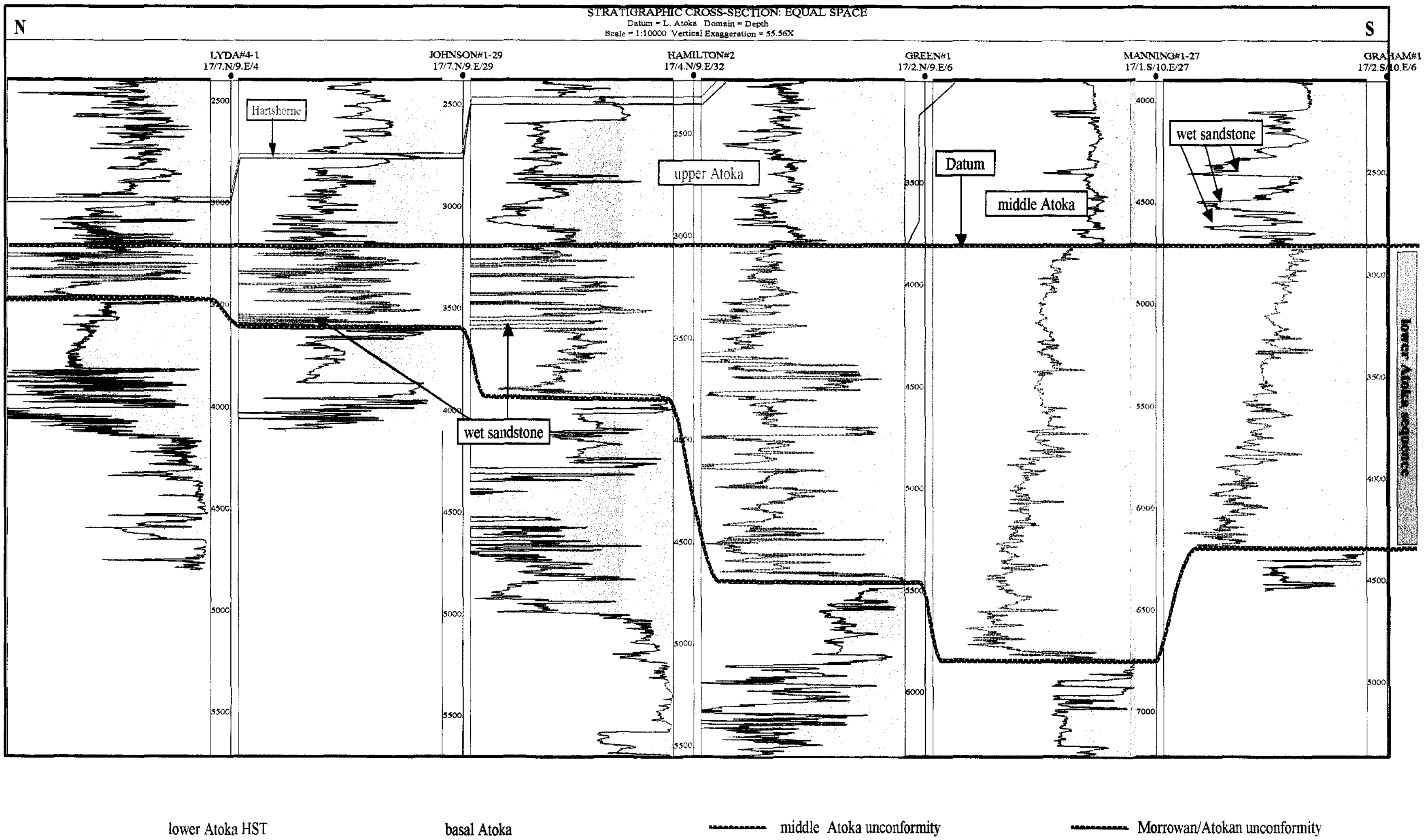


Figure 47. N-S regional stratigraphic cross section in the southwestern part of the Arkoma Basin using conductivity logs. Lower Atoka deltaic sandstones are stacked along the western margin of the basin. These deltaic sandstones grade to shale toward the south and east. The cross section datum is the middle Atoka unconformity. For location, see Fig. (48).

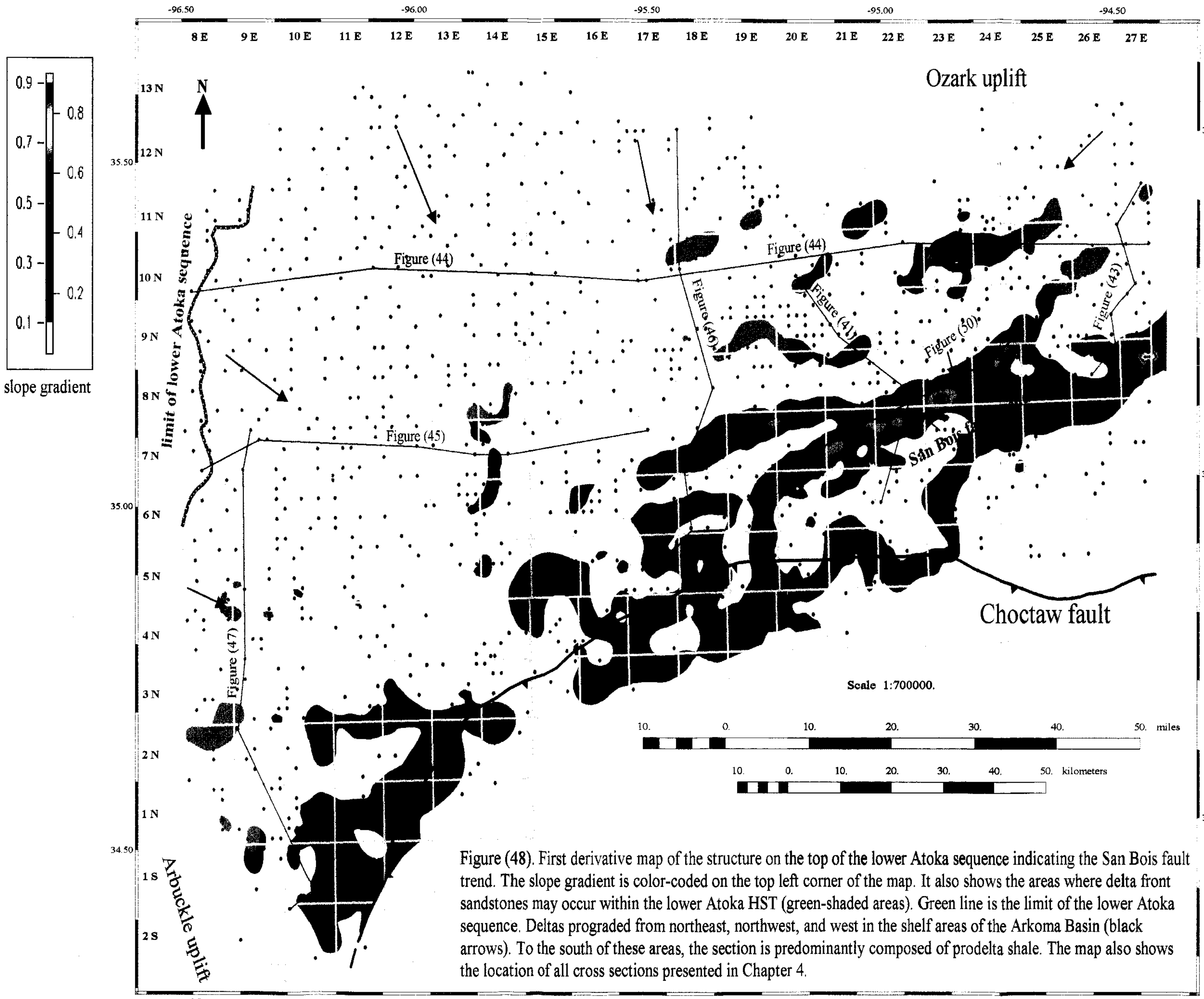


Figure (48). First derivative map of the structure on the top of the lower Atoka sequence indicating the San Bois fault trend. The slope gradient is color-coded on the top left corner of the map. It also shows the areas where delta front sandstones may occur within the lower Atoka HST (green-shaded areas). Green line is the limit of the lower Atoka sequence. Deltas prograded from northeast, northwest, and west in the shelf areas of the Arkoma Basin (black arrows). To the south of these areas, the section is predominantly composed of prodelta shale. The map also shows the location of all cross sections presented in Chapter 4.

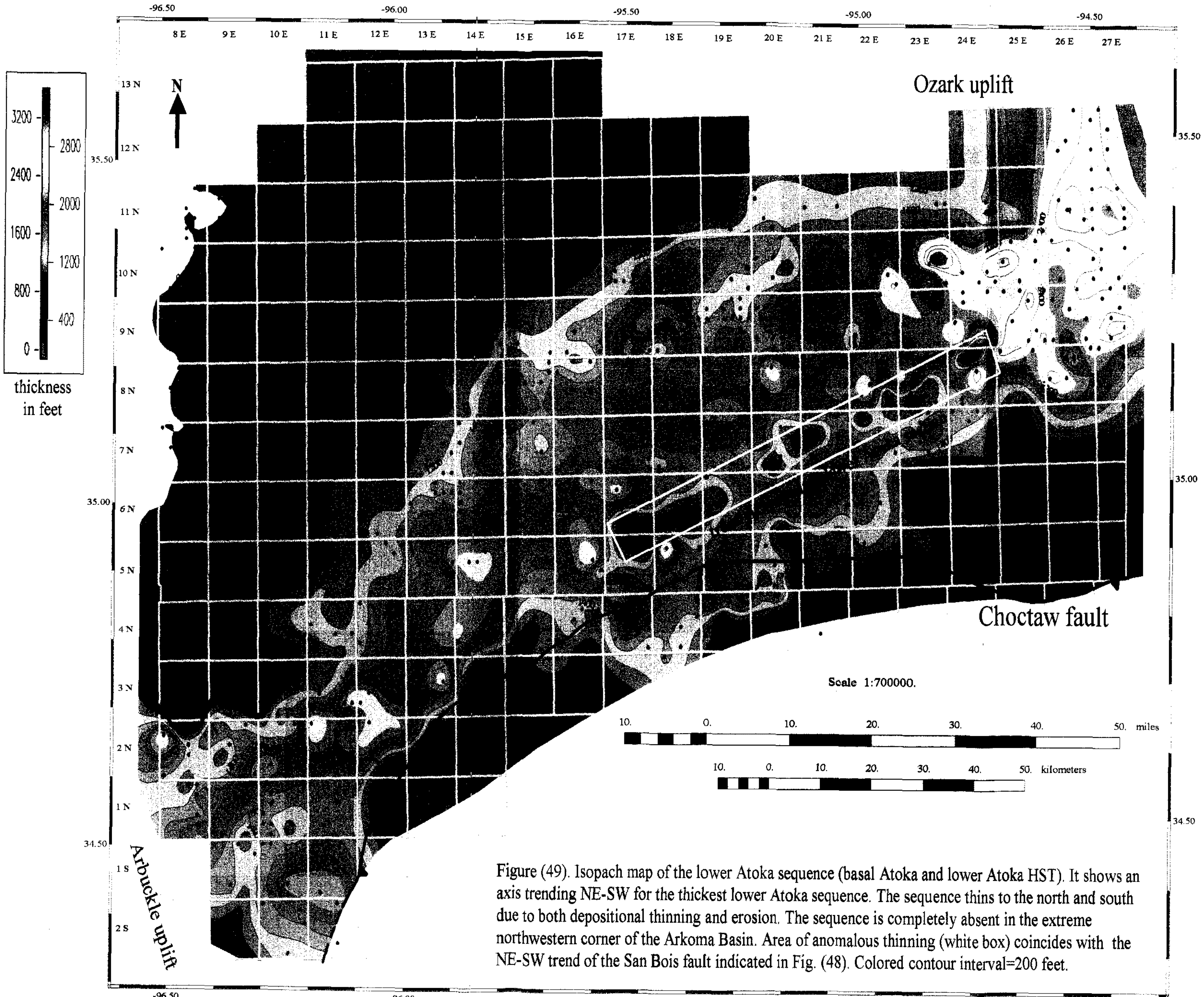
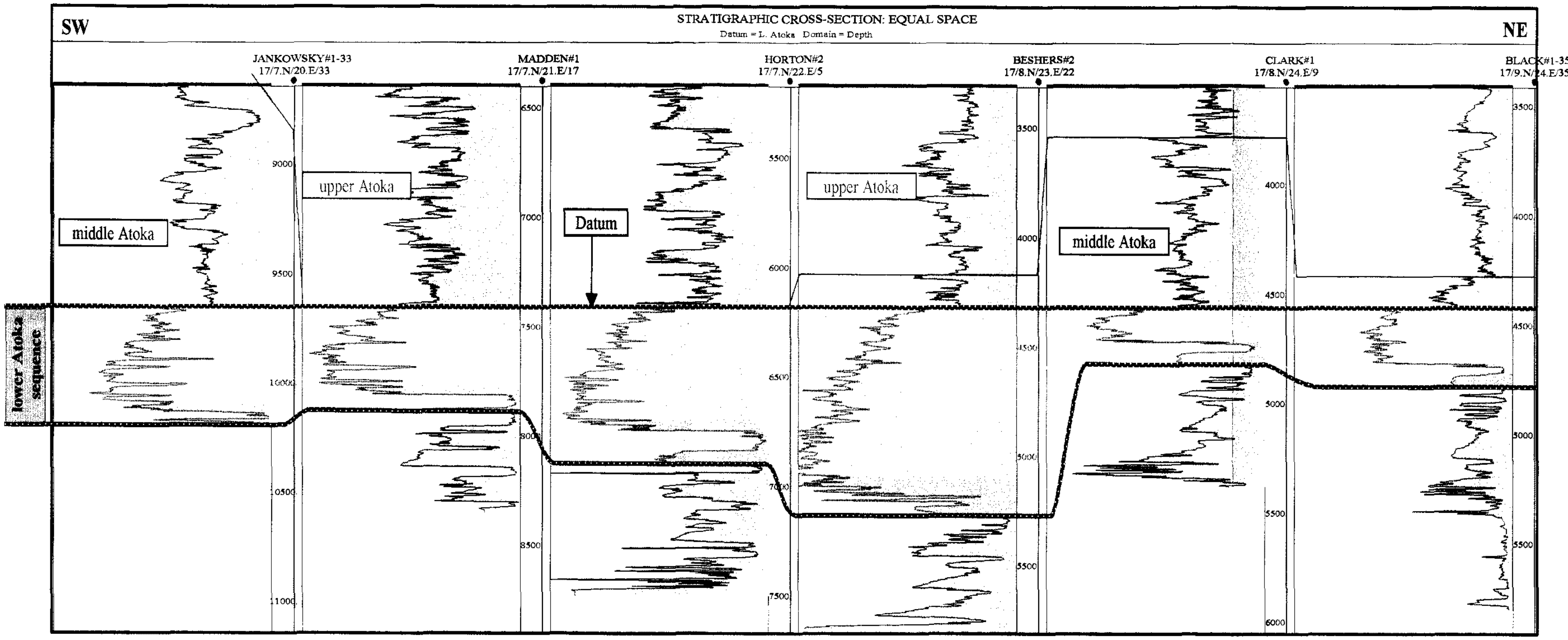


Figure (49). Isopach map of the lower Atoka sequence (basal Atoka and lower Atoka HST). It shows an axis trending NE-SW for the thickest lower Atoka sequence. The sequence thins to the north and south due to both depositional thinning and erosion. The sequence is completely absent in the extreme northwestern corner of the Arkoma Basin. Area of anomalous thinning (white box) coincides with the NE-SW trend of the San Bois fault indicated in Fig. (48). Colored contour interval=200 feet.



lower Atoka HST   basal Atoka   middle Atoka unconformity   Morrowan/Atokan unconformity

Figure 50. NE-SW detailed stratigraphic cross section along the upthrown side of the San Bois fault in the southern part of the Arkoma Basin. It shows that the lower Atoka HST is truncated at different levels, with over 1000 feet of section having been eroded in Clark#1 and Black#1-35 wells. The upthrown side of this syndepostional fault was probably an exposed shelf area during the middle Atokan time. To the south of this fault, thick middle Atoka turbidites were deposited. The cross section datum is the middle Atoka unconformity. For location, see Fig. (48).

CHAPTER 5

MIDDLE ATOKA

The middle Atoka section is the thickest stratigraphic interval within the Arkoma Basin in Oklahoma, and is mainly confined to the southern and eastern parts of the basin. The thickness changes dramatically from few hundred feet close to the shelf areas to about 10000 feet north of the Choctaw fault in the southeast part of the basin (Fig. 51). This interval is considered a lowstand systems tract, which is mainly composed of strata deposited in deep water as a result of significant structural relief associated with syndepositional faults. The lower bounding surface is a sequence boundary marked by the unconformity on top the lower Atoka sequence, which was described in the previous chapter. The upper bounding surface is the transgressive surface between the middle Atoka LST and the upper Atoka transgressive systems tract. A relatively high conductivity signature at the top of the middle Atoka LST marks this surface (Fig. 52). In areas where the upper Atoka TST becomes shaly, a condensed section occurs at its top. This condensed section is widespread in the deep parts of the Arkoma Basin, and makes it easy to track the transgressive surface beneath it (Fig. 52). All cross section locations are presented in Fig. (51).

Different nomenclatures are used to define the units within a lowstand systems tract. Vail (1987) and Van Wagoner et al. (1987) defined a basin floor fan, slope fan, and prograding complex as separate depositional units within the lowstand system tract. Posamentier and Vail (1988) and Posamentier et al. (1991) divided LST into: a lowstand fan (basin floor fan) and a lowstand wedge. The lowstand wedge has two components: early lowstand (slope fan) and late lowstand (prograding complex). This work follows Van Wagoner et al. (1988) terminology of dividing the LST into basin floor fan, slope fan, and lowstand wedge (Fig 53).

A comparison between the fault trends in Figs. (38 and 48) and the isopach map of middle Atoka LST (Fig. 51) reveals that this stratigraphic section is mainly confined to these faults, and manifests the complex interaction of sedimentation and tectonic evolution in this basin. Growth faults provided significant accommodation space for the deposition of basin floor and slope fans, which abruptly thicken on the downthrown side of both the San Bois and Kinta fault trends. The lowstand wedge occurs on both sides of the faults with thicker accumulations between the San Bois and Mulberry fault trends (Fig. 51).

Generally, basin-floor fans tend to be better developed on a third-order sequence boundary (Mitchum and Van Wagoner, 1991). The middle Atoka basin-floor fan is generally limited to the southeastern depocenter of the Arkoma Basin, where its thickness is over 3000 feet in the Short Unit#1 well (Fig. 53). Houseknecht (1986 and 1987) and Houseknecht and McGilvery (1990) described this fan as an "axial fan" implying a single-point source for sediment dispersal from the east. McGilvery and Houseknecht (2000), in a study that included outcrops in the Ouachita Mountains, acknowledged the multiple, coeval sediment-dispersal systems with primary sediment input from the east and southeastern margins of the basin. Based on this interpretation, they defined the basin floor fan as "apron complex". The sandstones within this basin floor fan are mistakenly called Cecil sandstones. The name Cecil was used for the first sandstone units occurring above the Spiro sandstone in Arkansas and the eastern part of the Arkoma Basin in Oklahoma. As explained earlier, Cecil sandstone is part of the lower Atoka sequence. Thus it should not be confused with the sandstones of the basin floor fan deposited unconformably on the top of the lower Atoka prodelta shale in the deep parts of the Arkoma Basin.

The basin floor fan is overlain by thick shale interval with thin sandstone beds. This interval is interpreted as a mud-rich slope fan that extends along the southern margin of the Arkoma Basin. This is shown in two E-W and N-S cross sections (Figs. 53 and 54 respectively). The maximum thickness of the slope fan lies to the south of both the San Bois and Kinta fault trends, where its thickness exceeds 5000 feet in some locations. The huge thickness of the slope fan indicates that despite the rapid sediment influx, the fault-controlled basin was subsiding at such a rapid rate that slope or basinal water depths were maintained. Several sandstone intervals occur within this mud-rich slope fan. These sandstones have been interpreted as deep-water sediments driven by gravity flows (Vedros and Visher, 1978; Wanslow, 1985; Johnson et al. 1989; Houseknecht and Ross 1992; Visher, 1996). They were deposited in slope channel complexes (Houseknecht and Ross, 1992; McGilvery and Houseknecht, 2000).

The vertically stacked channel-levee complexes deposited in the southern part of the Arkoma Basin to the south of San Bois and Kinta fault trends, can be grouped as a fourth order cycle. The Brazil sandstone is the oldest of these complexes within the slope fan of the third-order sequence. The base of the Brazil channel-levee complex can be considered a fourth-order sequence boundary because of its relative widespread occurrence south of the two major fault trends. Also, it separates the deeper slope-fan shale, overlying the basin floor fan, from the stacked channel-levee complexes above it (Figs. 53 and 54).

Several sandstone intervals within the channel-levee complexes occur south of the San Bois fault trend. Adapting the classification of Galloway (1998), the sediment feeder system for these complexes within the Arkoma Basin may have changed from a line source (shelf-fed) along the San Bois fault, in the east, to a point-source-like feeder (channel or canyon) in the west (Fig. 55). This is shown in three cross sections across the Arkoma deep basinal areas (Figs. 56, 57 and 58). Fig. (56) shows several channel-levee complexes within the slope fan without a clear indication of a point source such as a canyon or thick channel. Detailed correlations indicated that the sandstones within these complexes were funneled through notches, forming pod-like geometries, and are overlain by shales with some thin-bedded sandstones within a specific stratigraphic zone (Fig. 59). The line-source interpretation for the turbidites south of the San Bois fault is supported by the presence of a wide area of extensive erosion of the lower Atoka HST section, along the upthrown side of the fault. This extensively eroded shelf edge was illustrated in Figs. (49) and (50) in the previous chapter. Farther west, better indication of long channel or canyon-like sourcing from the north to the south can be observed in Figs. (57) and (58). For example, the thick sandstone interval at depth between 6235-6564 feet in

George Peden#2 well in Fig. (58) is correlative to the deeper sandstone at depth 6675-7210 feet at Lewis#4-12 well, about 10 miles to the south, where the slope fan section thickens. In the southwestern part of the Arkoma Basin, the shaly slope fan gradually becomes thin and several fining-upward parasequences dominate the middle Atoka LST.

Despite the general N-S dipping-trend of the channel-levee complexes (Figs 56-59), the sandsones within some complexes show an easterly or westerly component to the N-S trend, indicating changes in the source direction, or in the availability of accommodation space. Based on paleocurrent measurements from the Atoka turbidite outcrops in the frontal Ouachitas, Ferguson and Suneson (1988) concluded that sediments were distributed by at least two, spatially distinct and coeval, oppositely directed fan systems; some sourced from the east and others from the west (Fig. 60). In my view, the predominant idea of the eastern direction of the main sediment sourcing for the turbidites in the Arkoma Basin is incorrect, and was mainly influenced by the outcrop studies conducted in the Ouachitas. Viele and Thomas (1989) describing a tectonic model for the evolution of the Ouachita system, stated that the growth of the Ouachita accretionary prism probably formed a submarine ridge, imperfectly dividing the closing ocean into two primary basins: the southern Ouachitas of Arkansas and the central Ouachitas of Oklahoma forming one basin in the south, and the frontal Ouachitas and Arkoma Basin to the north. If this model is a valid hypothesis, then we should not extend the eastern sourcing observed in the Ouachitas to the Arkoma Basin, especially with the knowledge that the turbidite sequences from the southern parts of the Ouachita system were thrusted northward to their present position close to the southern margin of the Arkoma Basin.

It is very important to recognize a stratigraphic datum for correlating the channel-levee complexes composing the slope fan of the Arkoma Basin. Without such a datum, it is easy to miscorrelate the sandstones within these complexes due to their laterally discontinuous nature and vertical multiple occurrences within a thick shale section (Fig. 61). The transgressive surface, at the base of the overlying upper Atoka TST, is considered the proper datum due to its continuous nature above the middle Atoka LST and the presence of the overlying condensed section marker "hot shale" (Fig. 61). It is somewhat confusing to obtain the right order of the lithostratigraphic nomenclature of these sandstones from the scout tickets or literature. In many instances, scout tickets reported by drilling companies refer to such sandstones merely as middle Atoka sandstones, or upper and lower sandstones. Based on detailed correlations, the vertical succession of these sandstones is as follows from to top to bottom: Red Oak, Panola, Diamond, and Brazil sandstones, which is in agreement with Suneson and Hemish (1994). Some of these sandstones disappear and re-appear, but do so within a specific stratigraphic zone.

The Fanshawe sandstone represents the uppermost sandstone that occurs in the lowstand wedge above the slope fan in the Arkoma Basin. Houseknecht (1987) recognized tidal facies in the Fanshawe sandstone in the Red Oak field area in the southern part of the Arkoma Basin. The shaly lowstand wedge interval, in the south, becomes thicker and sandier to the northeast where it comprises the major part of the middle Atoka LST section between the San Bois and Mulberry fault trends. In this area, it is composed of incised-valley fill marking the unconformity (sequence boundary) on the top of the lower Atoka sequence (Fig. 62). Locally, thin sandstones in the upper part of the lowstand wedge were developed within an aggradational to retrogradational stacking pattern (Fig. 62). In the southwest corner of the Arkoma Basin, the thick lowstand wedge is dominated by fluvial deposition indicated by thin sandstones at the base of fining upward intervals (Battles#1-19 well in Fig. 62).

It is worth mentioning that the lack of recognition of the unconformity between the lower and middle Atoka sections may have resulted in disagreement regarding the age of the turbidites section in the Arkoma Basin and frontal Ouachitas. This is despite indications of the presence of this unconformity. In the outcrops of the type Atoka Formation area in Coal County in the southwestern edge of the Arkoma Basin, Sutherland and Manger (1984) reported fusulinids indicating a middle Atokan age at about 400 feet above the base of the Atoka Formation. Grayson (1984) reported in a study conducted on conodonts in outcrops of the same county, that the basal Atoka above the Wapanucka limestone is middle Atokan in age.

Fig (63) shows examples from two wells in the eastern and the western parts of the southern depocenter of the Arkoma Basin. The prodelta shale of the lower Atoka HST in both wells has been extensively eroded. The remaining section of the lower Atoka sequence is a few hundred feet thick, and is unconformably overlain by different units of the middle Atoka turbidites. This is compared to over 3000 feet of the lower Atoka section in the northeast of the Arkoma Basin. It is likely that the thin lower Atoka section was completely eroded in areas within the frontal Ouachitas resulting in the merging of the two unconformities, which bound the lower Atoka third-order sequence, and forming one major unconformity that likely spans the late Morrowan through early Atokan times. The merging of the two unconformities coupled with the inability to identify the shaly lower Atoka interval, partially preserved up dip, may have mistakenly led some workers such as Sprague (1985) to consider the turbidite deposits in the frontal Ouachitas to be lower Atokan, or Visher (1996) to assume that the turbidites in the Arkoma Basin and frontal Ouachitas span both the early and middle Atokan age.

Interesting features can be observed on the structural contour map on the transgressive surface at the base of the upper Atoka TST, which overlies the top of middle Atoka LST where it exists or the middle Atoka unconformity surface where it is absent (Fig. 64). A series of synclines separated by highs are aligned in a zone trending ENE-WSW on the downthrown side of the major syndepositional fault trends described earlier. If the plate collision during the Ouachita orogeny was from the southeast with the main compressional vector in that direction, then this en-echelon pattern of folds is aligned in a shear zone (Riedel antithetic shear zone, R'). These synclines or small pull-apart sub-basins helped in providing the accommodation space for the overlying upper Atoka, Hartshorne and Booch depositional systems. This will be demonstrated in the next chapters.

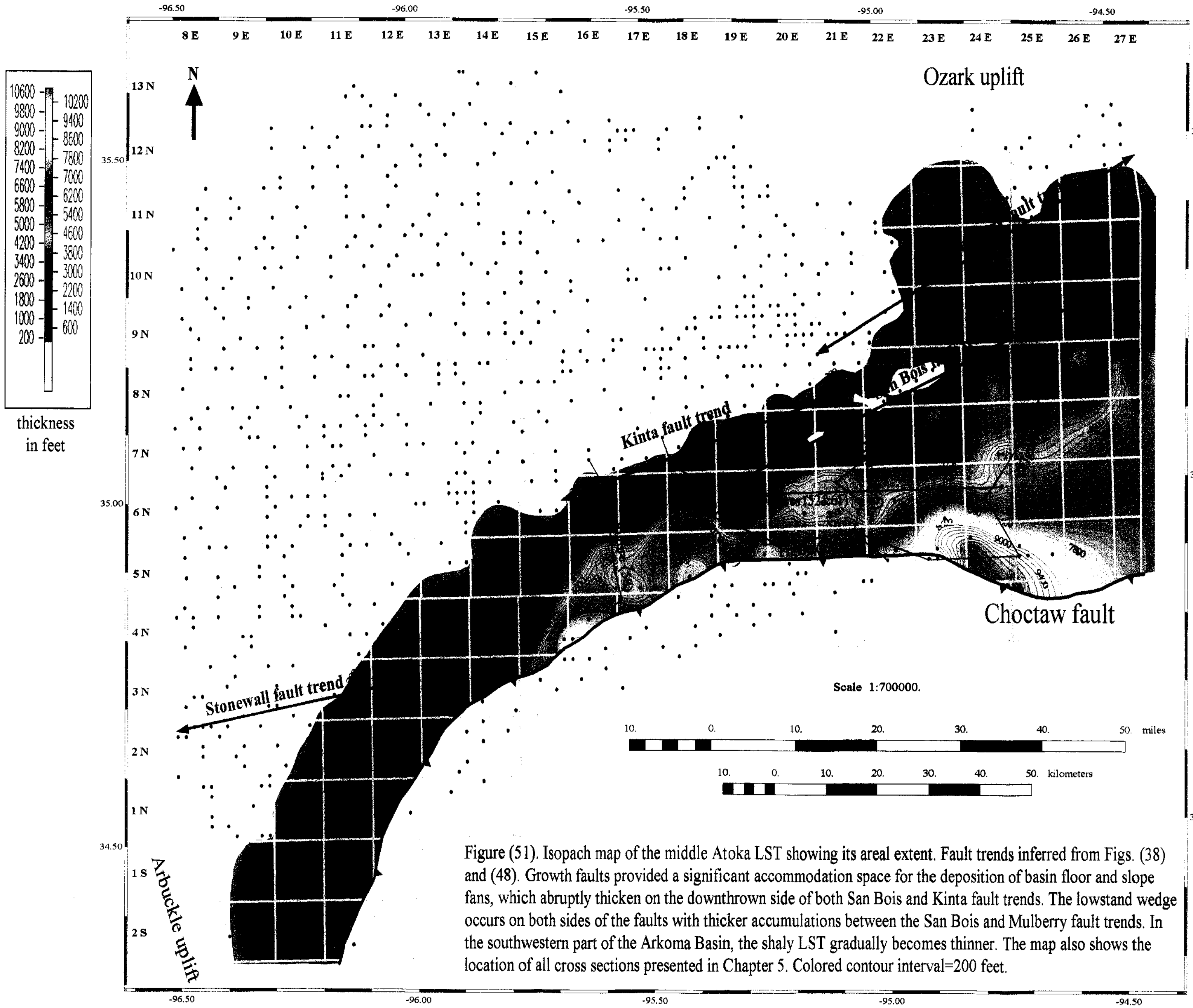


Figure (51). Isopach map of the middle Atoka LST showing its areal extent. Fault trends inferred from Figs. (38) and (48). Growth faults provided a significant accommodation space for the deposition of basin floor and slope fans, which abruptly thicken on the downthrown side of both San Bois and Kinta fault trends. The lowstand wedge occurs on both sides of the faults with thicker accumulations between the San Bois and Mulberry fault trends. In the southwestern part of the Arkoma Basin, the shaly LST gradually becomes thinner. The map also shows the location of all cross sections presented in Chapter 5. Colored contour interval=200 feet.

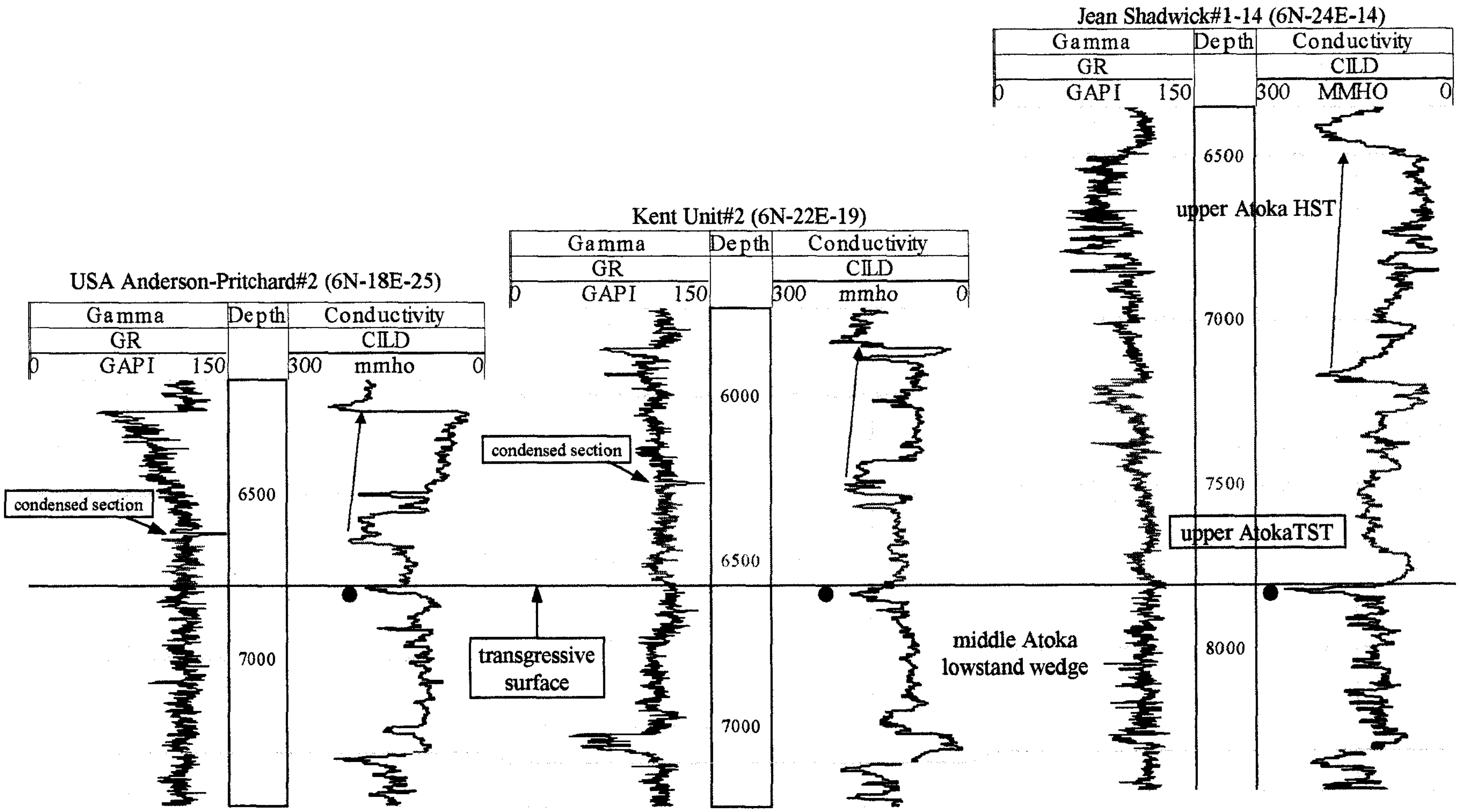


Figure 52. E-W detailed cross section using gamma ray and conductivity logs. A relatively high conductivity signature (green circle) marks the transgressive surface between the the middle Atoka LST and upper Atoka TST. In areas where the upper Atoka TST becomes shaly, a condensed section occurs at its top, and makes it easy to track the transgressive surface beneath it. Datum is the upper Atoka transgressive surface. Horizontal scale is equal spacing. For location, see Fig. (51)

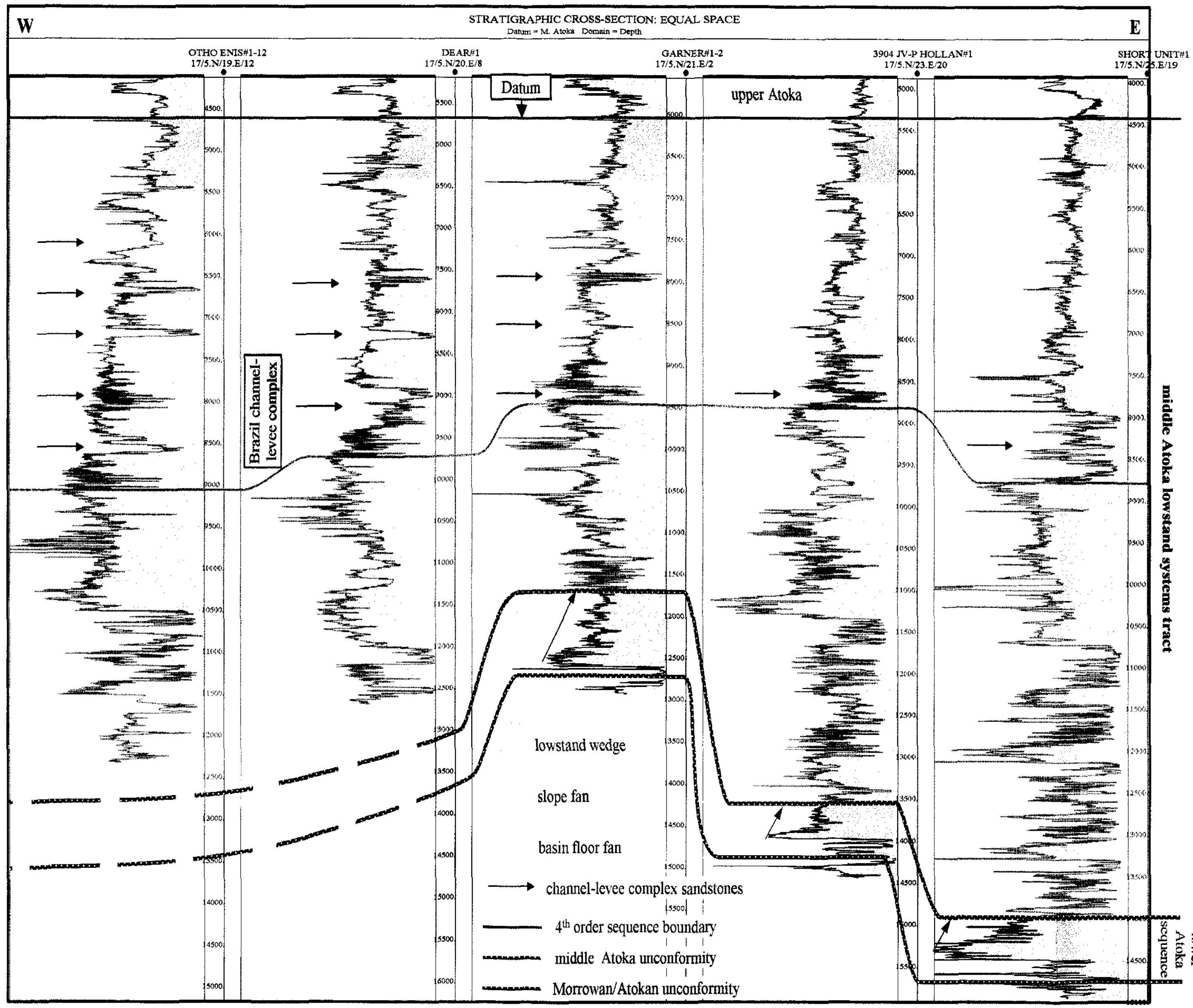


Figure 53. E-W stratigraphic cross section in the southeast margin of the Arkoma Basin where the thickest middle Atoka LST section occurs. The section is composed of basin floor fan, slope fan, and lowstand wedge. The sandstones within the basin floor fan are mistakenly called Cecil sandstones which were deposited within the lower Atoka sequence. The channel-levee complexes may represent a fourth-order cycle within the third-order mud-rich slope fan. The Brazil channel-levee complex is considered the base of this fourth-order sequence due to its widespread occurrence overlying an older thick shaly slope fan. The cross section datum is the upper Atoka transgressive surface. For location, see Fig. (51).

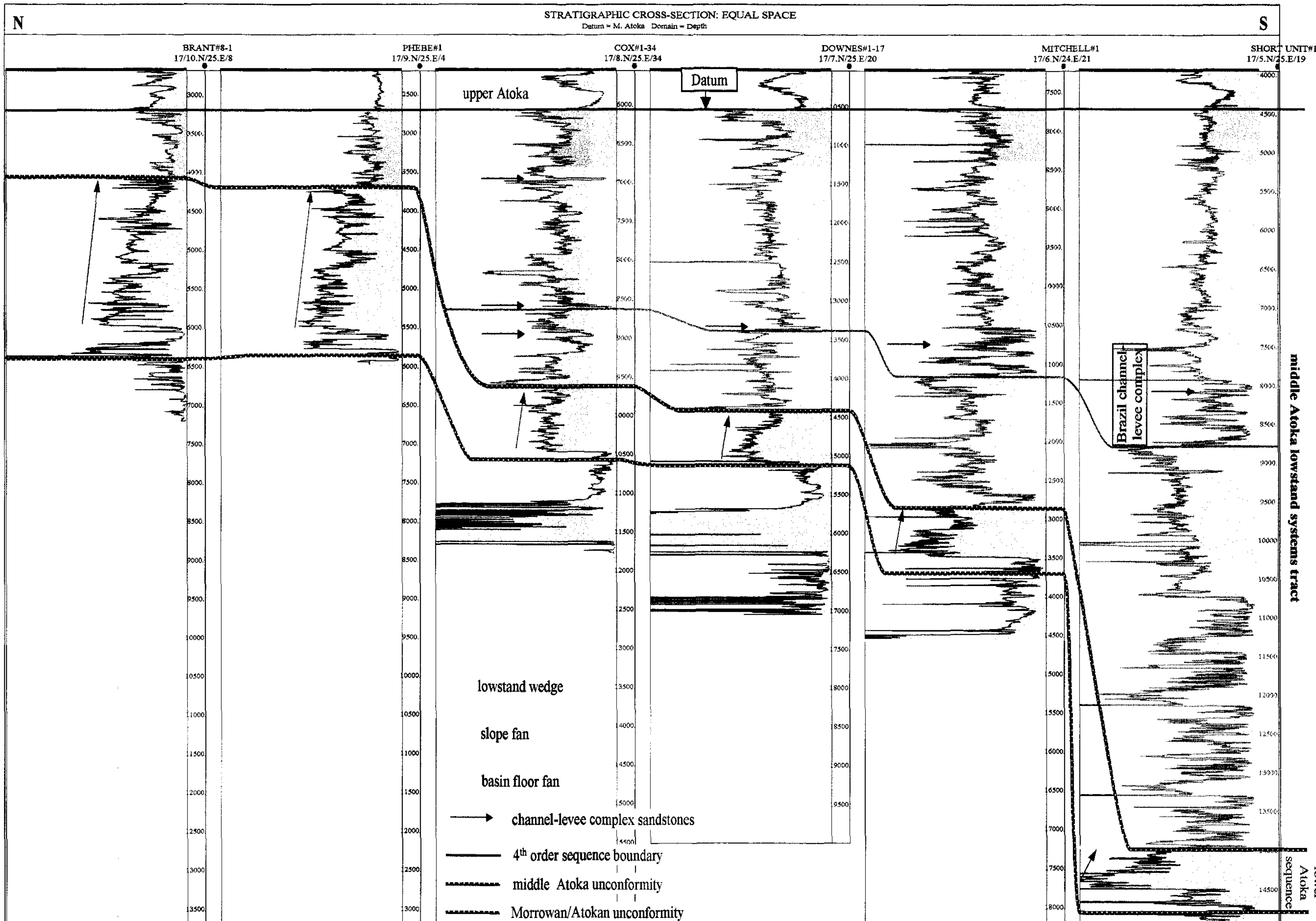


Figure 54. N-S stratigraphic cross section across the eastern part of the Arkoma Basin where the farthest northward extension of the middle Atoka LST section occurs. The section thickness change from few hundred feet to about 10000 feet within a distance of less than 30 miles. Growth faults in the south provided huge accommodation space for the deposition of the basin floor fan and the thick mud-rich slope fan. Both fans are mainly confined to these growth faults but the the lowstand wedge extends farther north as shown in Phebe#1 and Brant#8-1 wells. The cross section datum is the upper Atoka transgressive surface. For location, see Fig. (51).

(a)

(b)

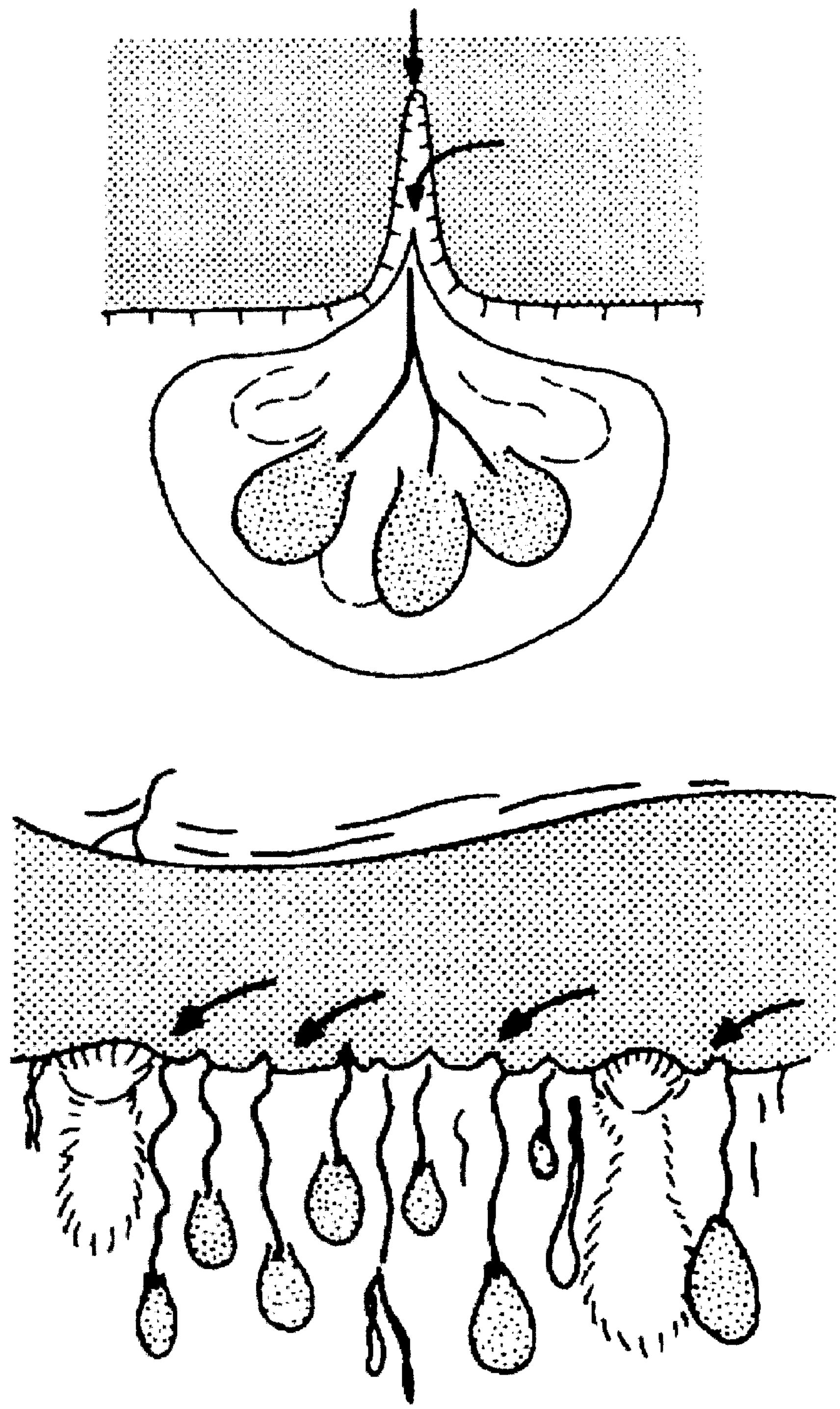


Figure 55. Two patterns among several others suggested by Galloway (1998) for the sediments sourcing of slope turbidite systems. (a) point source through submarine canyon, basin-floor channel, or tectonic trough. (b) sediments are locally funneled through notches or small erosional channels that shift frequently creating a line source along the shelf margin.

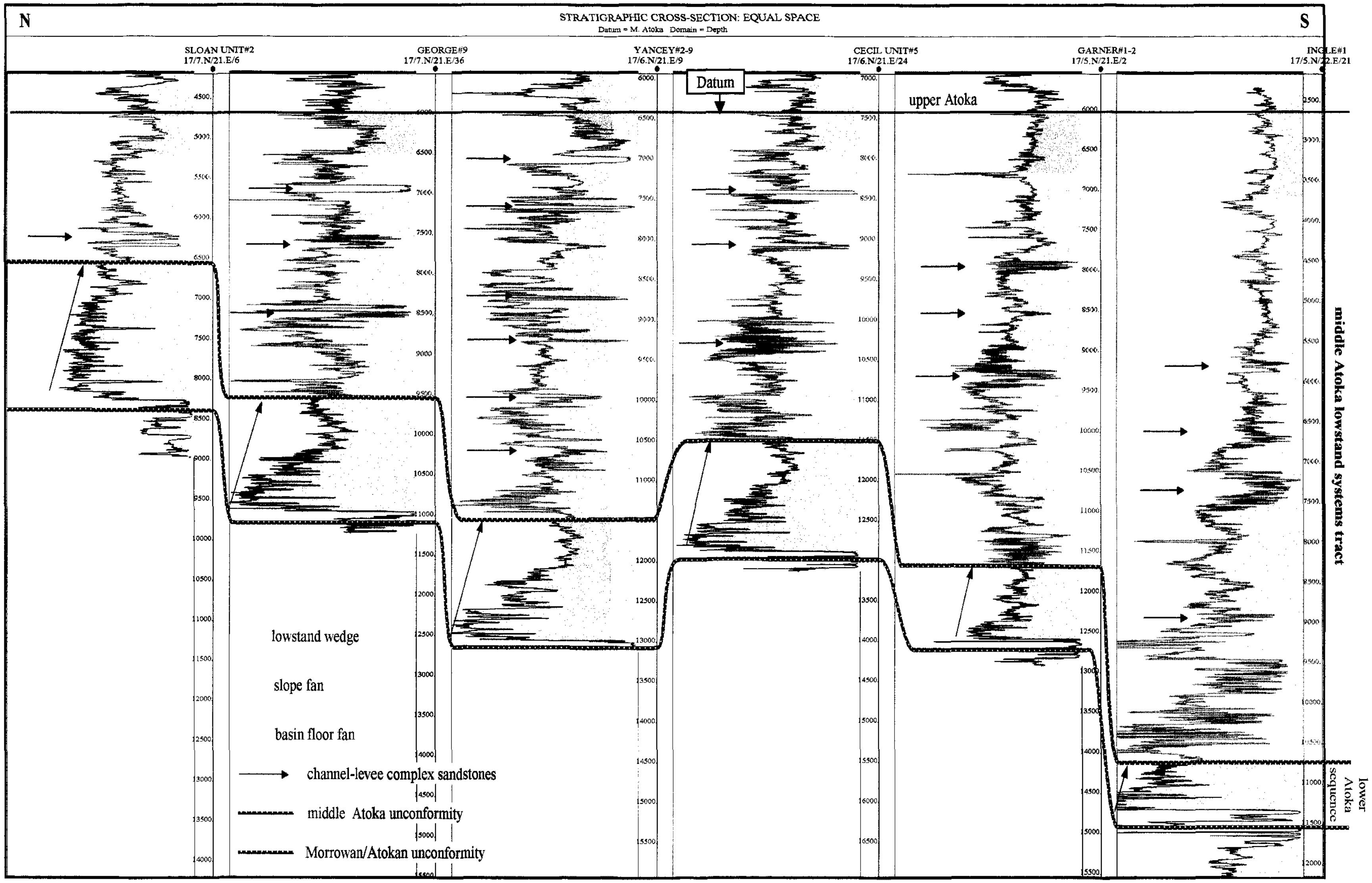


Figure 56. N-S stratigraphic cross section across the San Bois fault trend shown in Fig. (51). Several sandstones of the channel-levee complexes, composing the slope fan, occur south of the San Bois fault trend. Many of these sandstones occur without a clear indication of a point source such as a canyon or long thick channel. This suggests a line source for these sediments. The cross section datum is the upper Atoka transgressive surface. For location, see Fig. (51).

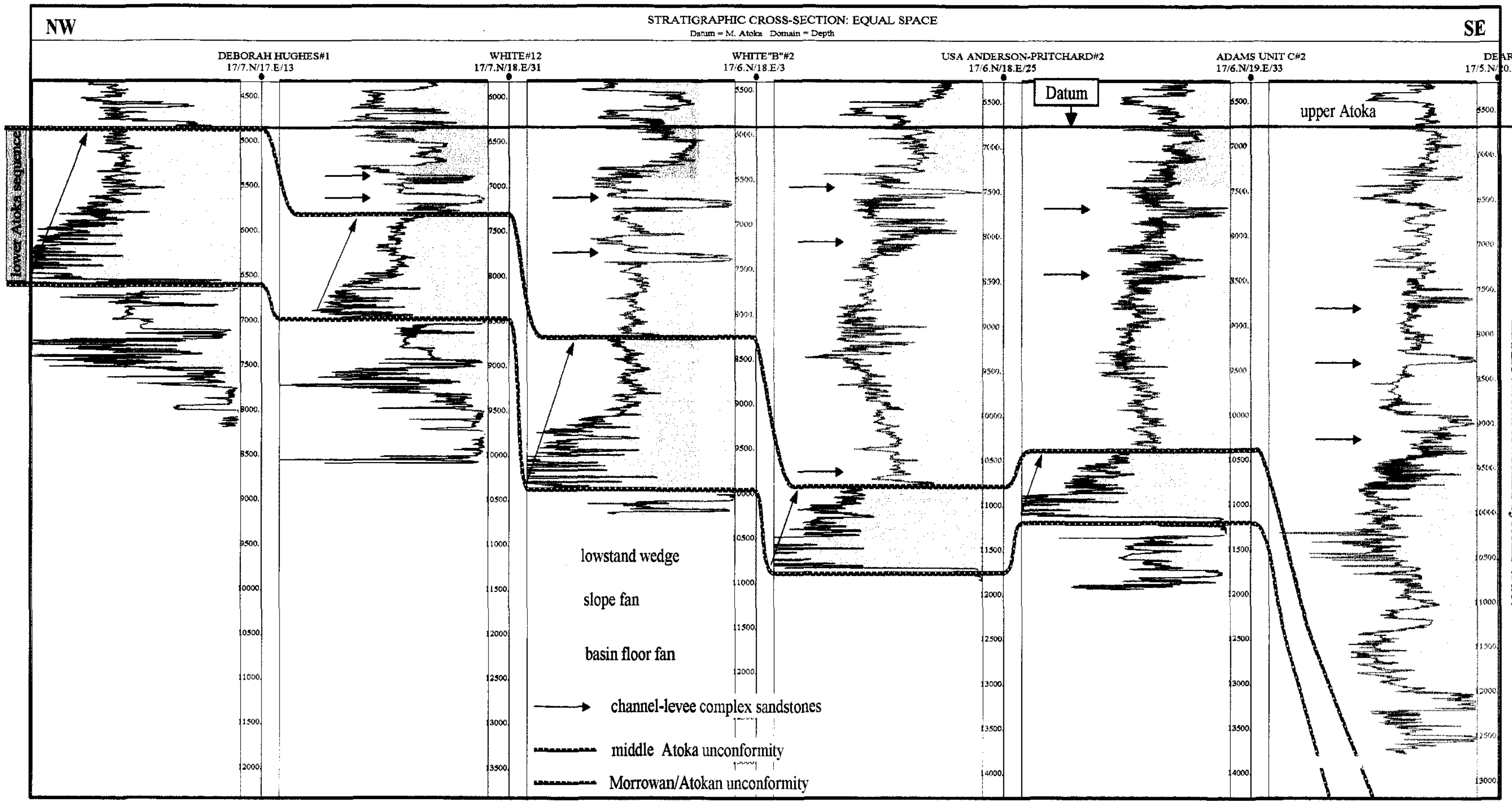


Figure 57. NW-SE stratigraphic cross section just west of the San Bois fault trend and across the Kinta fault trend shown in Fig. (51). Thick sandstones occur within the slope fan close to the shelf area of the Arkoma Basin indicating deposition within a canyon or long channel. Adapting the Galloway (1998) classification, this pattern may suggest a point source for these sediments. The cross section datum is the upper Atoka transgressive surface. For location, see Fig. (51).

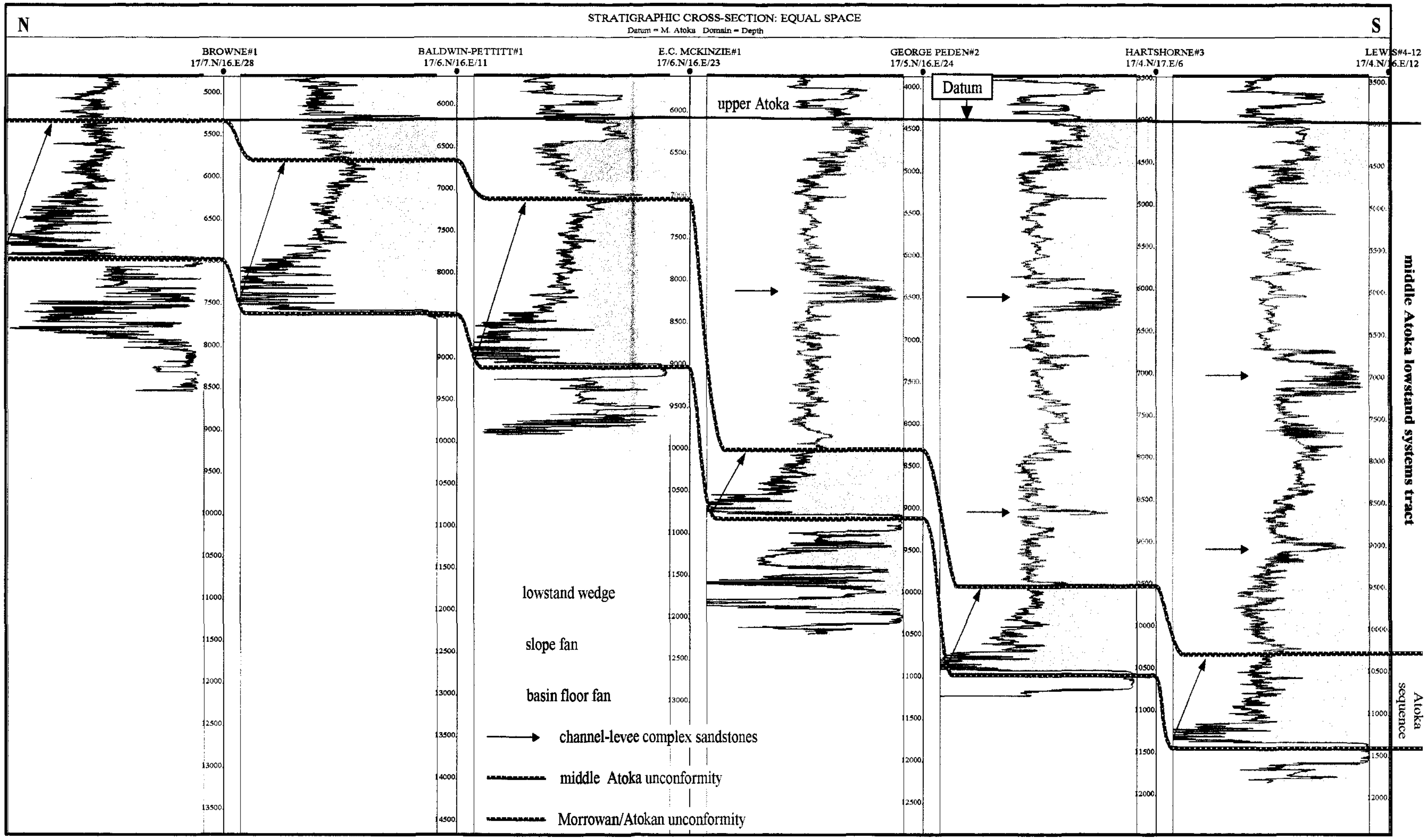
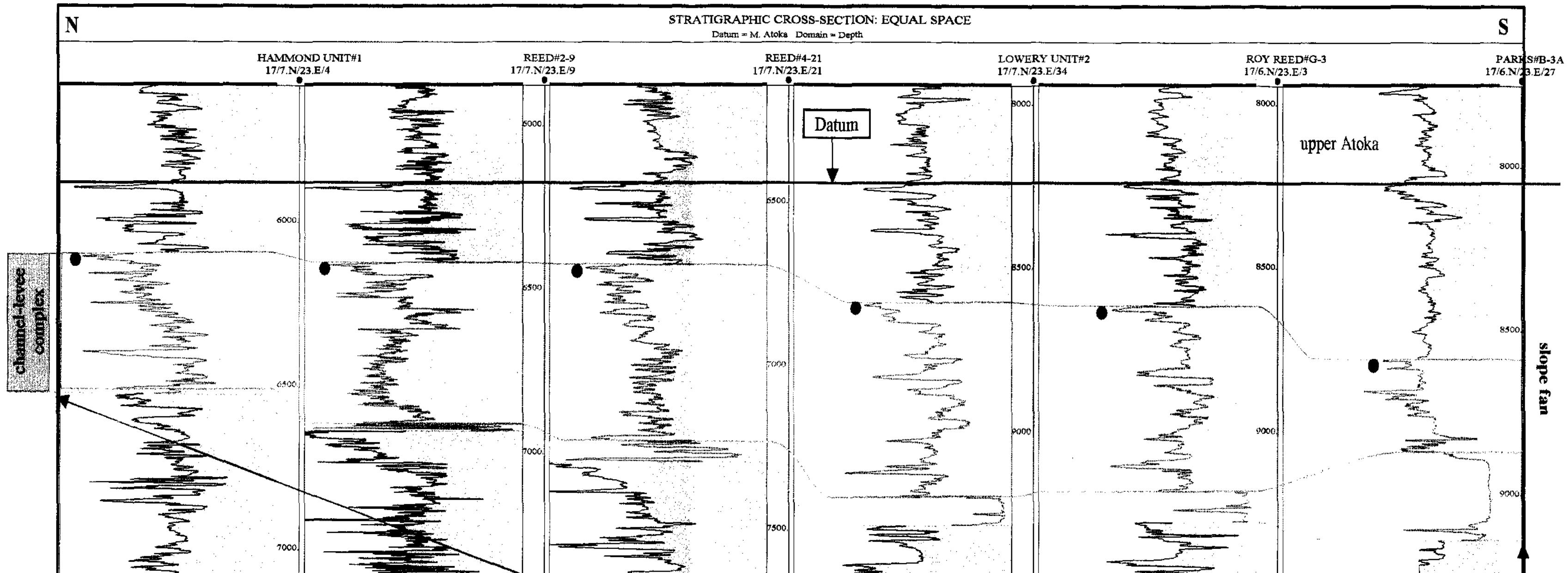
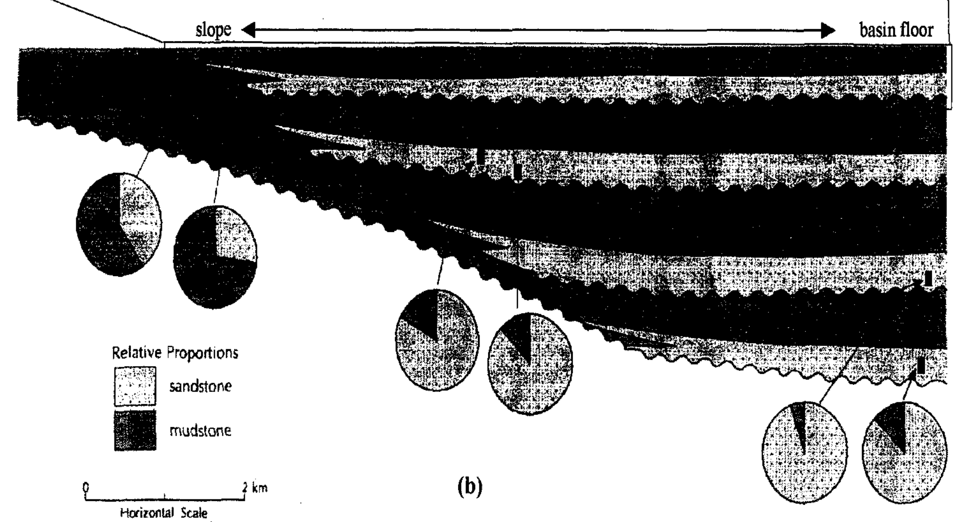


Figure 58. N-S stratigraphic cross section across the Kinta fault trend shown in Fig. (51). A thick sandstone channel occurs within the slope fan of the middle Atoka LST clearly indicating a point-source for sediment supply at this area of the Arkoma Basin. Note the general N-S dipping trend of this channel. The cross section datum is the upper Atoka transgressive surface. For location, see Fig. (51).



(a)



(b)

Figure 59. (a) N-S detailed stratigraphic cross section showing one channel-levee complex at the top part of the middle Atoka slope fan. A ten-mile long sandstone interval at the base of the complex (light brown) dips from north to south in contrary to the E-W direction suggested by other workers for turbidite channels in the Arkoma Basin. This sandstone body is funneled through a notch and overlain by shale with occasional thin-bedded sandstones within a specific channel-levee complex zone. The top of this complex is defined by a conductivity marker (green circle). The cross section datum is the upper Atoka transgressive surface. For location, see Fig. (51). Several of these complexes occur south of the San Bois fault trend. They are stacked both vertically and laterally as shown in the Fig. (61). (b) A depiction for a series of channel-levee complexes of slope fan outcrops in the Mt. Messenger Formation, New Zealand (after Browne and Slatt, 1997). This depiction serves as an analogue for the channel-levee complexes presented in this figure and Fig. (61).

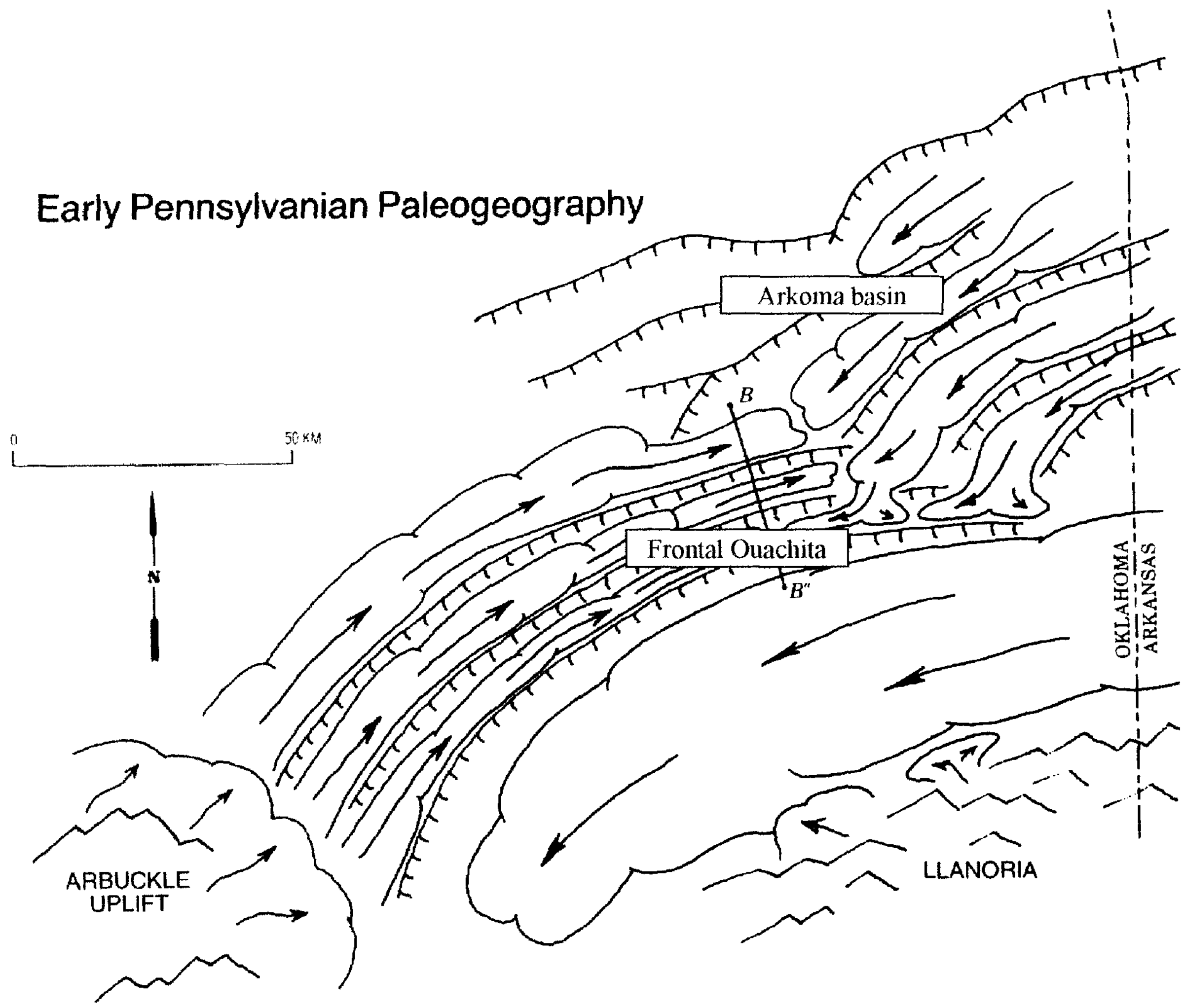


Figure 60. Early Pennsylvanian paleogeography of the Ouachita region, showing two opposing axial fan systems and their relationships to growth fault troughs along the northern edge of the Ouachita Basin. The three southernmost faults are from south to north: Ti Valley block, Pine Mountain block and the Choctaw block. The other faults are recognized in the subsurface of the Arkoma Basin (modified after Ferguson and Suneson, 1988).

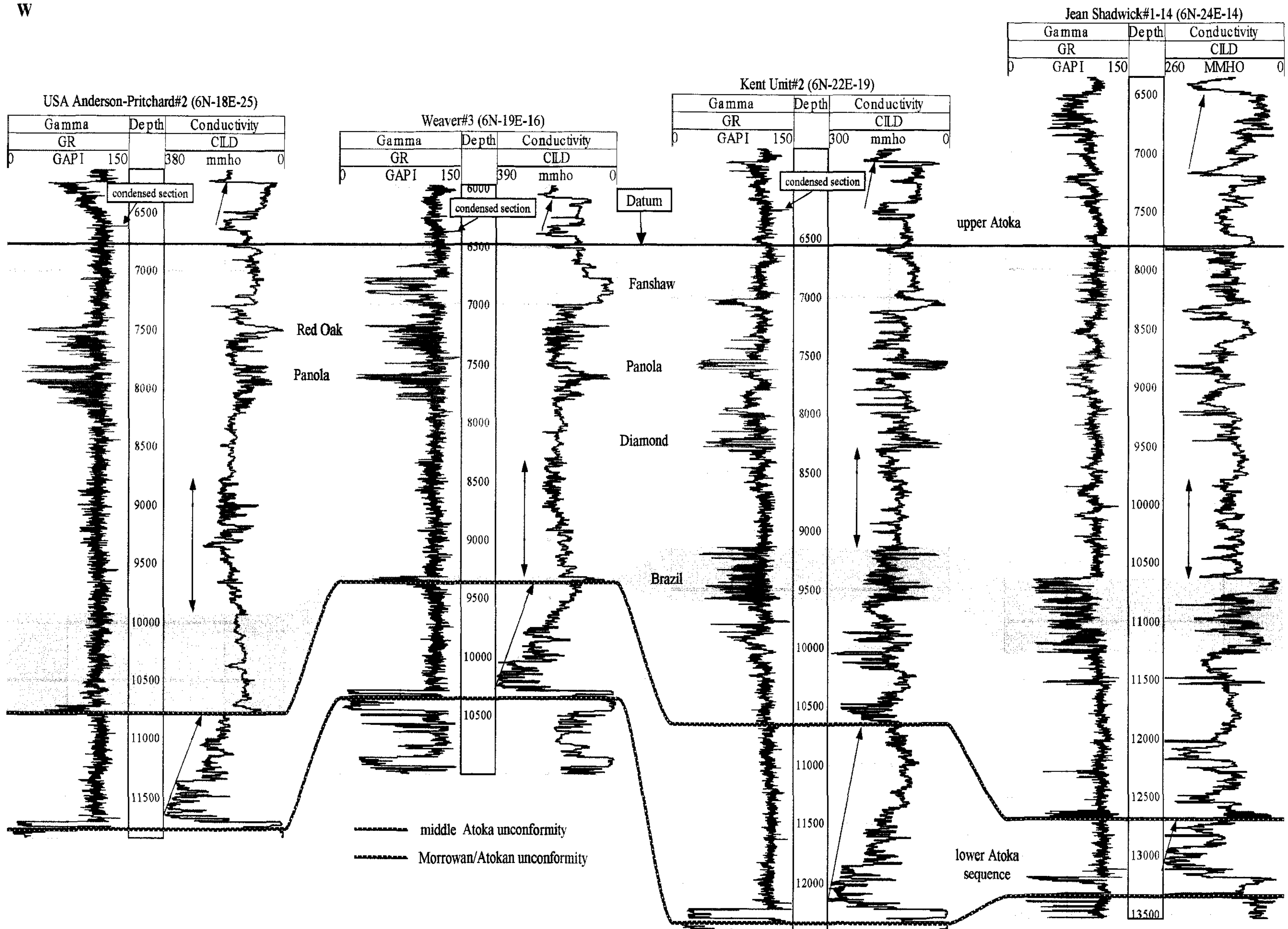


Figure 61. E-W stratigraphic cross section south of the San Bois fault trend. It shows the importance of recognizing a proper datum for correlating the sandstones within the channel-levee complexes. This is due to the lateral discontinuous nature of these sandstones and their vertical multiple occurrences within a thick shale section. The transgressive surface at the base of the upper Atoka section provides the proper datum for correlation because of its continuous nature and the presence of a condensed section "hot shale" above. Horizontal scale is equal spacing. For location, see Fig. (51).

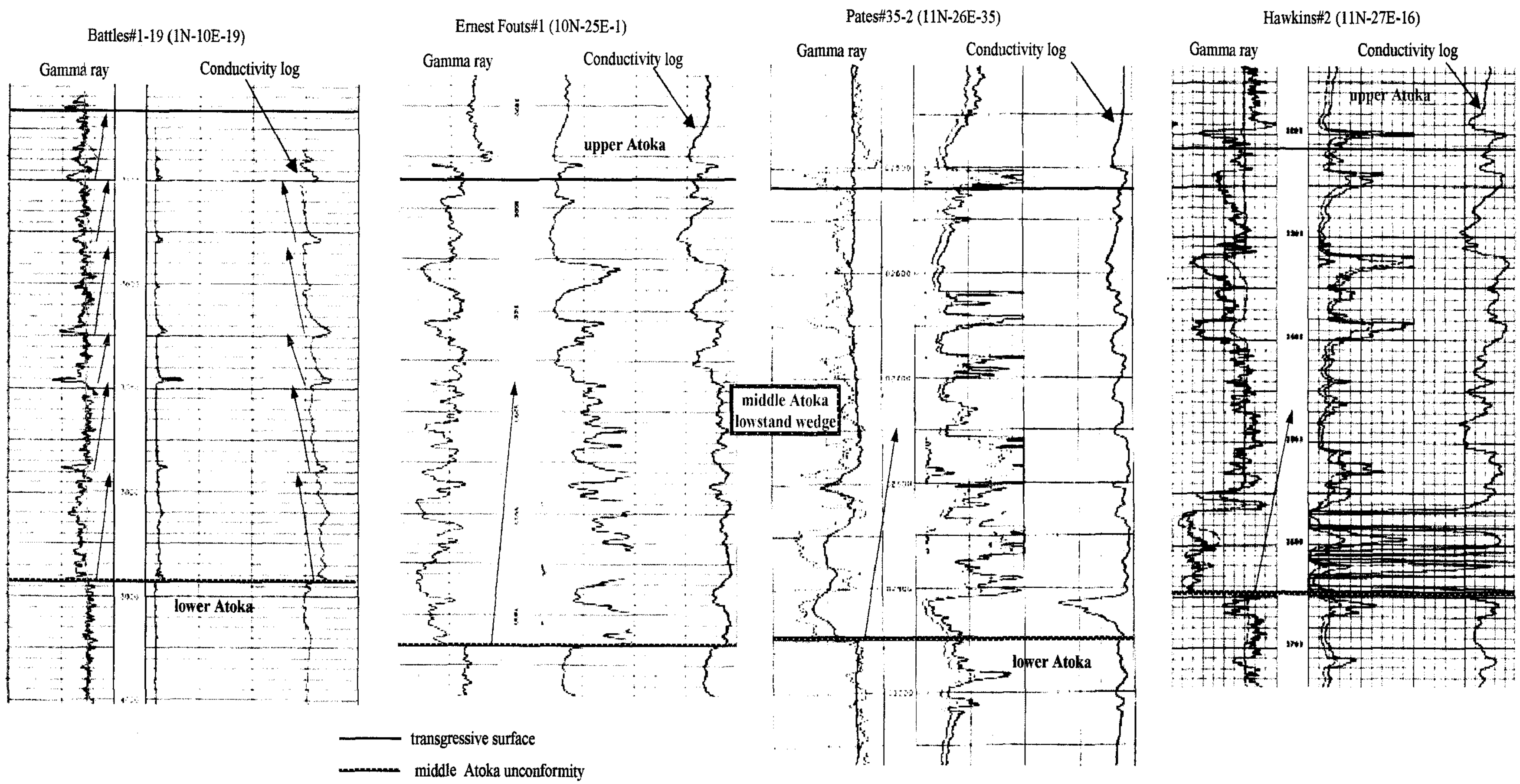


Figure 62. The lowstand wedge of the middle Atoka LST in four wells in the northeastern and southwestern parts of the Arkoma Basin. It unconformably overlies the lower Atoka sequence in these wells. The lowstand wedge is composed of fining upward valley-fill deposits followed by aggradational to retrogradational marine sandstones in the three wells in the northeast (on the right). Meanwhile, it is dominated by fining upward parasequences deposited in fluvial environment in the southwestern part of the Arkoma Basin (Battles#1-19 well). The lithostratigraphic name of Fanshawe is assigned to these sandstones.

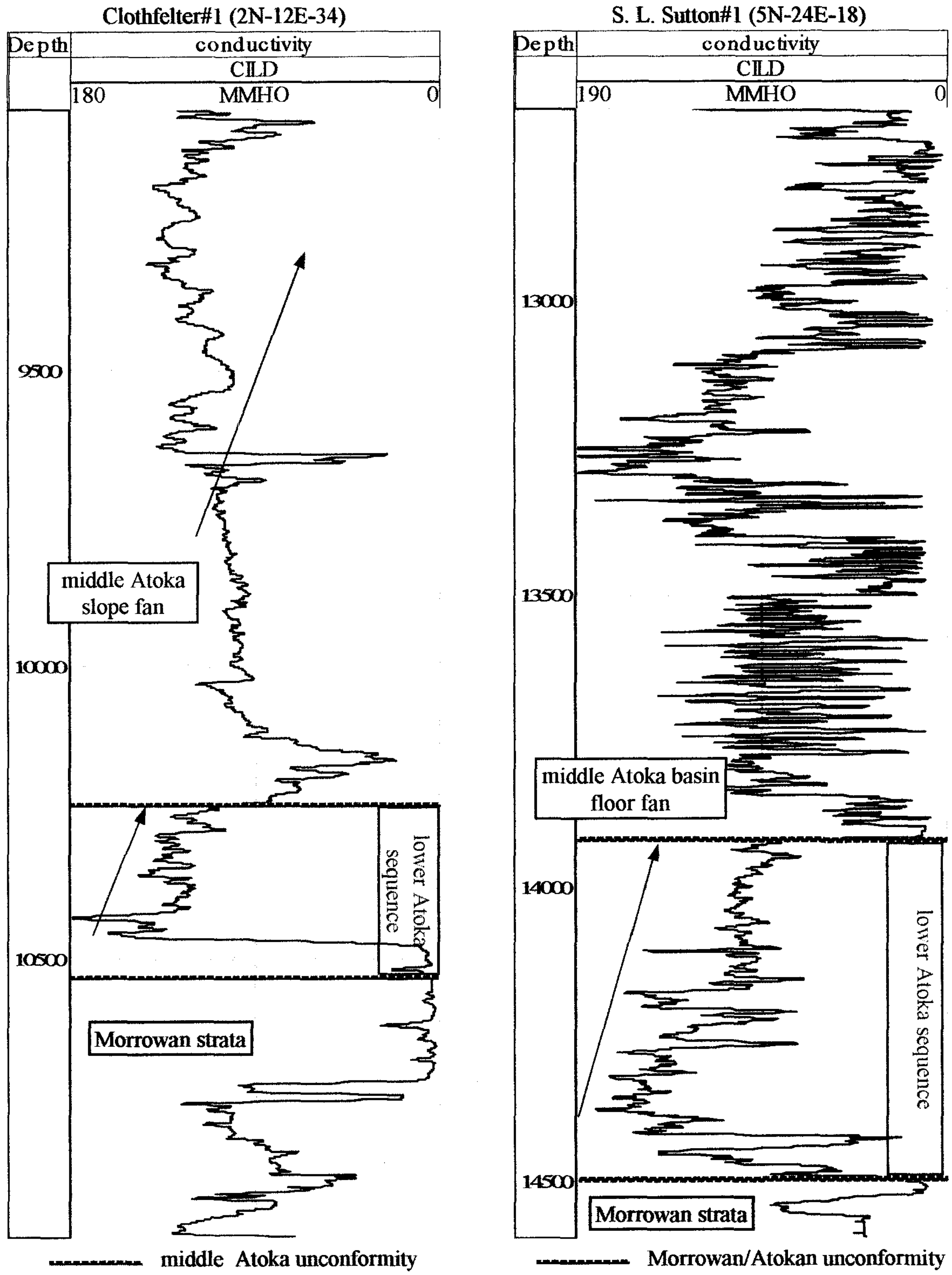
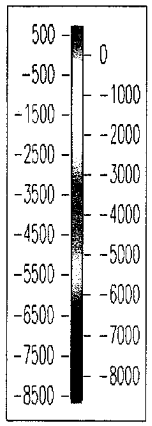


Figure 63. Two wells in the east and west within the southern depocenter of the Arkoma Basin showing the remaining section of the lower Atoka sequence. It is likely that the thin lower Atoka section was completely eroded in areas in the frontal Ouachita resulting in the merging of the two unconformities bounding the lower Atoka sequence, and forming one major unconformity that may span the late Morrowan through early Atokan times.



elevation
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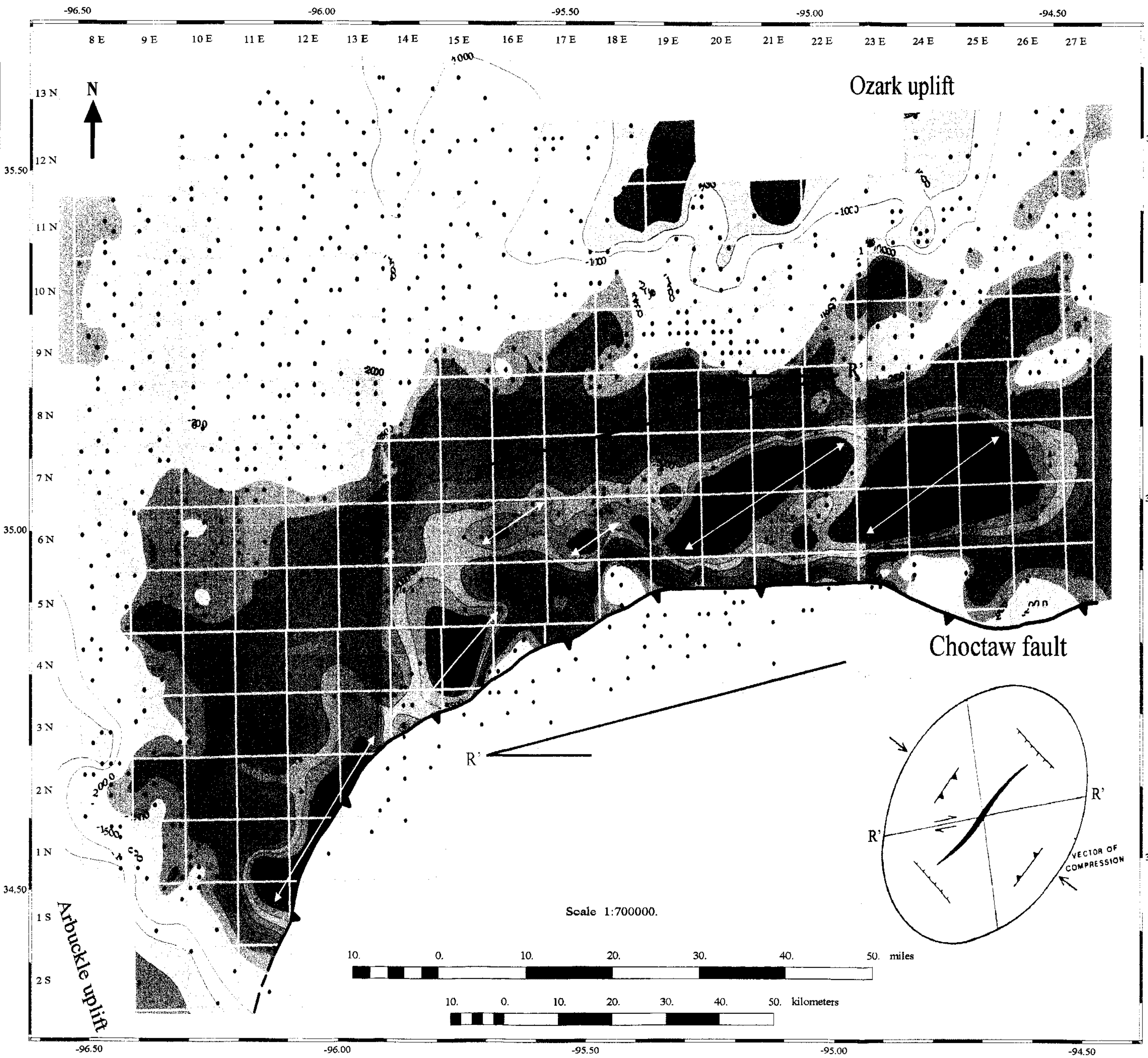

Figure 64. Structure contour map on the base of upper Atoka TST. A series of synclines (dark blue areas) separated by highs are aligned in a zone trending ENE-WSW (light blue area) on the downthrown side of the major syndepositional fault trends shown in Fig. (51). If the plate collision during the Ouachita orogeny was from the southeast with the main compressional vector in that direction, then this en echelon pattern of folds is aligned in a shear zone (Riedel antithetic shear zone, R'). Riedel shear ellipse (bottom right) is modified from Sultan and Halim (1988), and Davis and Reynolds (1996). These synclines or small pull-apart sub-basins were the depocenter sites for the overlying upper Atoka, Hartshorne and Booch depositional systems. Colored contour interval=500 feet.

CHAPTER 6

UPPER ATOKA

Zachry (1983) stated that the upper Atoka sandstone succession in the Arkansas part of the Arkoma Basin accumulated in delta systems that prograded southward after faulting had ceased. An isopach map of the upper Atoka section in the Arkoma Basin in Oklahoma shows a general thickening trend to the south, where the synclinal areas illustrated in Fig. (64) occur, with over 4000 feet of upper Atokan sediments deposited south of the San Bois fault trend (Fig. 65). This thickening trend indicates that during late Atokan time, the Arkoma Basin was still subsiding but at a lesser rate than during middle Atokan time. All cross section locations are shown in Fig. (65).

The upper Atoka section consists of several distinctive parasequences composing transgressive and highstand systems tracts. These parasequences extend across the major syndepositional faults present in the southeast part of the Arkoma Basin (Fig. 66). The lower boundary of the upper Atoka section is a transgressive surface that overlies the middle Atoka LST in the southern and eastern parts of the Arkoma Basin, and the unconformity at the top of the lower Atoka sequence on the shelf of the basin (Fig. 66). Overlying this surface, a thick interval is well developed in the eastern part of the Arkoma Basin (Figs. 67 and 68). This interval includes the most widespread sandstones at the base of the upper Atoka section, and extends onto the shelf of the Arkoma Basin forming the transgressive systems tract (Fig. 66). The trends for the development of sandstones within this interval are in the eastern part of the Arkoma Basin (Goodwin#1 and Hoffman unit#1 wells in Fig. 67), parallel to the trend of the San Bois fault (Frederick#4-33 well in Fig. 67), and generally in the northern shelf of the Arkoma Basin. To the south and west, these sandstones become thin and shaly (Davis Kemp#1 well in Fig. 67).

The upper boundary of this transgressive system tract is a downlap surface usually marked by a condensed section recognized as hot shale on the gamma ray logs (Figs. 66 and 67). The Alma sandstone is the basal interval in the upper Atokan section in Arkansas, which is composed of single or multiple sandstone units (Zachry, 1983). The same nomenclature can be used for the sandstones in this interval in the eastern part of the Arkoma Basin in Oklahoma, which is equivalent to the upper part of the lithostratigraphic Gilcrease sandstones in the northwestern part of the basin.

The upper Atoka TST and HST are best developed in the eastern part of the Arkoma Basin with well-defined and thick parasequences to the southeast (Figs. 68 and 69). In that area, the upper Atoka HST is composed of at least five thick aggradational parasequences with sandstone intervals at their tops. Along the southern margin of the Arkoma Basin, the upper Atoka HST parasequences remain thick but become less defined and shaly to the west, indicating a prodelta marine environment (Fig. 70). Close to the Arbuckle uplift in the extreme southwest corner of Arkoma Basin, the upper Atoka section is composed of fining-upward parasequences developed in a fluvial environment (the Riley#2-3 well in Fig. 70). High gamma ray spikes (condensed sections) occur at the toe of several highstand parasequences where they become thinner and shaly in the central part of the Arkoma Basin (Fig. 71). This indicates a prodelta marine environment with less sediment supply in that area of the Arkoma Basin. An E-W cross section in the northern part of the Arkoma Basin shows that the thickness of the upper Atoka section changes significantly (Fig. 72). The thick highstand parasequences with several sandstone intervals in the east become very thin and merge, forming a shaly interval marked at its base by the upper Atoka TST. This TST commonly includes thin sandstones that unconformably overlie the lower Atoka sequence and the Morrowan strata in the northwestern part of the Arkoma Basin (McKee#3 and Cook#1-33 wells in Fig. 72).

The parasequence pattern for both the TST and HST of the upper Atoka section indicates that the source for sediment supply was generally from the east where the parasequences thicken and are topped by delta front sandy facies (coarsening upward pattern). The availability of substantial accommodation space, provided by the tectonic subsidence along the syndepositional faults and the formation of synclinal areas in the southeastern part of the Arkoma Basin, allowed the development of thick well-defined parasequences. On the other hand, the northwestern area was dominated by thin marine shale indicative of lack of both sediment supply and accommodation space.

The Desmoinesian Hartshorne Formation overlies the upper Atoka section. Several interpretations have been proposed for the nature of the upper boundary of the upper Atoka HST. In the eastern part of the Arkoma Basin, several drilling operators mistakenly put the top of the upper Atoka at the base of one of the highstand parasequences confusing it with the base of Hartshorne. Sutherland and Manger (1984) in their study on the boundaries of the Atoka Formation in the Arkoma Basin, mentioned that biostratigraphic information is extremely limited for the upper part of the Atoka Formation. Zachry and Sutherland (1984) stated that a pre-Desmoinesian unconformity truncates Atoka strata adjacent to the Arbuckle Mountains to the west of the Arkoma Basin, and also, along the western margin of the Ozark uplift in northeastern Oklahoma. Some workers supported the unconformable relationship between the upper Atoka and Hartshorne (Haley, 1961; Visher, 1996; Storm, 1998). Others interpreted this contact as conformable to disconformable in different parts of the Arkoma Basin (Hemish and Suneson, 1997; Andrews, 1998).

Houseknecht et al. (1983) concluded that the Atokan-Hartshorne contact is regionally conformable based on the argument that the uppermost Atokan shales are prodelta facies deposited in the Hartshorne delta system. Donica (1978) noted two thin coal beds in the upper part of the Atoka Formation in the Arkoma Basin in southeastern Oklahoma. He suggested that this Atokan section represents interdistributary bay deposits. Williams (1978) suggested that the upper part of the Atoka Formation consists of delta front or delta fringe clastics grading upward to delta-plain marsh and swamp deposits.

Two criteria were used in this work to define the nature of the upper Atoka-Hartshorne contact: 1) the presence of a conductivity marker that represents the base of the major upper parasequence of the upper Atoka HST. 2) the characteristic fining upward pattern of the Hartshorne incised-channel deposits in the southern parts of the

Arkoma Basin. Based on these two criteria, a regional unconformity between the upper Atoka HST and the Hartshorne LST is identified. Fig. (73) shows that the Hartshorne channel incises into the upper Atoka HST at different levels with respect to the underlying conductivity marker. This may explain the different interpretations of the depositional environment of the upper Atoka at the base of the Hartshorne. Where the incision is deepest, the Hartshorne is underlain by prodelta facies (McCafferty Unit#2 well in Fig. 73). Where the incision becomes shallower, the Hartshorne is underlain by shallow marine or delta-plain marsh/swamp deposits (USA Anderson-Pritchard#2 and Owens#e-1 wells in Fig. 73, also see Fig. 74). Accordingly, the Atokan/Desmoinesian contact should be cautiously defined by tracking the topmost parasequence of the upper Atoka HST to avoid including its prograding sandy facies into the Hartshorne Formation (Fig. 74). The characteristic pattern of the Hartshorne incised channel-fill, which marks the Atokan/ Desmoinesian unconformity, will be discussed in the next chapter.

Thus, in terms of sequence stratigraphy, both the middle Atoka LST and the upper Atoka section (TST and HST) can be interpreted as one third-order sequence. This middle-upper Atoka sequence is bounded by the middle Atoka unconformity at its base and the Atokan/Desmoinesian unconformity at its top.

Fig. (75) is a structure map on the top of the upper Atoka HST showing the same structural trend and features that are present on the map of the base of the upper Atoka TST. This indicates that the same tectonic conditions that prevailed throughout the late Atokan continued, at least, through early Desmoinesian time.

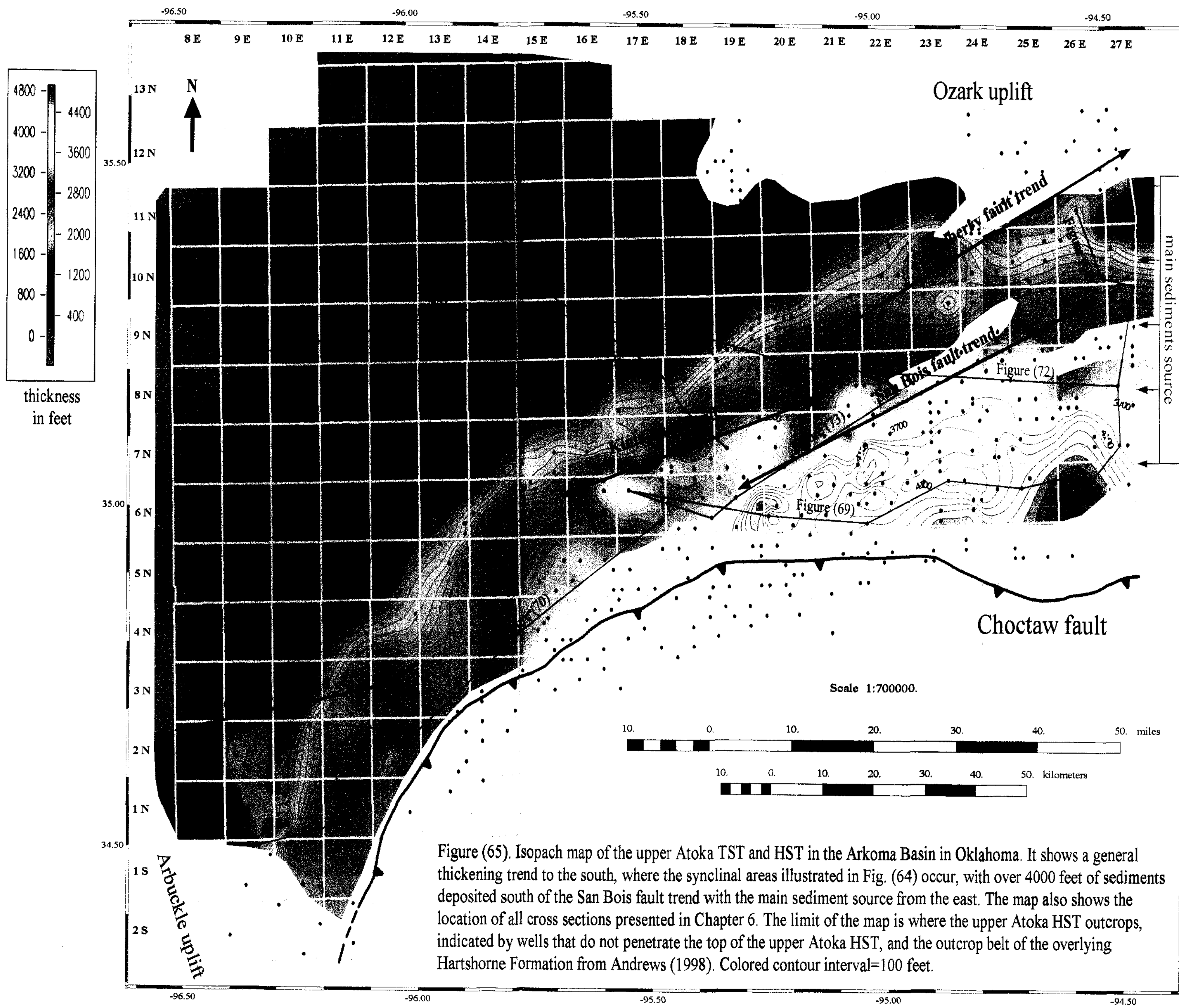

Figure (65). Isopach map of the upper Atoka TST and HST in the Arkoma Basin in Oklahoma. It shows a general thickening trend to the south, where the synclinal areas illustrated in Fig. (64) occur, with over 4000 feet of sediments deposited south of the San Bois fault trend with the main sediment source from the east. The map also shows the location of all cross sections presented in Chapter 6. The limit of the map is where the upper Atoka HST outcrops, indicated by wells that do not penetrate the top of the upper Atoka HST, and the outcrop belt of the overlying Hartshorne Formation from Andrews (1998). Colored contour interval=100 feet.

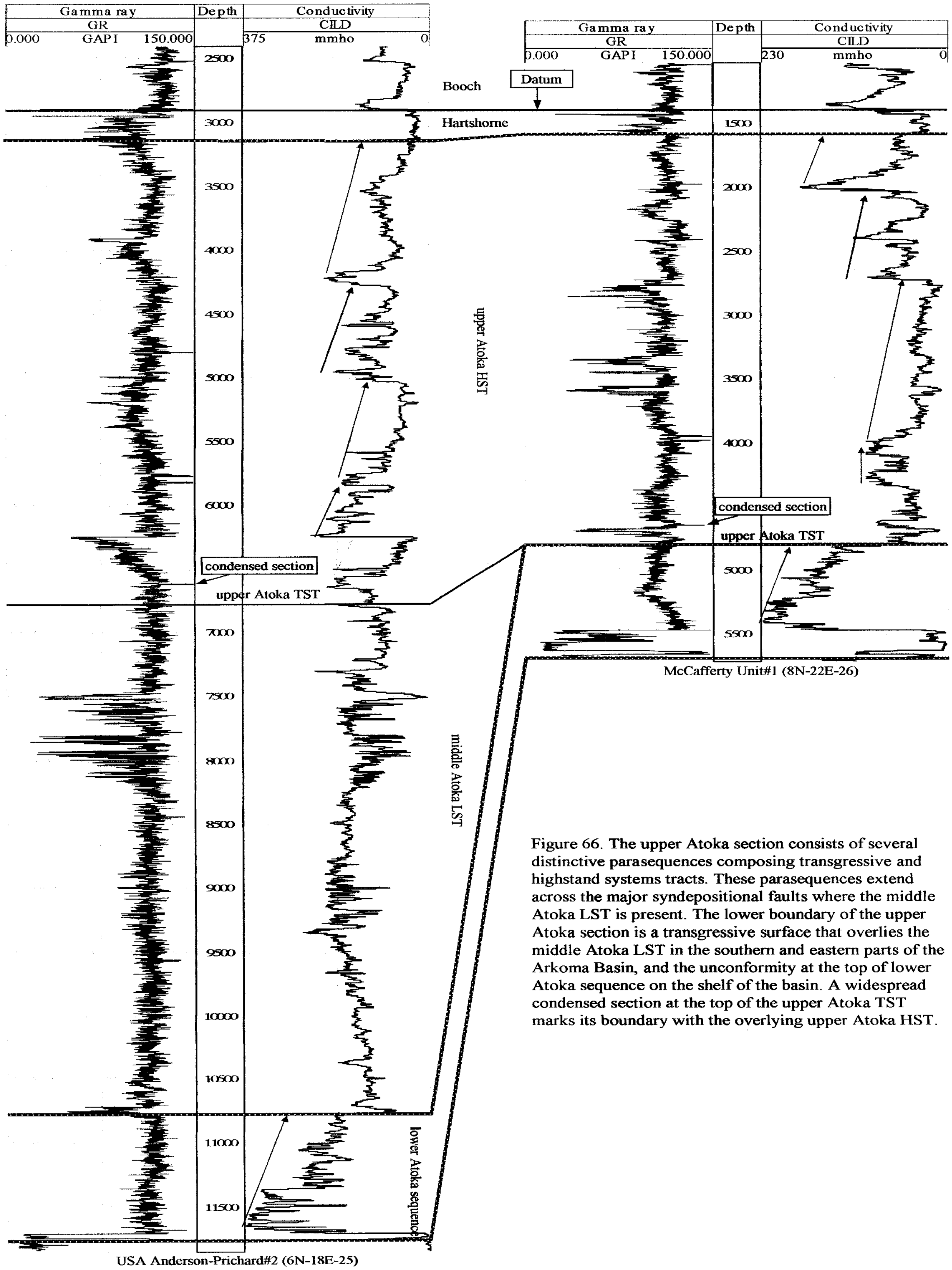

Figure 66. The upper Atoka section consists of several distinctive parasequences composing transgressive and highstand systems tracts. These parasequences extend across the major syndepositional faults where the middle Atoka LST is present. The lower boundary of the upper Atoka section is a transgressive surface that overlies the middle Atoka LST in the southern and eastern parts of the Arkoma Basin, and the unconformity at the top of lower Atoka sequence on the shelf of the basin. A widespread condensed section at the top of the upper Atoka TST marks its boundary with the overlying upper Atoka HST.

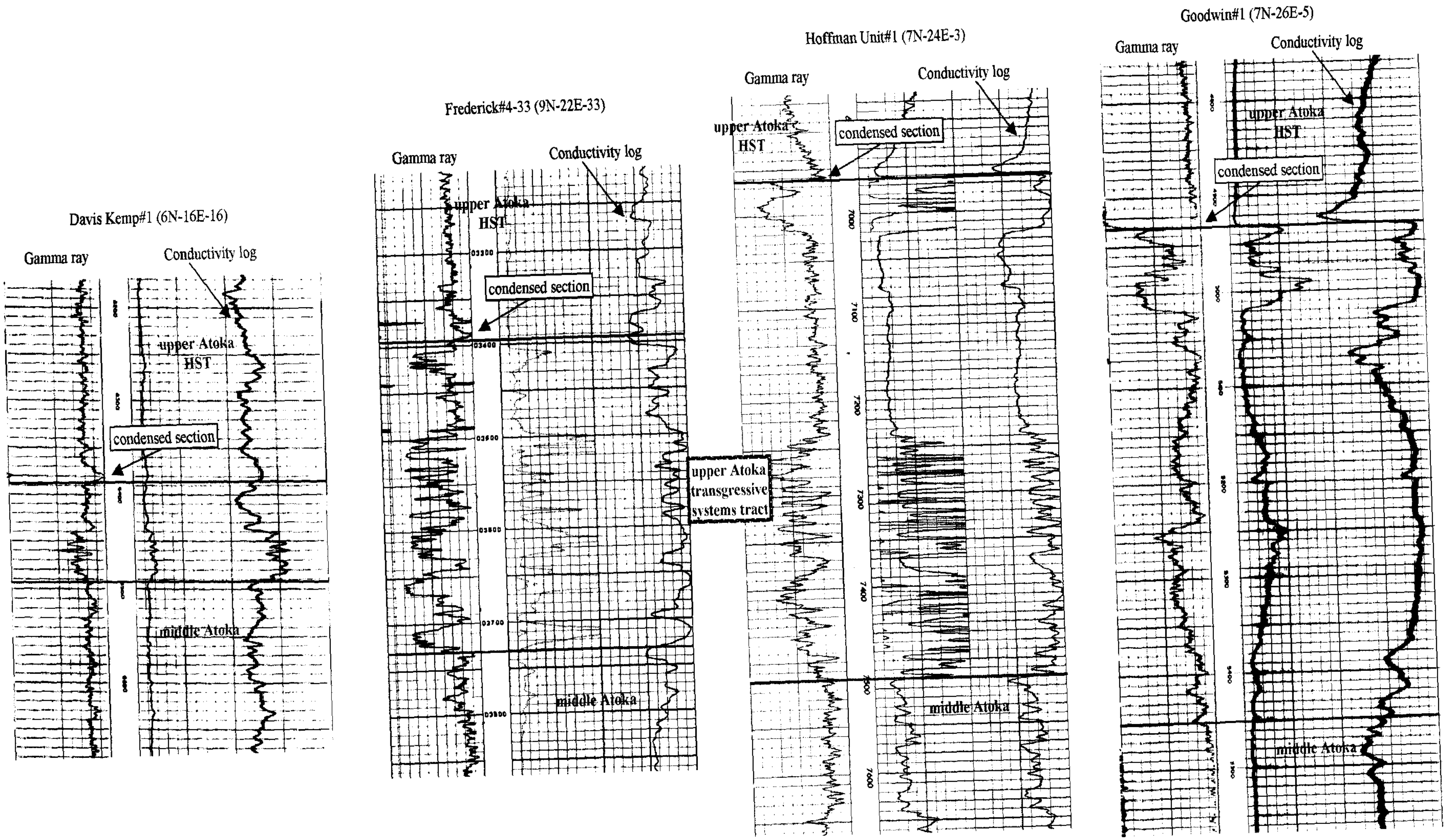

Figure 67. The transgressive systems tract of the upper Atoka section shown in four wells in the Arkoma Basin in Oklahoma overlies the middle Atoka LST in these wells. It is composed of several sandstones with blocky and coarsening upward stacking patterns in the eastern part of the Arkoma Basin (three wells on the right). To the south and west, the upper Atoka TST becomes thin and shaly (Davis Kemp#1 well). A condensed section usually marks the top of this interval. The lithostratigraphic name assigned to these sandstones is Alma.

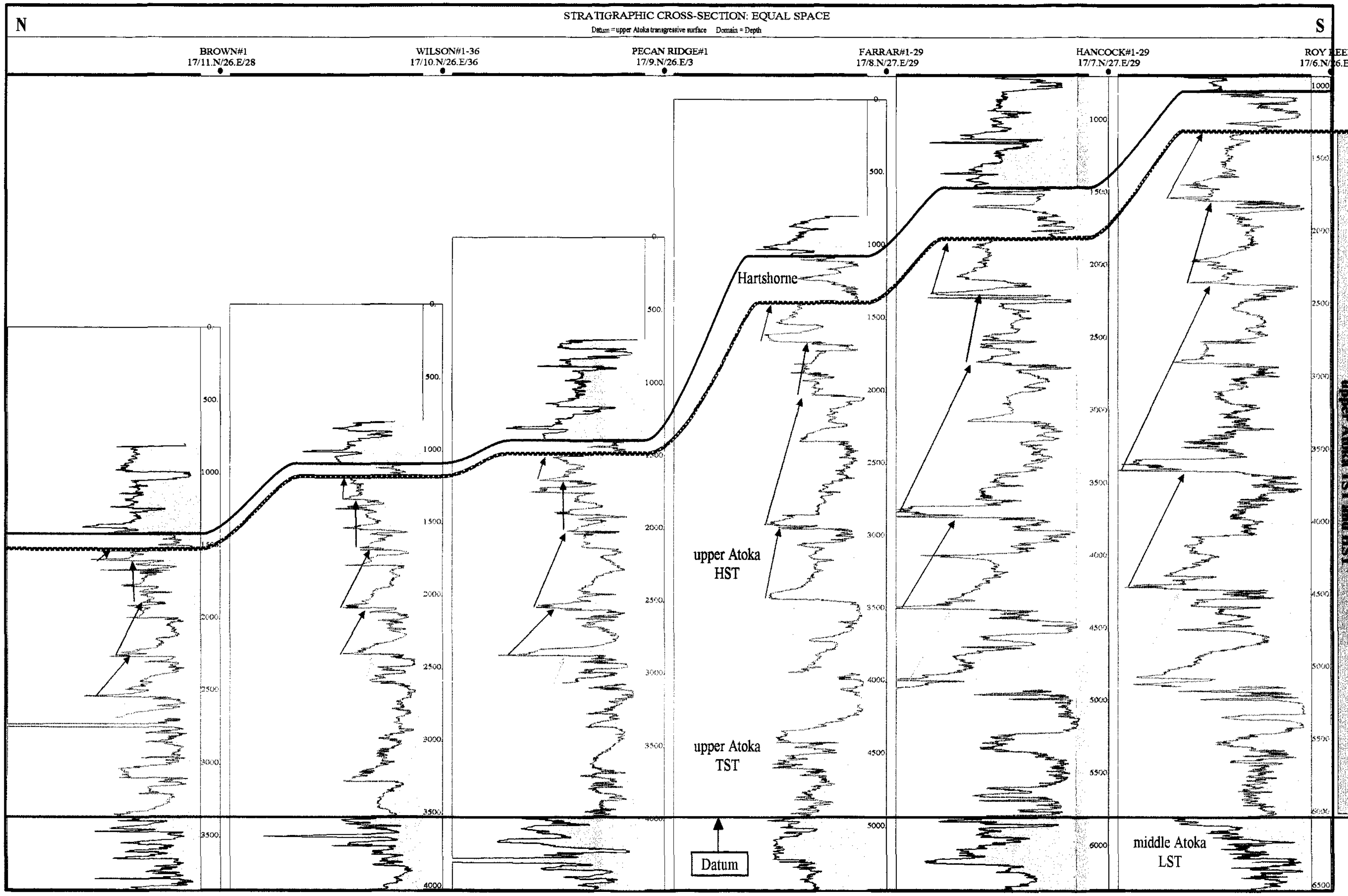

Figure 68. A N-S regional stratigraphic cross section across the eastern part of the Arkoma Basin shows that the upper Atoka TST is well-developed and thick in this part of the basin. In the south of the cross section, the upper Atoka HST is composed of at least five thick aggradational parasequences. These parasequences thin to the north but remain distinguishable with sandstone intervals at top of several of them. The cross section datum is the upper Atoka transgressive surface. For location, see Fig. (65).

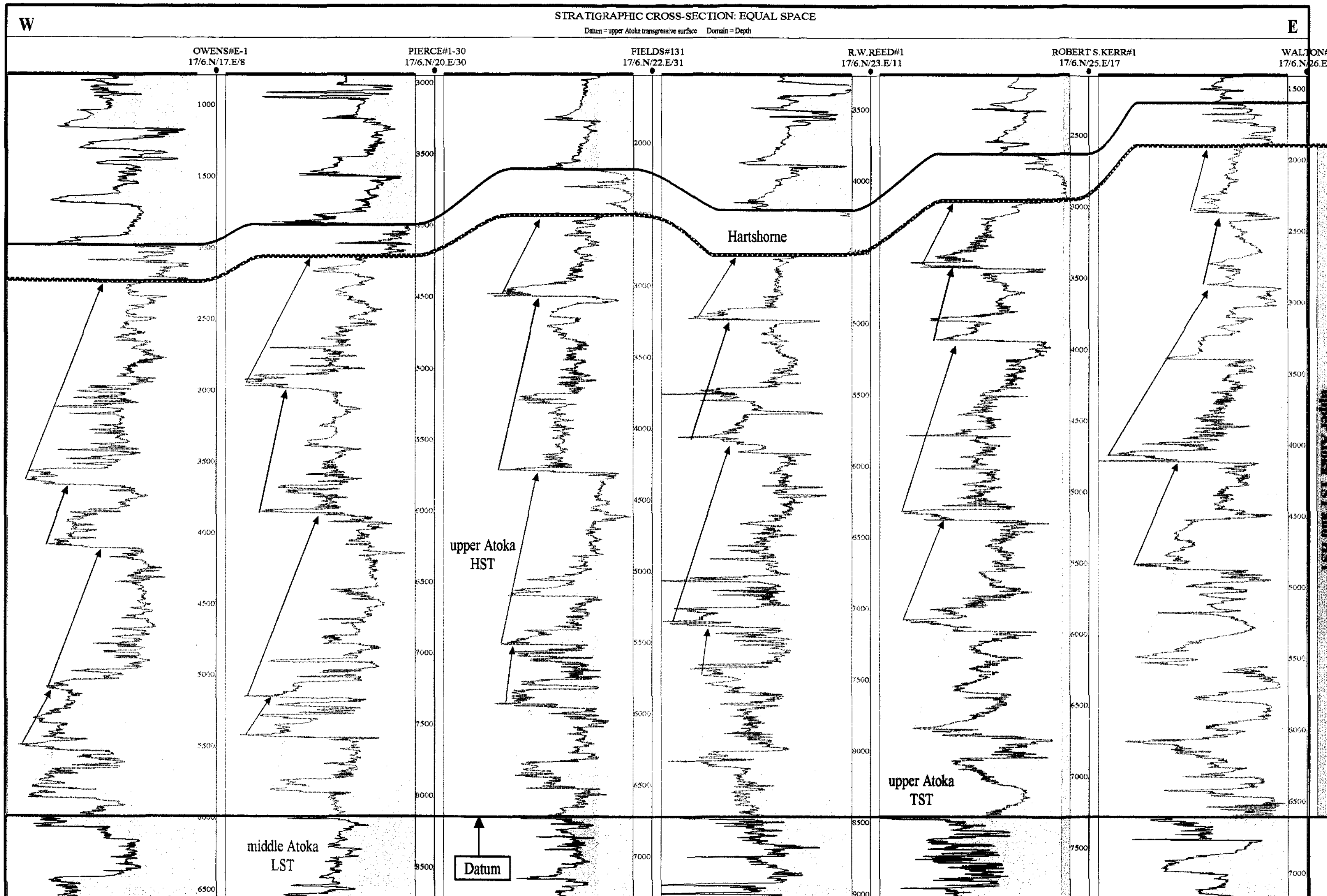

Figure 69. An E-W regional stratigraphic cross section in the southeastern part of the Arkoma Basin showing that the upper Atoka TST becomes thicker toward the east (over 1000 feet in Walton#1-8 well). It thins significantly and become shaly to the west where it is capped by condensed section marking the maximum flooding surface. The upper Atoka HST is best developed in this part of the Arkoma basin, where it is composed of well-defined and thick parasequences that extend for long distance along the southern margin of the basin (the cross section length is over 50 miles). The cross section datum is the upper Atoka transgressive surface. For location, see Fig. (65).

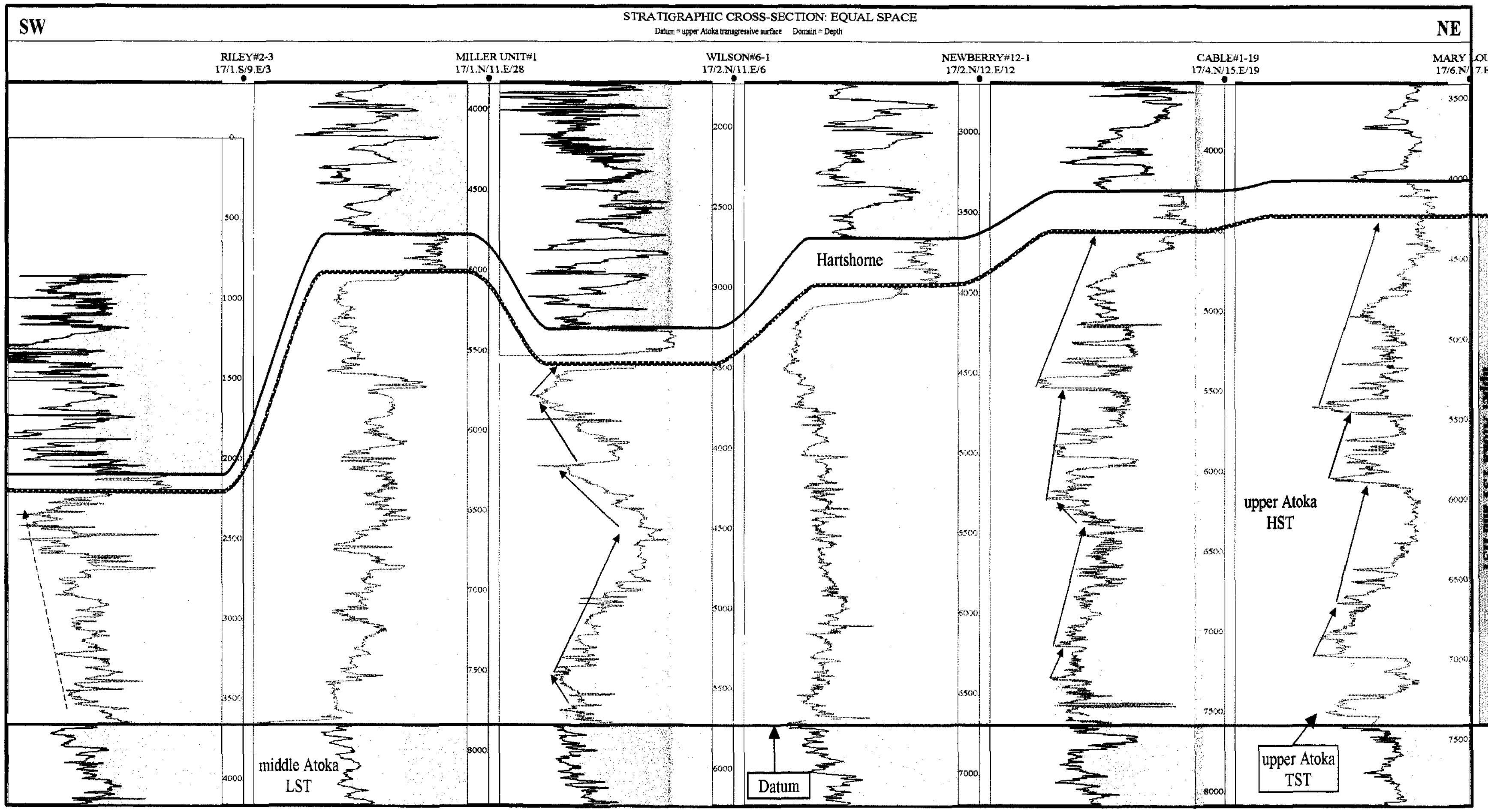

Figure 70. A NE-SW regional stratigraphic cross section along the southwestern margin of the Arkoma Basin showing that the upper Atoka HST parasequences remain thick but become less defined and shaly to the west, indicating prodelta marine environment. Close to the Arbuckle uplift in the extreme southwest corner of the Arkoma Basin, the upper Atoka section is composed of fining-upward parasequences developed in fluvial environment (Riley#2-3 well). The cross section datum is the upper Atoka transgressive surface. For location, see Fig. (65).

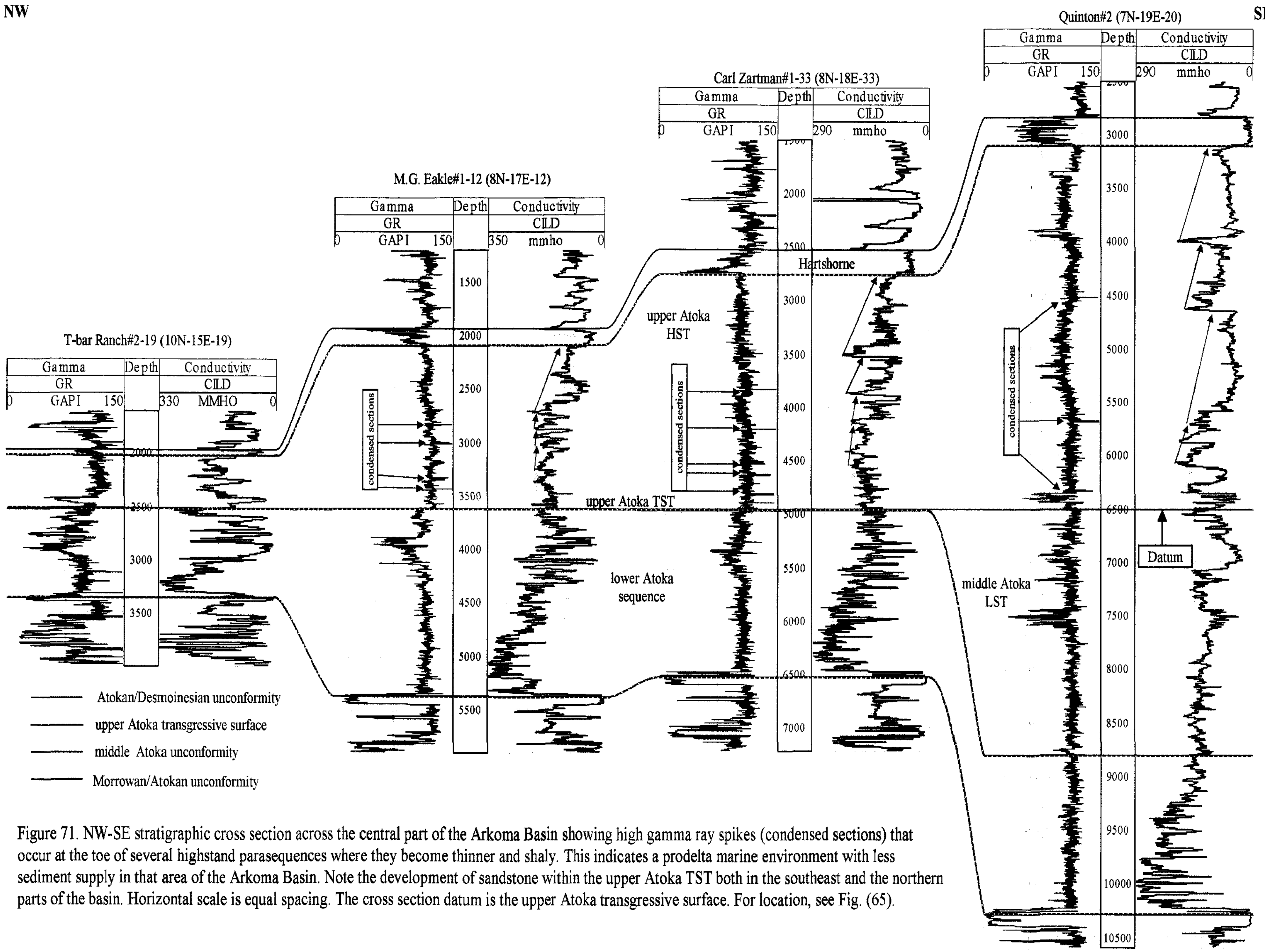

Figure 71. NW-SE stratigraphic cross section across the central part of the Arkoma Basin showing high gamma ray spikes (condensed sections) that occur at the toe of several highstand parasequences where they become thinner and shaly. This indicates a prodelta marine environment with less sediment supply in that area of the Arkoma Basin. Note the development of sandstone within the upper Atoka TST both in the southeast and the northern parts of the basin. Horizontal scale is equal spacing. The cross section datum is the upper Atoka transgressive surface. For location, see Fig. (65).

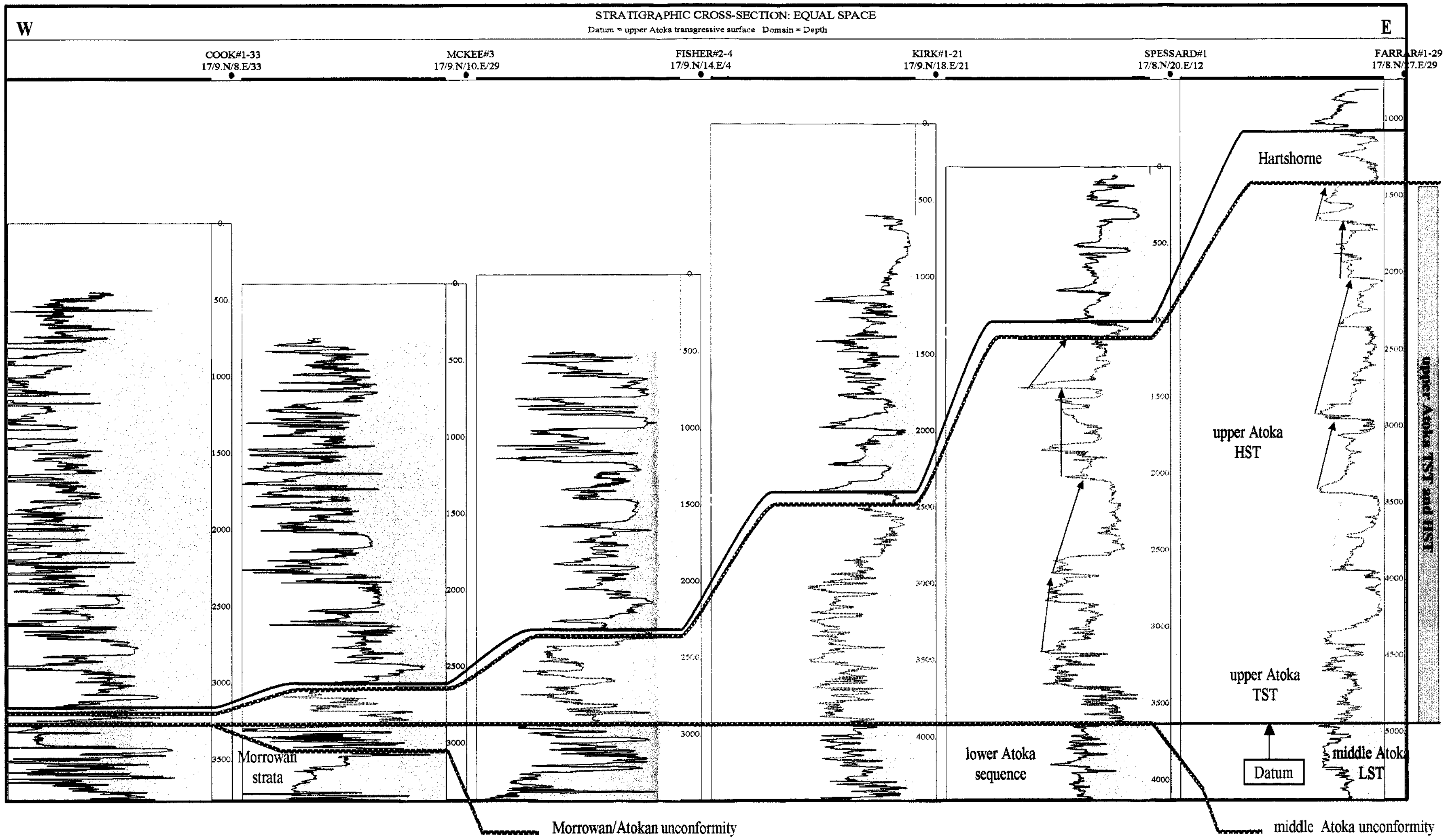

Figure 72. An E-W regional stratigraphic cross section showing that the thickness of the upper Atoka section changes significantly across the northern part of the Arkoma Basin. The highstand parasequences with several sandstone intervals in the east become very thin and merge together forming a shaly interval marked at its base by the upper Atoka TST. This TST usually includes thin sandstones that unconformably overlie the lower Atoka sequence (McKee#3 well), and the Morrowan starta (Cook#1-33 well) in the northwestern part of the Arkoma Basin The cross section datum is the upper Atoka transgressive surface. For location, see Fig. (65).

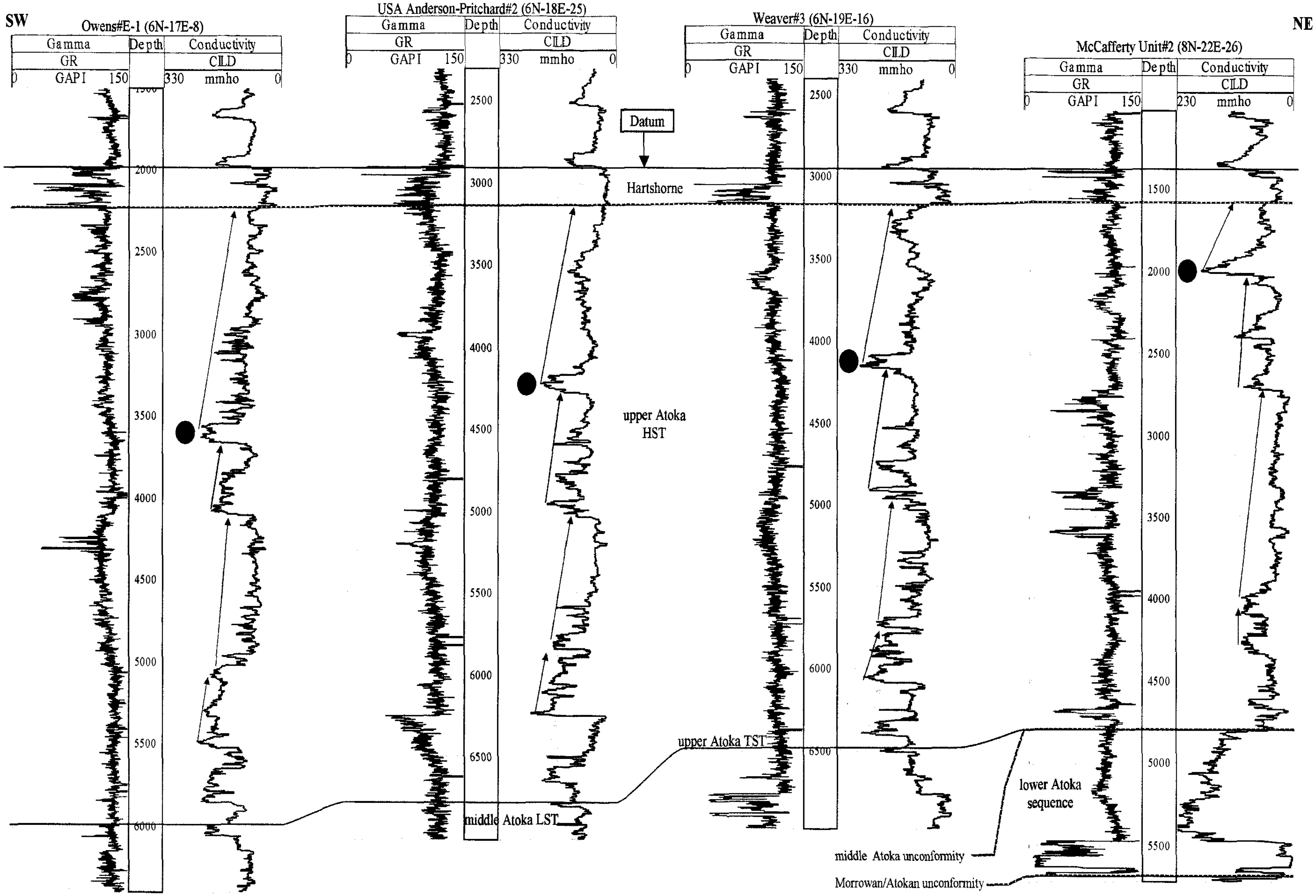

Figure 73. NE-SW stratigraphic cross section in the southern part of the Arkoma Basin. Note the conductivity marker at the base of the topmost parasequence of the upper Atoka HST (green circle). Tracking this marker helps in defining the nature of the upper Atoka-Hartshorne contact as an unconformity surface. It shows how the Hartshorne channel incises into the upper Atoka HST at different levels with respect to this underlying conductivity marker. Where the incision is deepest, the Hartshorne is underlain by prodelta facies (McCafferty Unit#2 well). Where the incision becomes shallower, the Hartshorne is underlain by shallow marine or delta-plain marsh/swamp deposits (USA Anderson-Pritchard#2 and Owens#e-1 wells). The cross section datum is top of Hartshorne Formation. Horizontal scale is equal spacing. For location, see Fig. (65).

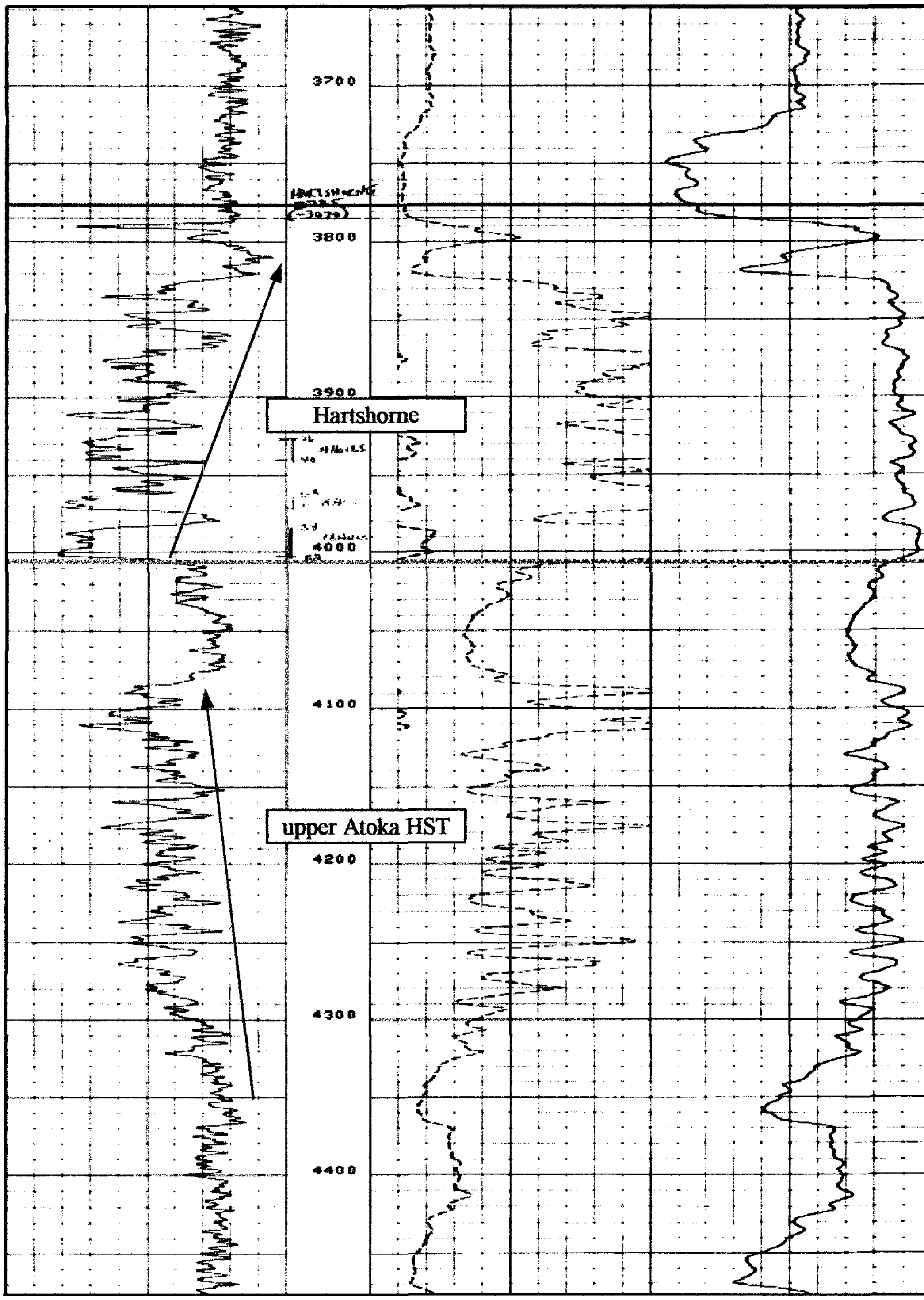

Figure 74. An example from Rouse#1 well (6N-15E-23) showing the clear distinction between the top parasequence of the upper Atoka HST and the Hartshorne Formation. The upper Atoka parasequence shows a coarsening-upward pattern, while the Hartshorne Formation shows a fining upward pattern. In wells where the Hartshorne channels incise deep into the upper Atoka HST, the sandy facies of the upper Atoka parasequence were mistakenly included into the Hartshorne Formation.

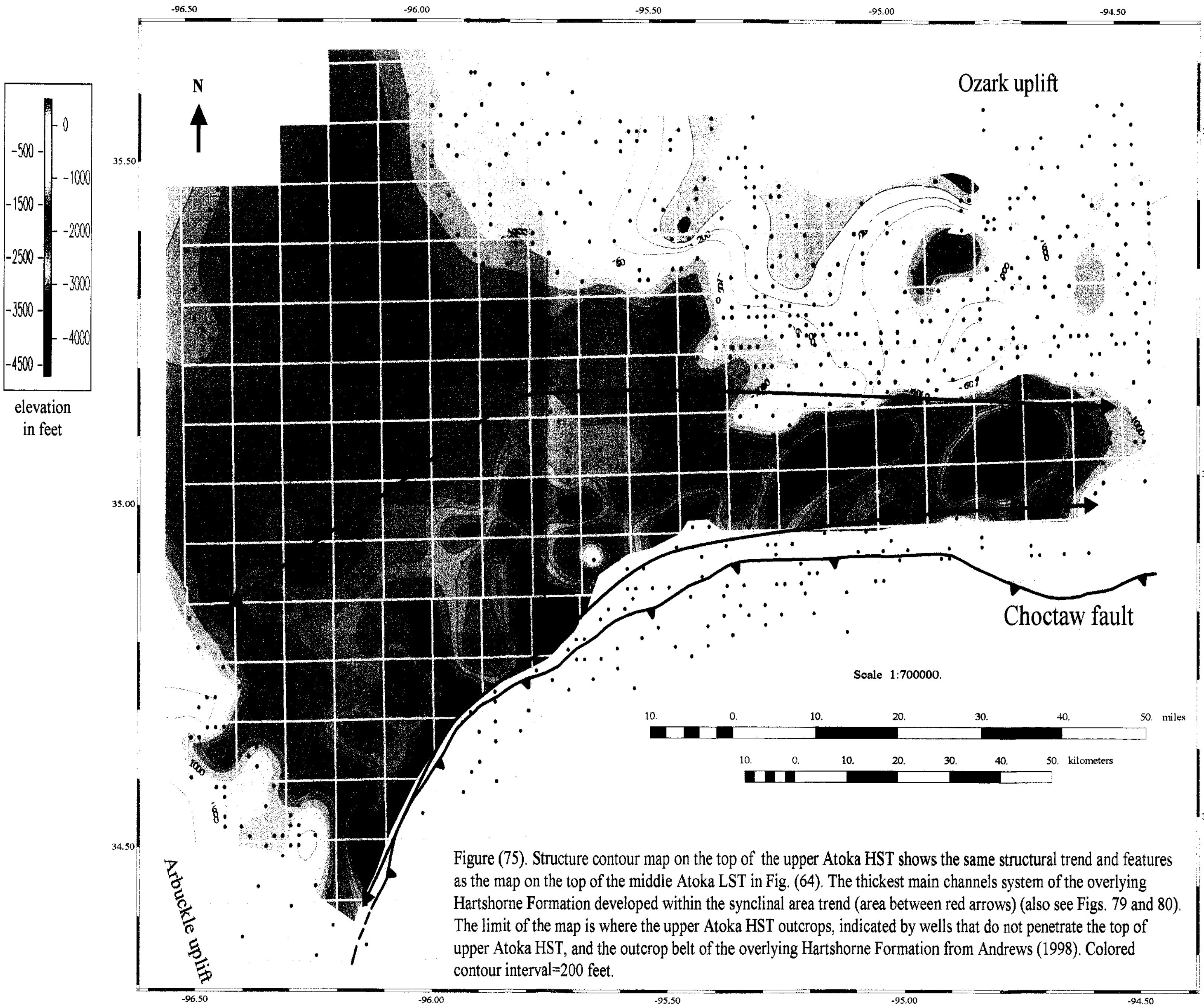

Figure (75). Structure contour map on the top of the upper Atoka HST shows the same structural trend and features as the map on the top of the middle Atoka LST in Fig. (64). The thickest main channels system of the overlying Hartshorne Formation developed within the synclinal area trend (area between red arrows) (also see Figs. 79 and 80). The limit of the map is where the upper Atoka HST outcrops, indicated by wells that do not penetrate the top of upper Atoka HST, and the outcrop belt of the overlying Hartshorne Formation from Andrews (1998). Colored contour interval=200 feet.

CHAPTER 7

HARTSHORNE-BOOCH

The Hartshorne and Booch intervals represent the lower part of the Desmoinesian Krebs group (Fig. 76). Both intervals have been extensively studied, in outcrops and shallow wells, because of their economic significance for gas production and coal mining. The base of the Hartshorne Formation is considered in this study to overlie an angular unconformity where channels incised into the upper Atoka HST at progressively deeper levels to the north and east. Mainly fluvial deposits filled these channels during early Desmoinesian time. The log pattern of the Hartshorne channels is typical of the fluvial incised valley-fill deposits of a lowstand systems tract (Fig. 77). Fig. (78) shows the characteristic fining-upward log pattern of the Hartshorne interval in selected wells drilled in the Arkoma Basin in Oklahoma. The filling of the Hartshorne channels may be interpreted as flood-capped valley-fill. The evolution of such valley fills starts with a slow rise in sea level with the prevalence of fluvial deposition and ends by transgressive marine flooding (Willis, 1997).

Andrews (1998) was the first to recognize the Hartshorne channels as incised-valley fills instead of distributary channels of prograding deltas as interpreted by Houseknecht et al. (1983). But his interpretation was that these channels incised into older Hartshorne delta front sandstones, not the upper Atoka section. The main channel system trends E-W, where most of the thick sandstone and coal intervals were developed (Fig. 79). Several workers suggested an eastern source area for the sediments filling these channels such as Houseknecht et al. (1983) and Andrews (1998). A first-derivative map for the thickness of the Hartshorne interval shows a change in the gradient where the thickest channel system occurs in the southern part of the Arkoma Basin in an E-W trend parallel to the thrust belt (Fig. 80). The incised-valley fill followed the same structural trend shown on the top of the upper Atoka structure map (areas between red arrows in Fig. 75), where greater accommodation space was available. The thickest Hartshorne interval in this area is between 350-400 feet. It should be noted that this general trend for the thickest Hartshorne channels does not necessarily mean that thick sandstones are always found in these channels. Fig. (81) is an example from two wells drilled in the same section within a half-mile from each other, indicating the high variability of the development of sandstone within the Hartshorne channels.

Lithostratigraphically, the Hartshorne Formation is divided into lower and upper members; each is capped by a coal bed in the southern part of the Arkoma Basin (Oaks and Knechtel, 1948; Hemish and Suneson, 1997; Suneson, 1998; Andrews, 1998) (Fig. 82). To the northwest, the upper Hartshorne member pinches out, and these two coal beds coalesce to form one coal bed (Houseknecht et al. 1983; Hemish and Suneson, 1997; Suneson, 1998; Andrews, 1998). A coal-split line has been mapped by Andrews (1998) to define the areas of either one or two coal beds in the Arkoma Basin in Oklahoma. In this study, more than two coal beds were encountered in several wells drilled in the southern part of the Arkoma Basin, which supports the findings of Donica (1978) and Rieke and Kirr (1984). Detailed correlations of the Hartshorne Formation did not provide evidence for the merging or splitting of coal beds across the coal-split line. It is more likely that the lower coal bed pinched out or was eroded prior to the deposition of the overlying upper channel of the Hartshorne Formation. The widespread nature of the coal beds capping the fluvial channels may indicate peat deposition after the filling of these channels with fluvial sediments.

The Hartshorne interval is recognized in this study based on the characteristic low-conductivity and fining-upward gamma ray log patterns (Fig. 78). It was divided into three units where the thickest Hartshorne channel system occurs in the southern part of the Arkoma Basin (Fig. 83). As further explained below, the lower two units represent a lowstand systems tract, which is equivalent to the lithostratigraphic upper and lower Hartshorne members. The upper much thinner unit is a transgressive systems tract capped by a MFS. This genetically related package in terms of sequence stratigraphy, is sometimes hard to divide where it becomes silty or shaly, yet it maintains an overall characteristic log pattern of low conductivity values (Fig. 84).

The Hartshorne LST is composed of two fining upward channels and their equivalent splay/overbank deposits (Figs. 83 and 85). These channels were locally the sites of continuous deposition as the two channels can not be separated (Fig. 84). Yet, it seems that these channels do not follow exactly the same axis. This is indicated by the switching and variability of thick sandstone deposition between the channels (Fig. 85). The lower channel is generally confined to the south (Fig. 86). The upper channel extends into the northeastern part of the Arkoma Basin forming an E-W trending channel beyond the northern limit of the thick channel deposits defined by Andrews (1998) (Fig. 87).

The Hartshorne transgressive systems tract is the unnamed siltstone recognized by Andrews (1998) as the lowermost part of the McAlester Formation in the southern part of Arkoma Basin. This silty and/or sandy unit usually underlies a condensed section and is the only Hartshorne interval that extends in the northwestern part of the Arkoma Basin outside the channel system areas (Fig. 87). Despite its thinness, it represents the most widespread unit of the Hartshorne interval and in many cases it shows indication of marine environment (coarsening upward pattern) (Figs. 83 and 88). A condensed section marks the maximum flooding surface (MFS). This condensed section is easily recognized on the gamma ray log as a hot shale marker at the top of the Hartshorne interval especially in the western part of the Arkoma Basin (Figs. 84 and 88). The occurrence of condensed sections to the west indicates a very low rate of sediment supply. This supports the interpretation of an eastern source for sediments during the deposition of the Hartshorne Formation.

The Booch interval in the Arkoma Basin is the informal subsurface equivalent of surface exposures formally named the McAlester Formation (Fig. 76). Based on the faunal content and the lithologic characteristics of the shale in this formation, Karvelot (1973) suggested that its depositional environment is dominantly shallow marine, and secondarily, prodelta, interdistributary, marsh and swamp. Busch (1971 and 1974) identified this interval as " the Booch delta" in his work in the northwestern part of the Arkoma Basin.

The McAlester Formation is divided into six members based on the number of sandstone intervals within the formation. In the subsurface, some of these sandstones merge, and as a result, the Booch interval is lithostratigraphically divided into three units: lower, middle, and upper. In this study, the Booch interval is divided into four coarsening-upward parasequences that can be further subdivided. This is demonstrated in two cross sections running E-W and N-S (Figs. 89 and 90 respectively). The upper two parasequences are equivalent to the upper Booch lithostratigraphic unit.

The Booch HST is thicker in the southern part of the Arkoma Basin, where the greatest accommodation space was available (Fig. 90). This may indicate that the areas south of the major syndepositional faults continued subsiding throughout the early Desmoinesian as a result of the northward advance of the Ouachita thrust belt. Unlike the easterly source for the Hartshorne interval, the Booch deltas were generally sourced from the north (Busch 1974; Sutherland, 1988; Johnson et al., 1989). Major distributary channels of the Booch prograding deltas show a general N-S trend in the northern part of the Arkoma Basin (Fig. 91). In the northwest, these channels are thick as shown in Fig. (92a), where a middle Booch distributary channel cuts into the underlying upper Atoka section.

The aggradational to progradational Booch parasequences constitute the highstand systems tract above the Hartshorne LST and TST. The lower surface of this HST is the condensed section at the top of the Hartshorne interval (Fig. 92b). The upper surface is more likely an unconformity (paraconformity) surface (Hendricks, 1937; Hemish and

Suneson, 1997), where the Spaniard Limestone Member of the Savanna Formation overlies the McAlester Formation to the north of the Arkoma Basin (Fig. 76). In terms of sequence stratigraphy, the Hartshorne LST and TST, and the Booch HST would represent a third-order sequence. This lower Desmoinesian sequence is bounded by the Atokan/Desmoinesian unconformity at its base and the Booch/Savanna unconformity at its top. All cross section locations in this chapter are shown in Fig. (80).

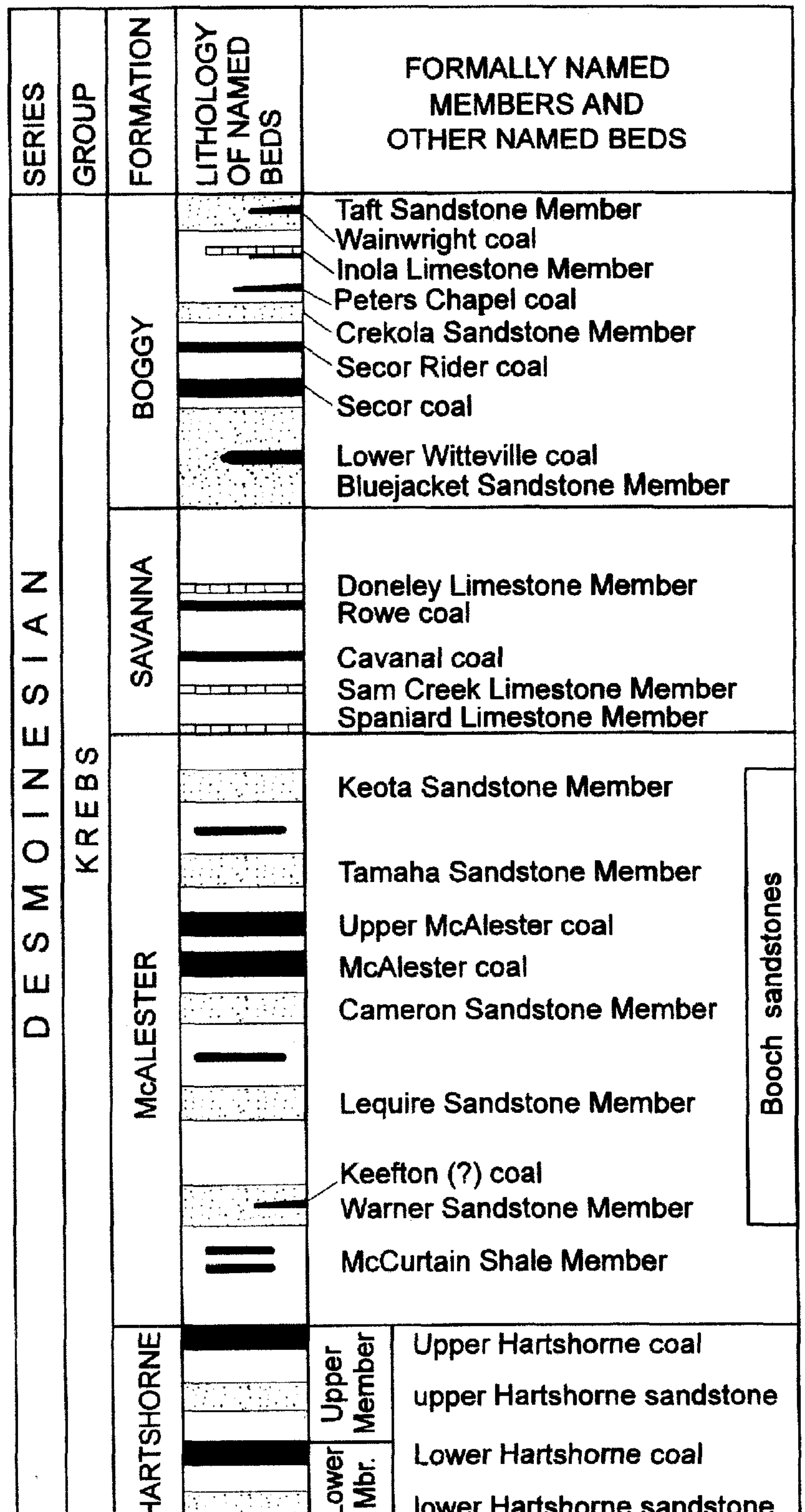

Figure 76. Generalized stratigraphic column of the Krebs Group in the Arkoma Basin and adjacent areas in Oklahoma showing the relative position of the formally named members, names of coal beds, and informal subsurface names (after Hemish and Suneson, 1997). Note the abundance of coal beds in the section.

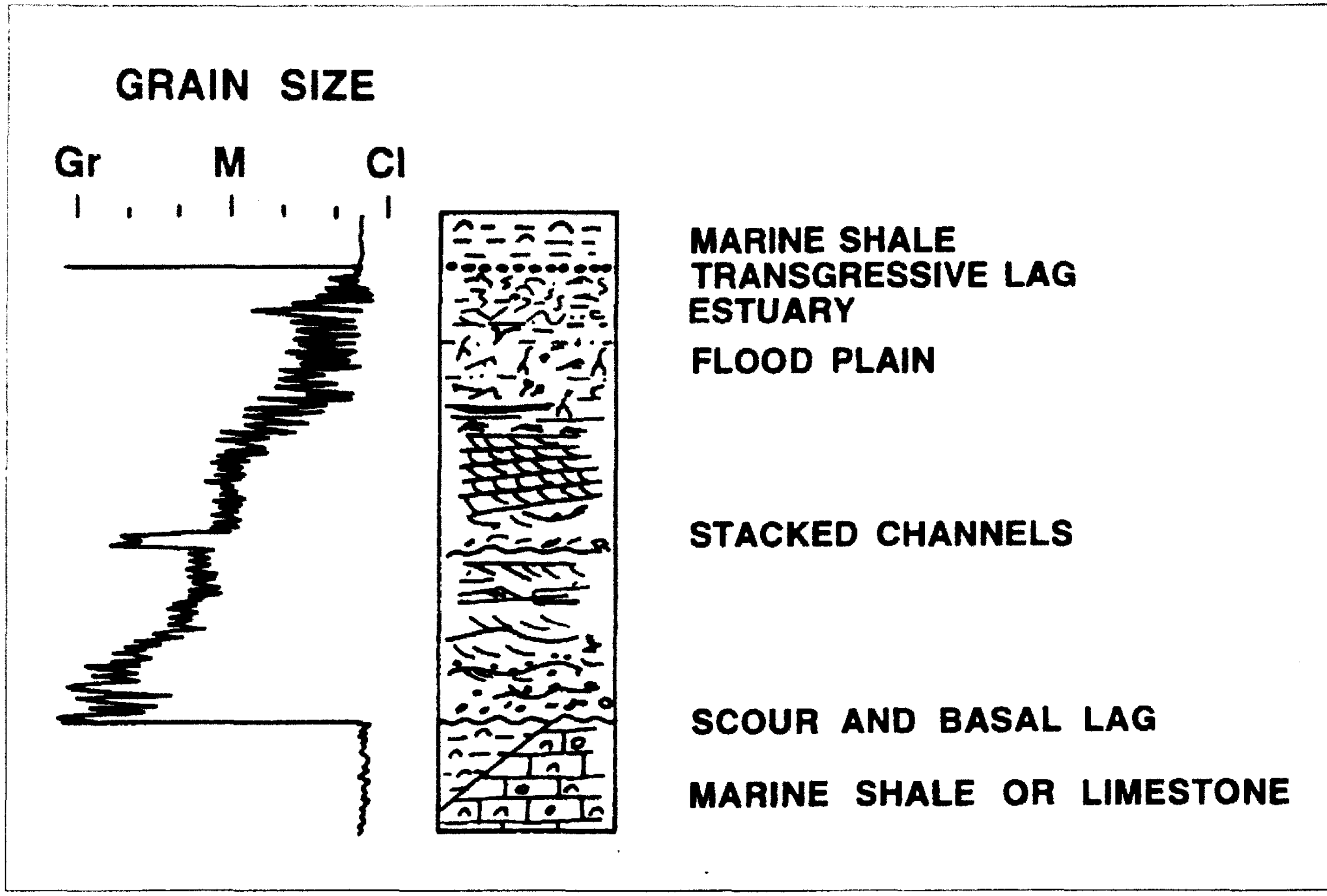

Figure 77. Typical vertical profile through a valley-fill deposit (after Krystinik and Blakeney, 1990). This fining-upward stacking pattern compares to that of the Hartshorne Formation in Figs. (78, 81, and 84).

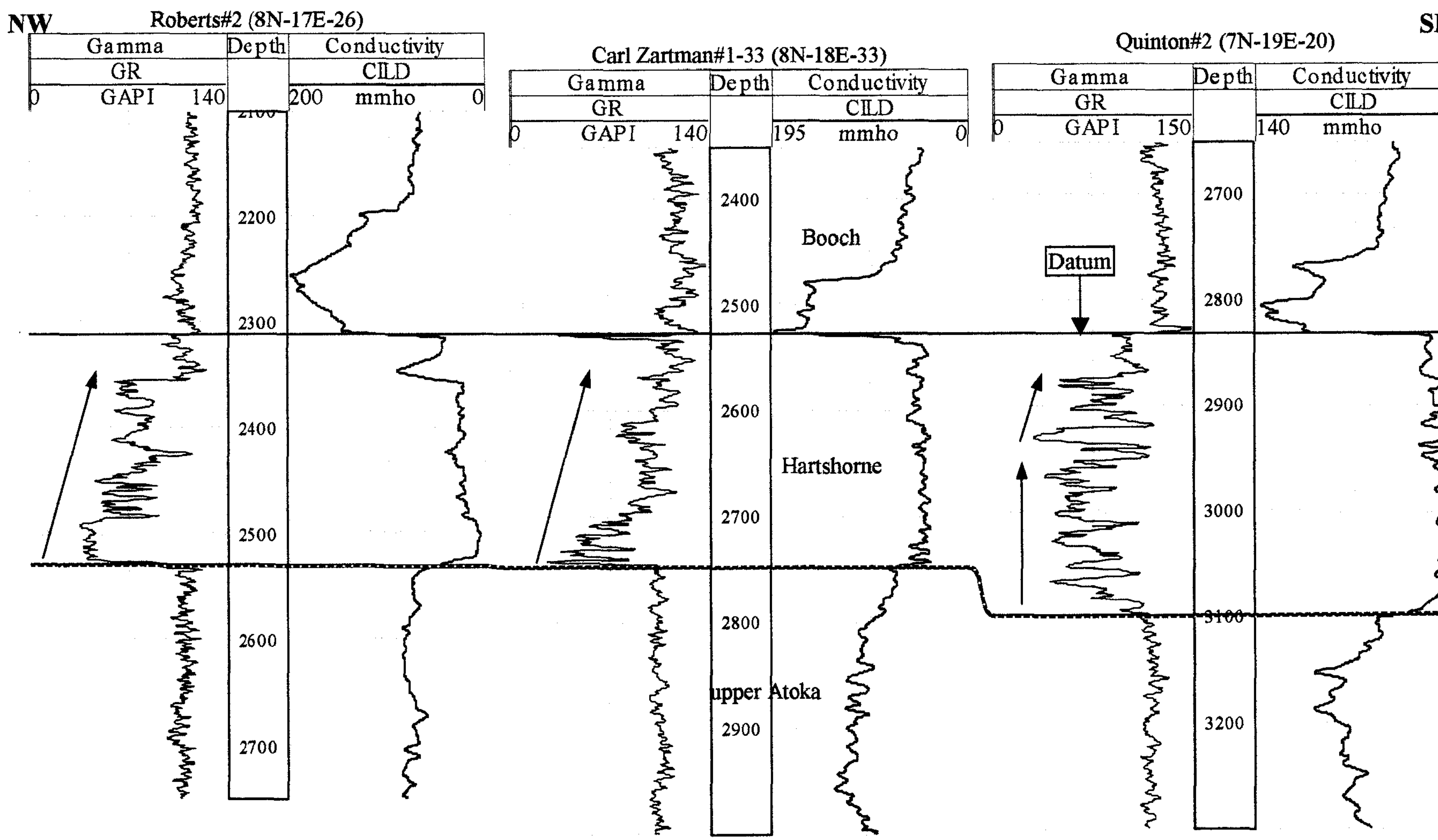

Figure 78. NW-SE stratigraphic cross section for the Hartshorne Formation showing its characteristic low conductivity pattern, and a fining upward pattern on the gamma ray log. Datum is the Hartshorne top. Horizontal scale is equal spacing. For location, see Fig. (80)

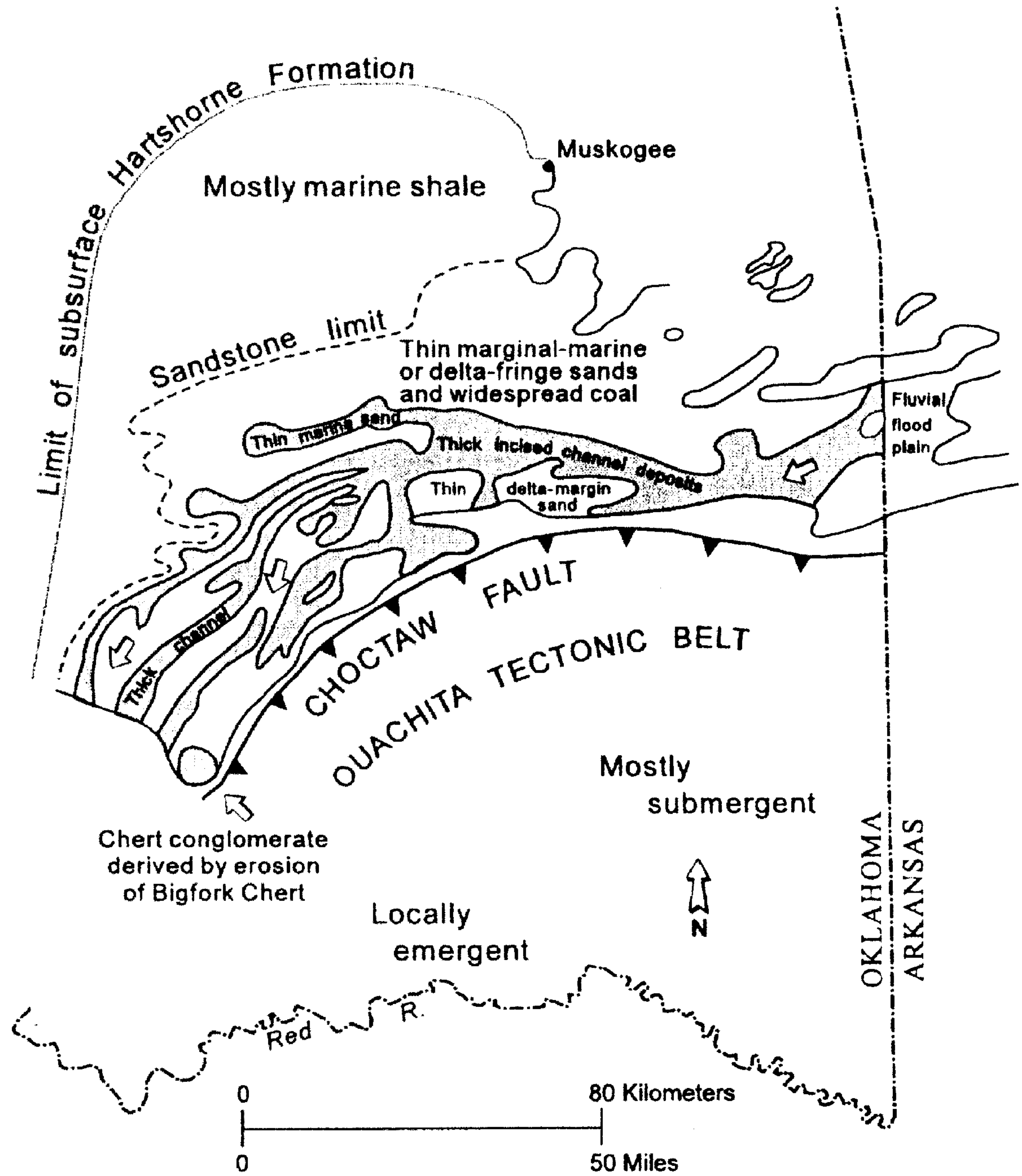

Figure 79. Generalized distribution and depositional environment of the Hartshorne Formation in southeastern Oklahoma (after Andrews, 1998). Note the correlation between the thick channels system trend in this map and the synclinal-areas trend (area between red arrows in Fig. 75).

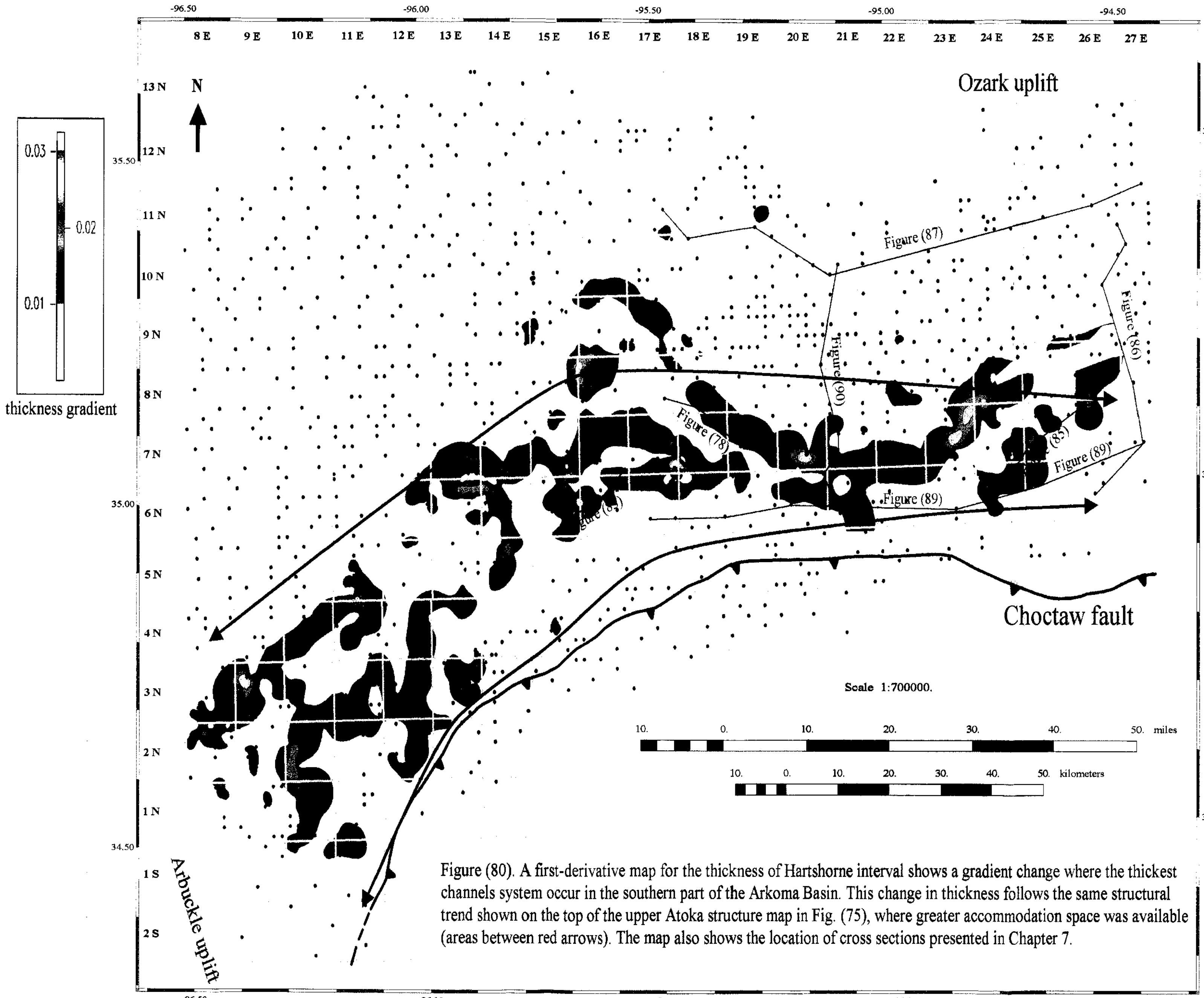

Figure (80). A first-derivative map for the thickness of Hartshorne interval shows a gradient change where the thickest channels system occur in the southern part of the Arkoma Basin. This change in thickness follows the same structural trend shown on the top of the upper Atoka structure map in Fig. (75), where greater accommodation space was available (areas between red arrows). The map also shows the location of cross sections presented in Chapter 7.

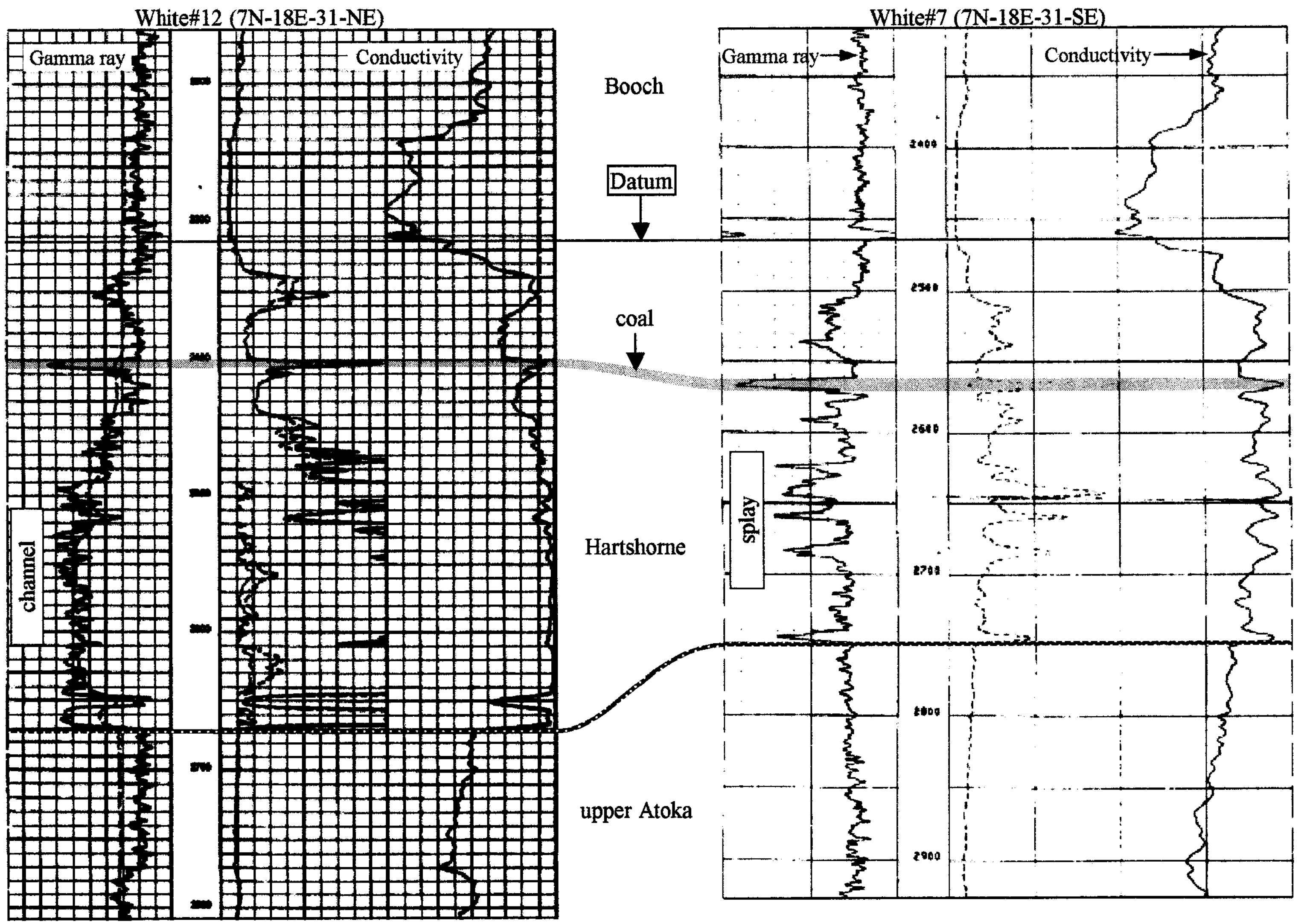

Figure 81. Two wells drilled in the same section (about a half-mile apart) showing the high variability of the development of sandstone in the Hartshorne interval. Datum is the Hartshorne top.

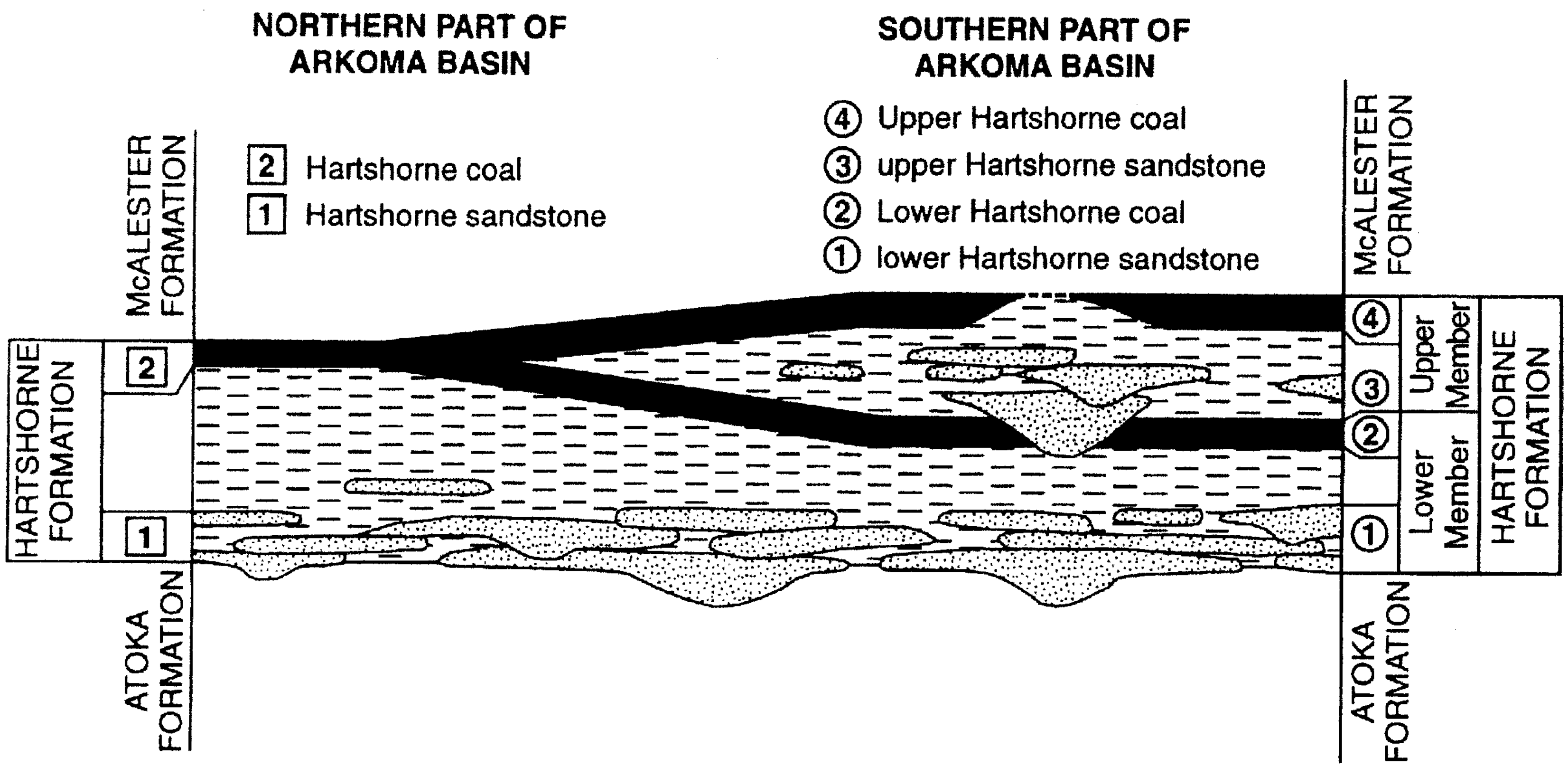

Figure 82. Lithostratigraphic divisions of the Hartshorne Formation in the Arkoma Basin in Oklahoma. The formation is divided into upper and lower members. Each is capped by a coal bed in the southern part of the basin. To the northwest, the two coal beds merge or the upper member of the Hartshorne Formation appears to pinch out (after Hemish and Suneson, 1997).

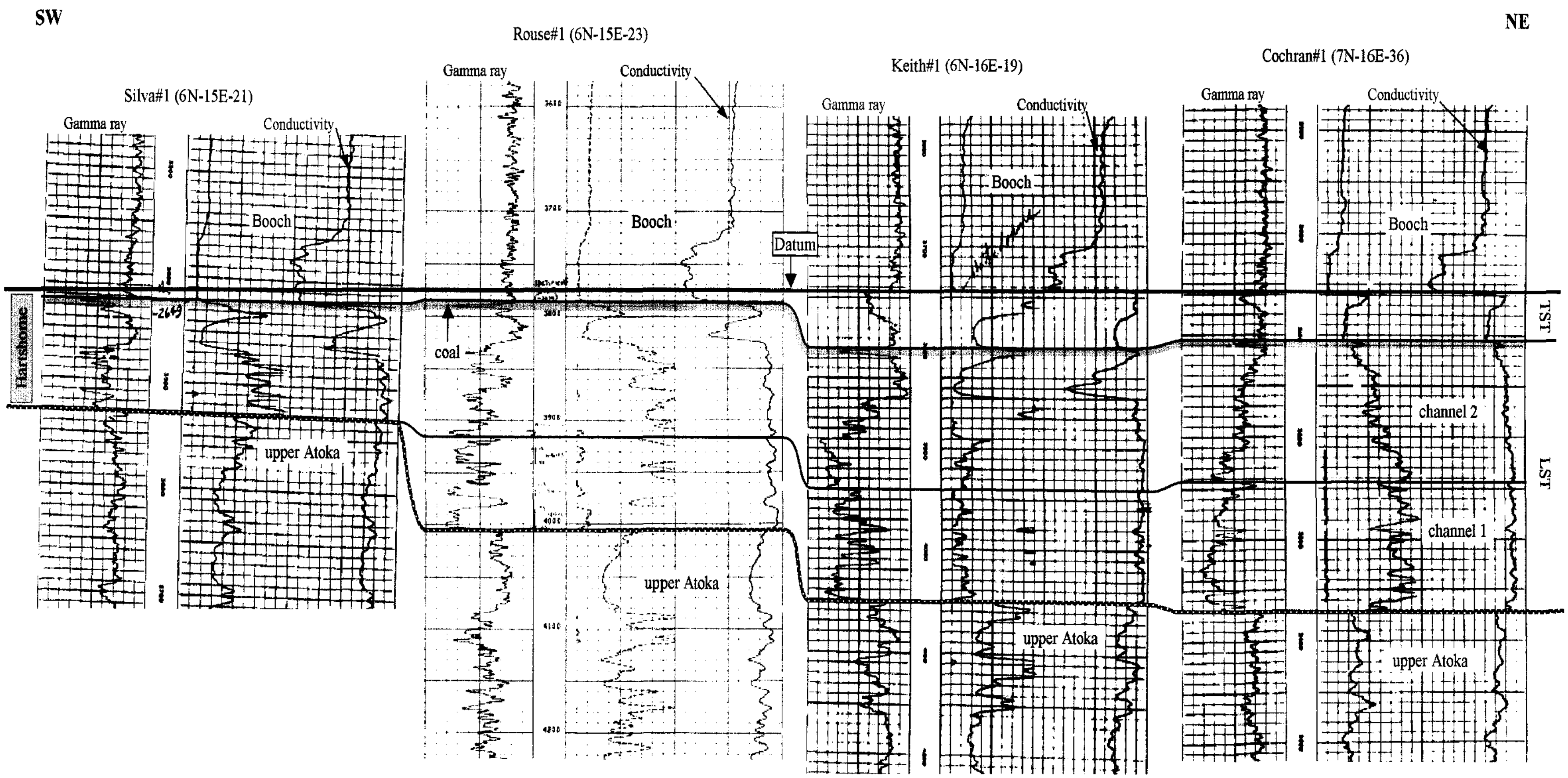

Figure 83. NE-SW stratigraphic cross section in the central part of the Arkoma Basin. The Hartshorne Formation is divided into a LST and a TST. The LST is composed of two fining upward channels. The TST is a thin sandy/shaly unit. The cross section datum is top of Hartshorne TST. Horizontal scale is equal spacing. For location, see Fig. (80).

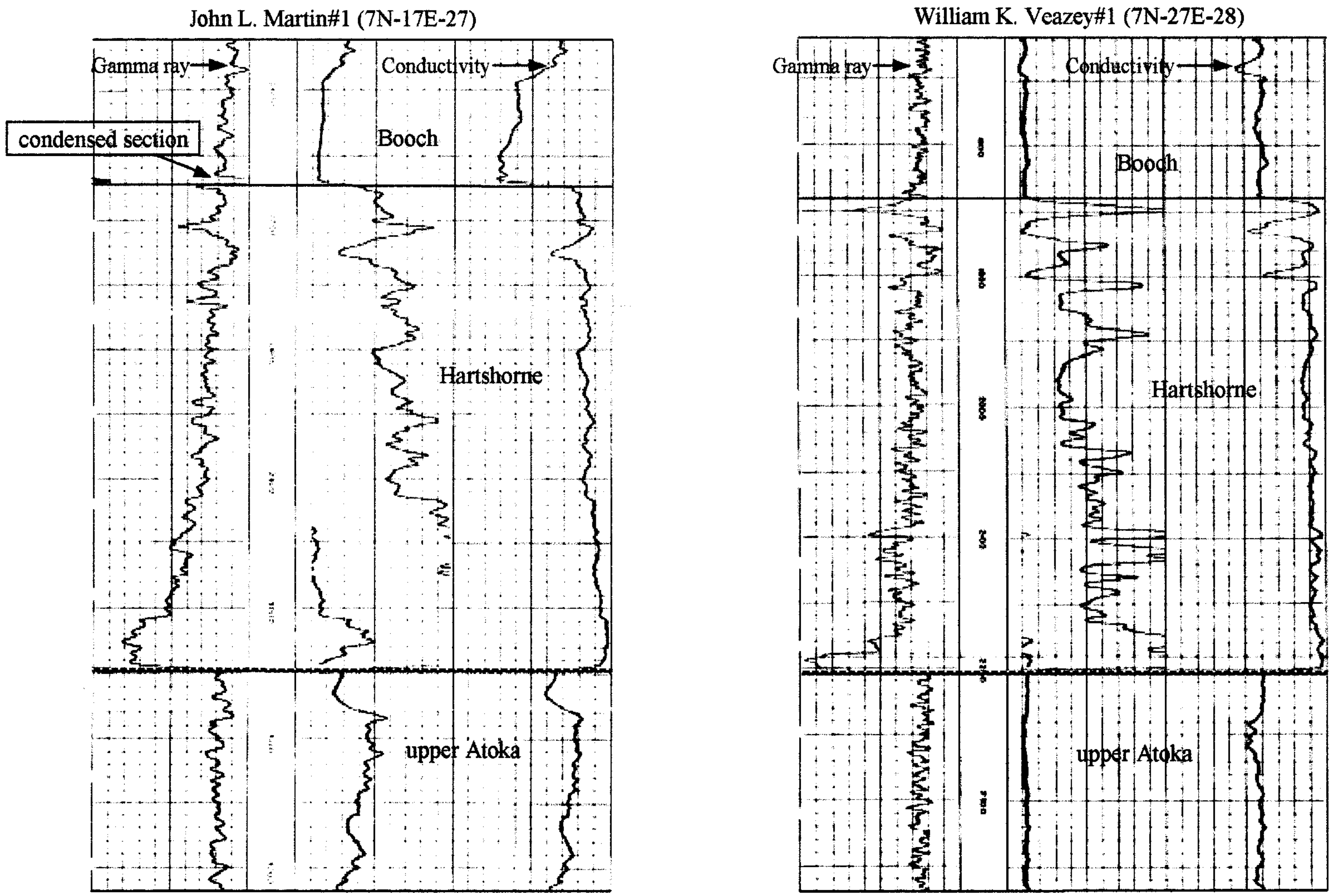

Figure 84. Two wells in different parts of the Arkoma Basin showing the characteristic low conductivity pattern of the Hartshorne LST and TST that persists even where the interval becomes shaly. A condensed section marks the top of Hartshorne TST at wells in the western part of the Arkoma Basin as in the John L. Martin well (left).

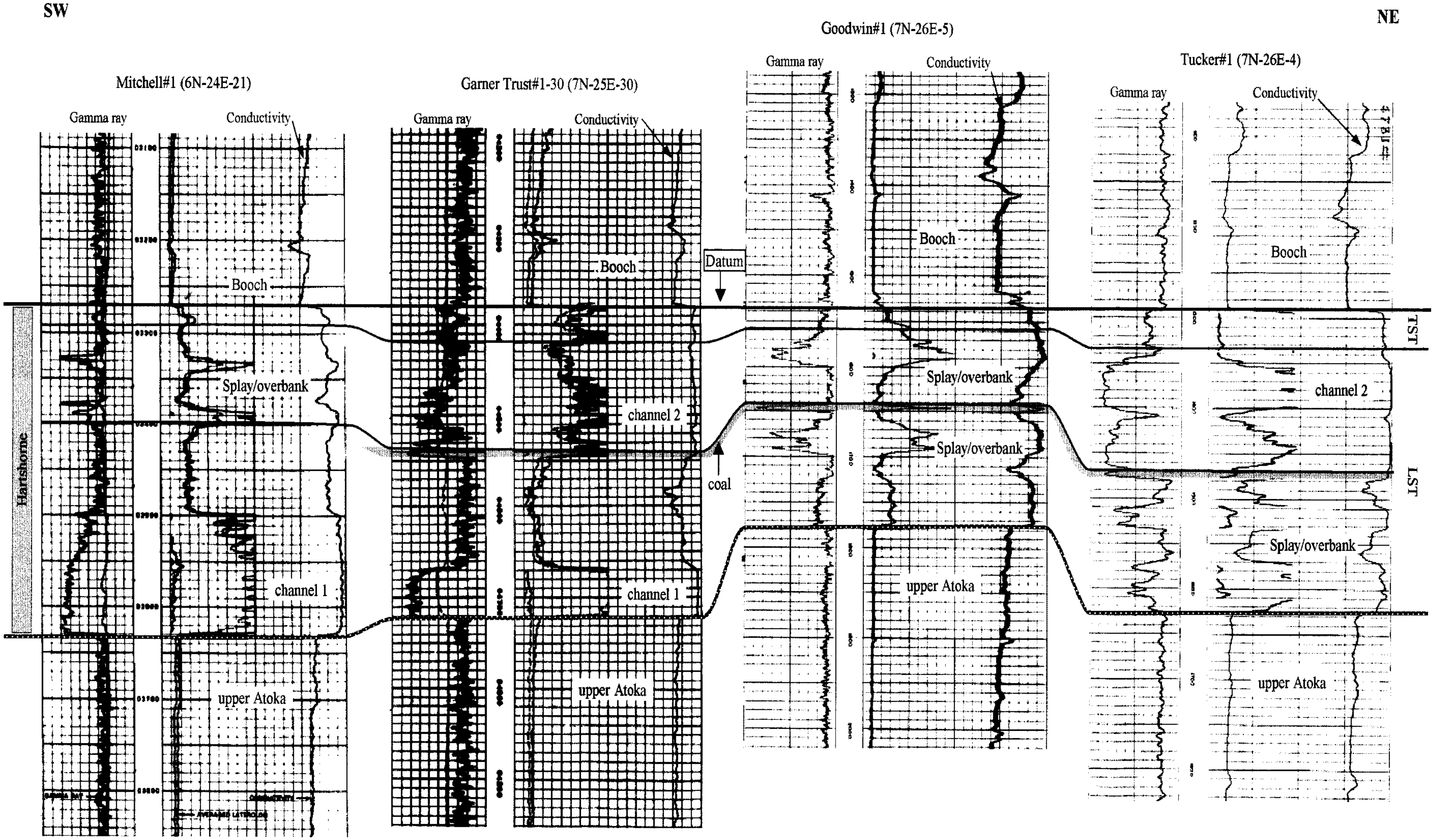

Figure 85. NE-SW stratigraphic cross section in the eastern part of the Arkoma Basin showing the Hartshorne LST channels and their equivalent splay/overbank deposits. These channels do not follow the same axis as indicated by the switching and variability of thick sandstone deposition between channels as in the Garner Trust#1-30 and Mitchell#1 wells. The cross section datum is top of Hartshorne TST. Horizontal scale is equal spacing. For location, see Fig. (80).

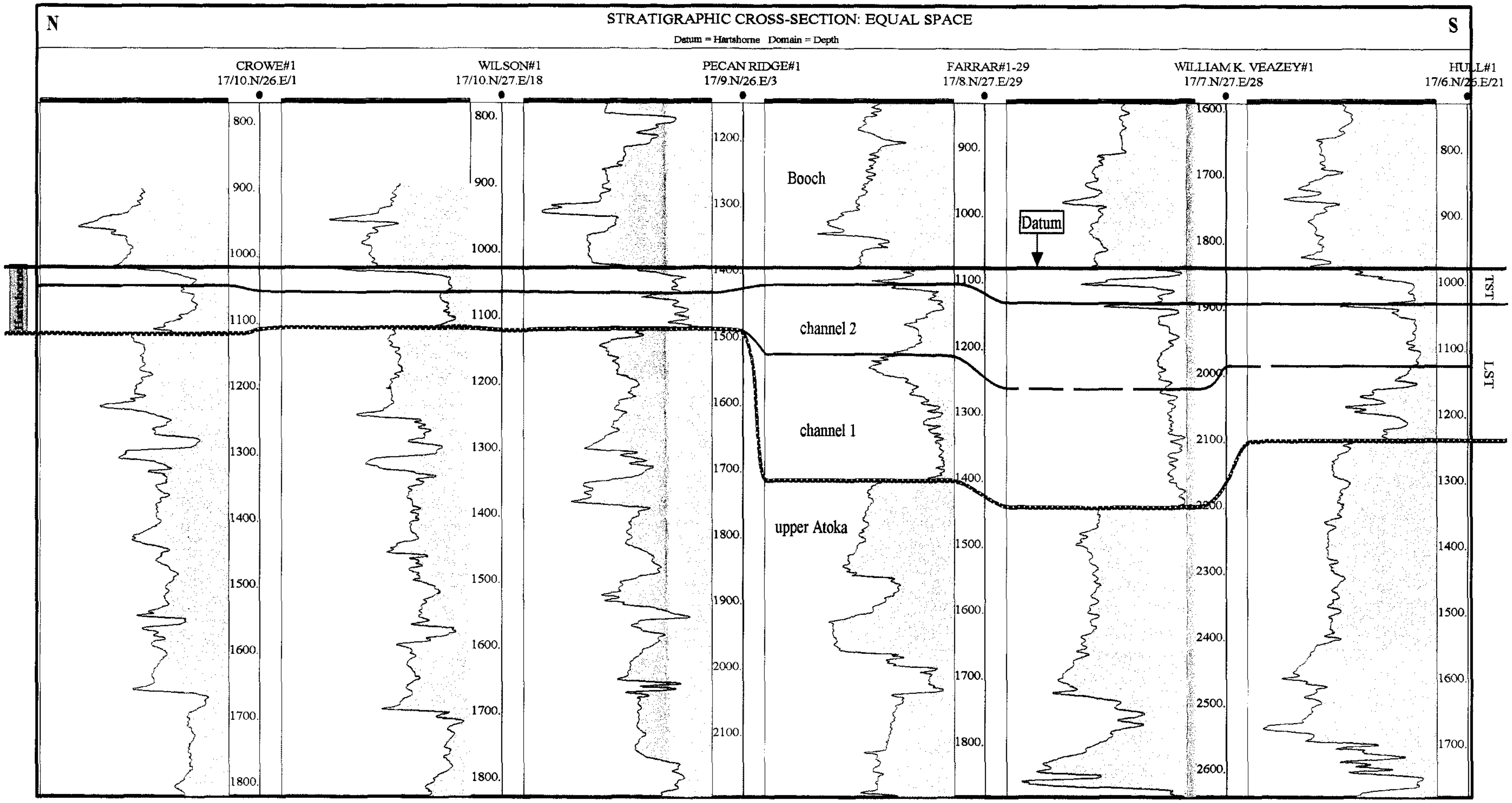

Figure 86. N-S regional stratigraphic cross section showing the extension of the Hartshorne LST and TST in the eastern part of the Arkoma Basin. The lower channel of the Hartshorne LST is confined to the southern part of the basin. Both the upper channel and the Hartshorne TST extend farther north. The cross section datum is top of Hartshorne TST. For location, see Fig. (80).

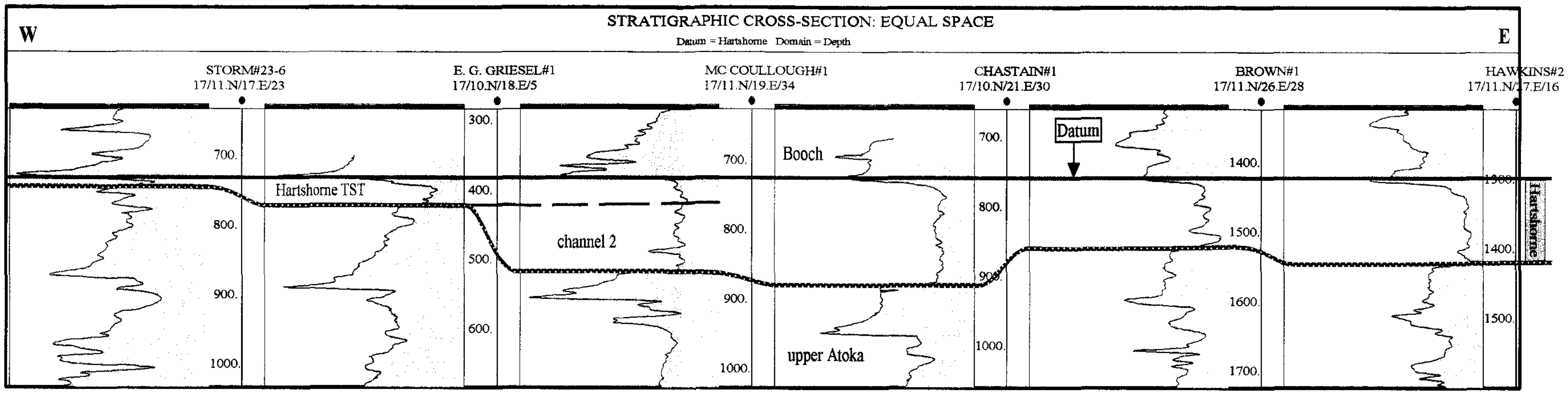

Figure 87. E-W regional stratigraphic cross section in the northern part of the Arkoma Basin. The upper channel of of the Hartshorne LST (channel 2) extends in the northeastern part of the basin forming an E-W trending channel beyond the southern limit of the thick channel deposits defined by Andrews (1998). The Hartshorne TST is the only Hartshorne interval that extends in the northwestern part of Arkoma Basin outside the channel system areas. The cross section datum is top of Hartshorne TST. For location, see Fig. (80).

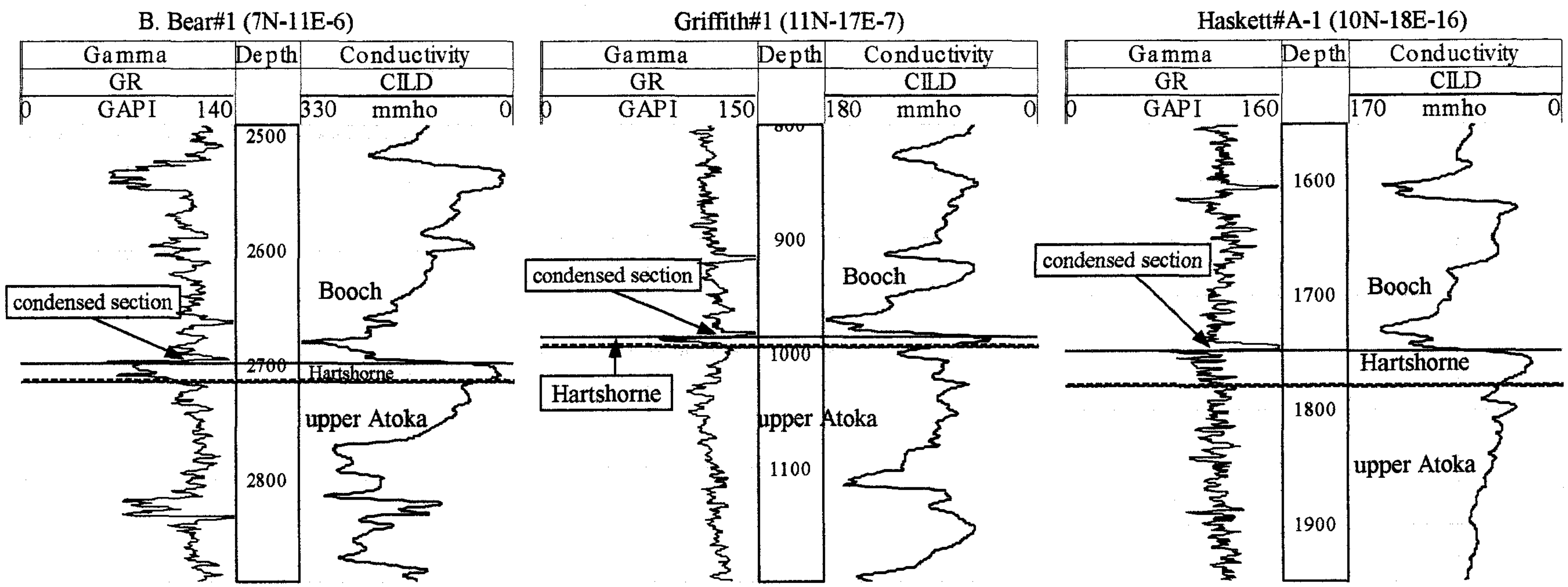

Figure 88. Three wells in different townships in the western part of the Arkoma Basin showing the thin sandy interval of the Hartshorne TST. It is usually capped by a condensed section marking the maximum flooding surface.

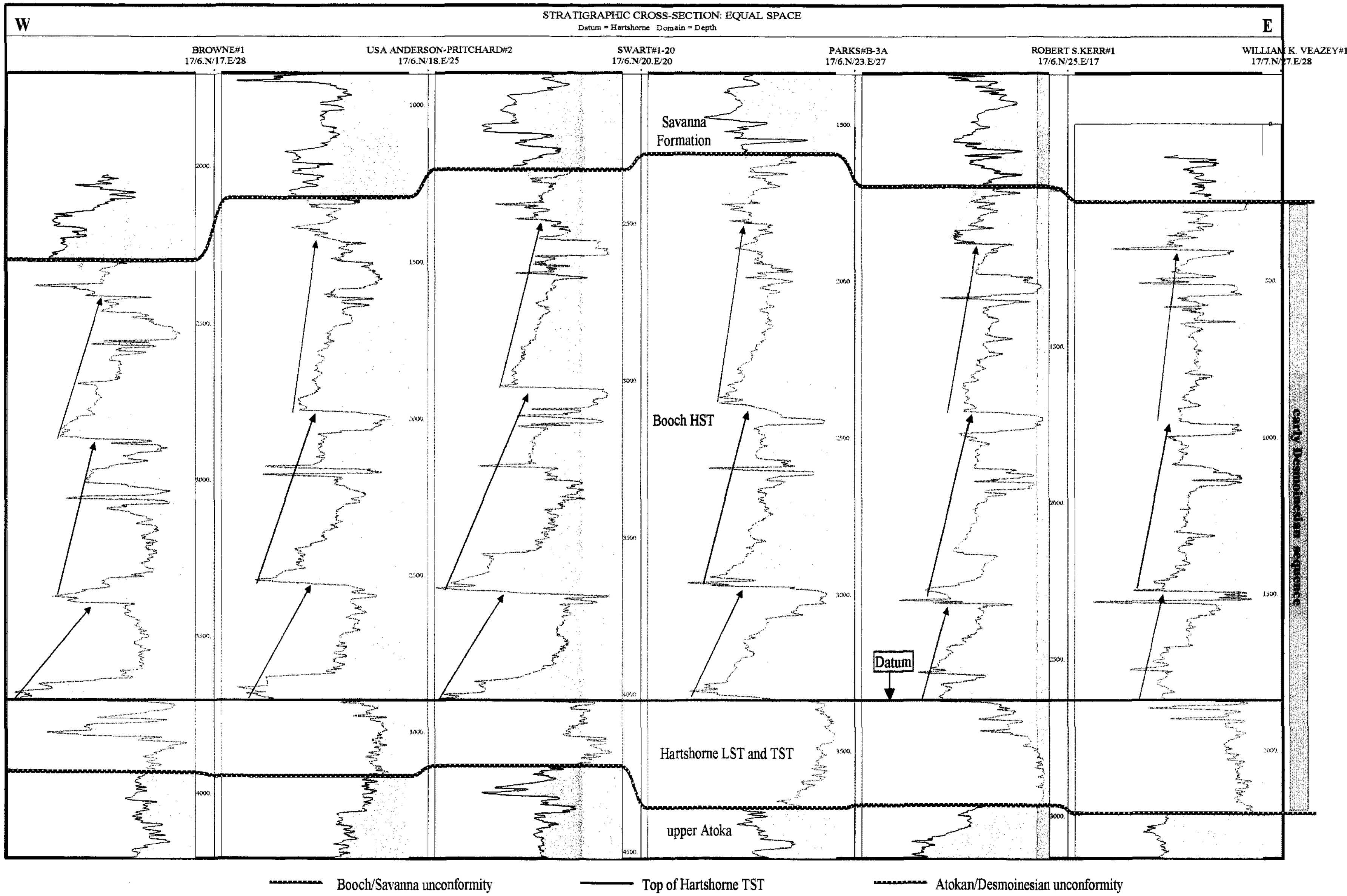

Figure 89. E-W regional stratigraphic cross section showing the thick parasequences of the Booch HST in the southern part of the Arkoma Basin. the Booch interval is lithostratigraphically divided into three units: lower, middle, and upper. In this study, the Booch interval is divided into four coarsening-upward parasequences that can be further subdivided. The upper two parasequences are equivalent to the upper Booch lithostratigraphic unit. The cross section datum is top of Hartshorne TST. For location, see Fig. (80).

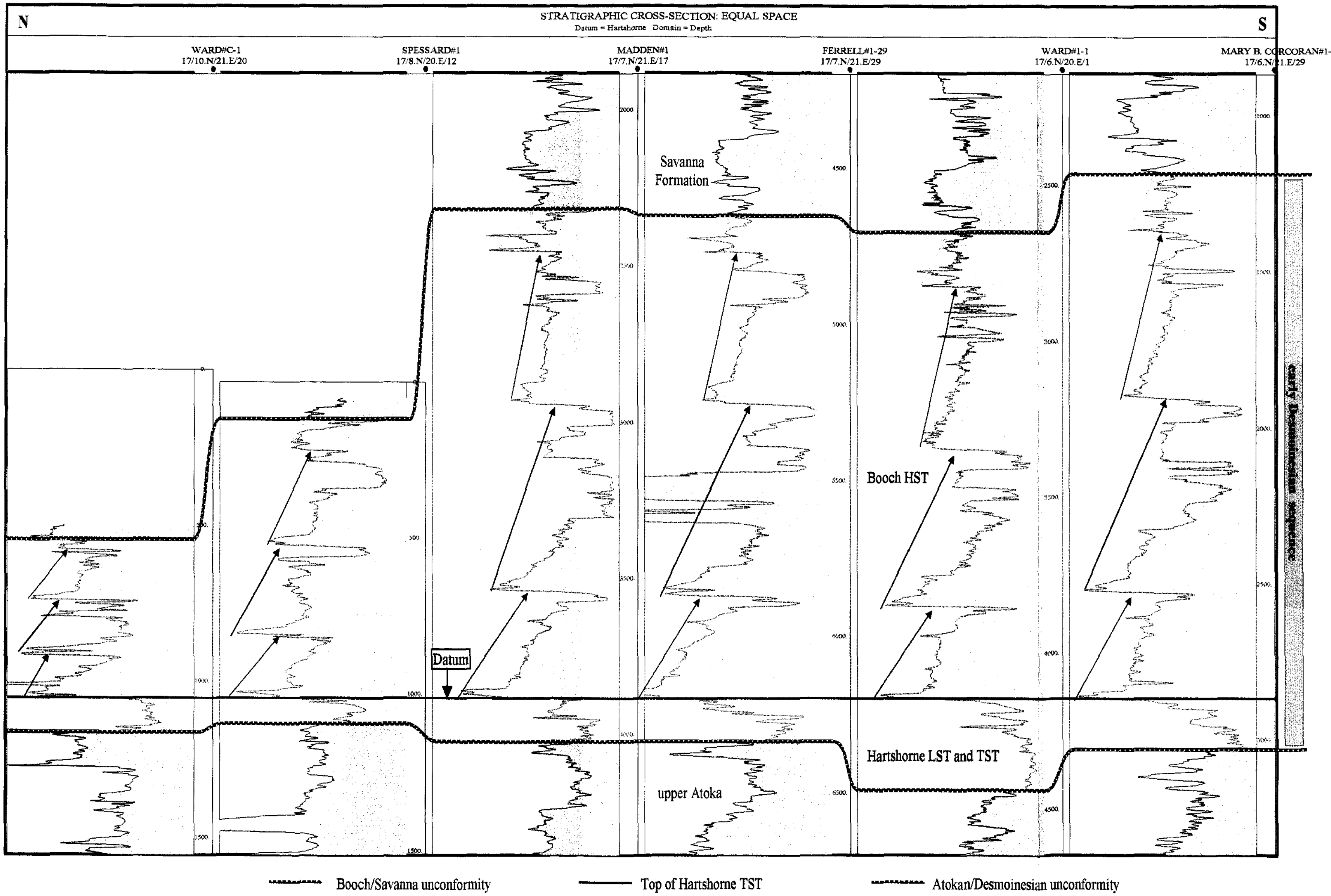

Figure 90. N-S regional stratigraphic cross section in the central part of the Arkoma Basin showing that the thick parasequences of the Booch HST become thin to the north. Despite the thinning of the parasequences, they remain distinguishable with each parasequence topped by a deltaic sandy facies. The cross section datum is top of Hartshorne TST. For location, see Fig. (80).

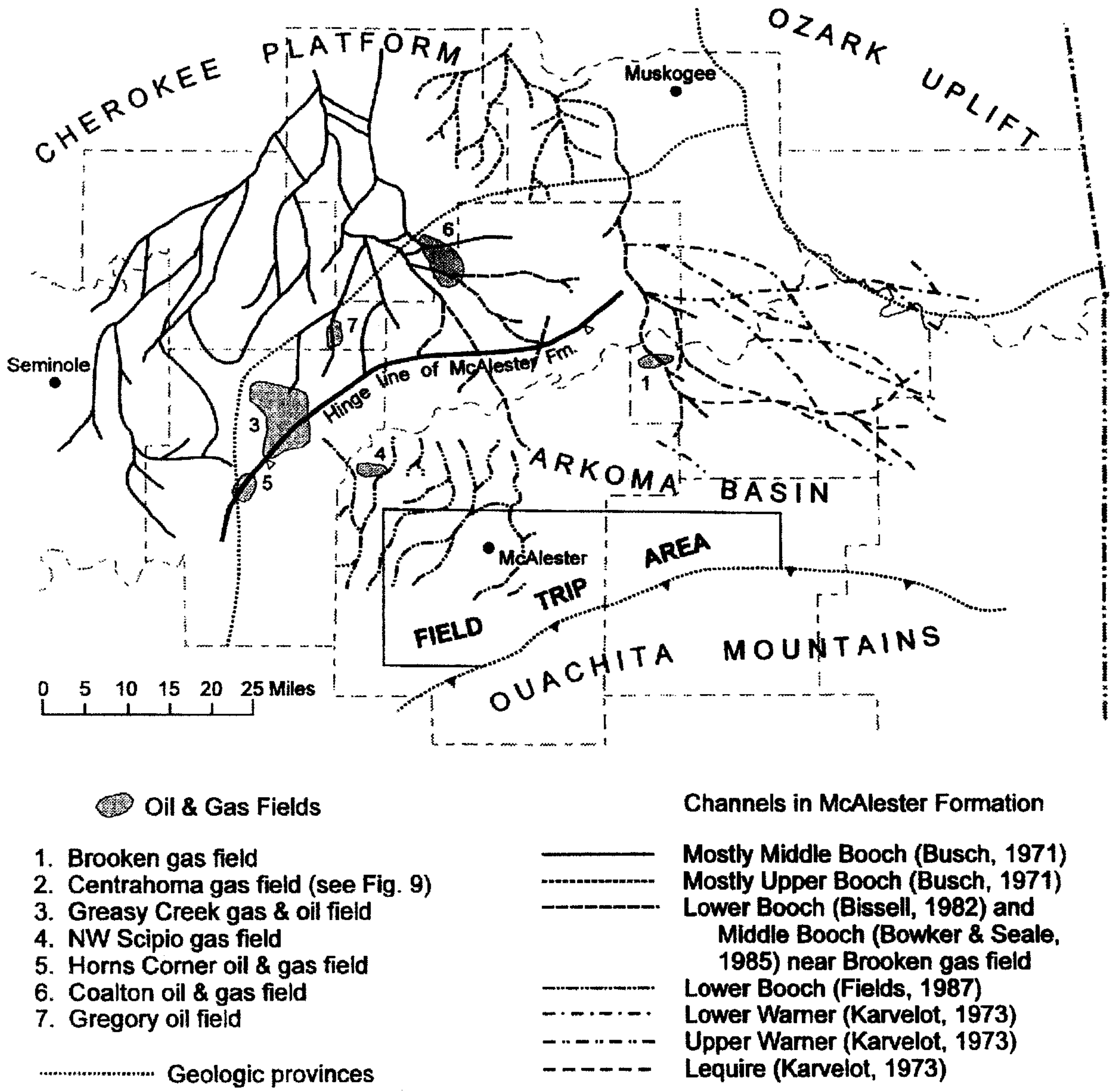

Figure 91. Map showing distribution of some Booch channel sandstones in the Arkoma Basin and on the Cherokee platform (central Oklahoma platform) (after Hemish and Suneson, 1997). Note the general N-S trend for the distributary channels.

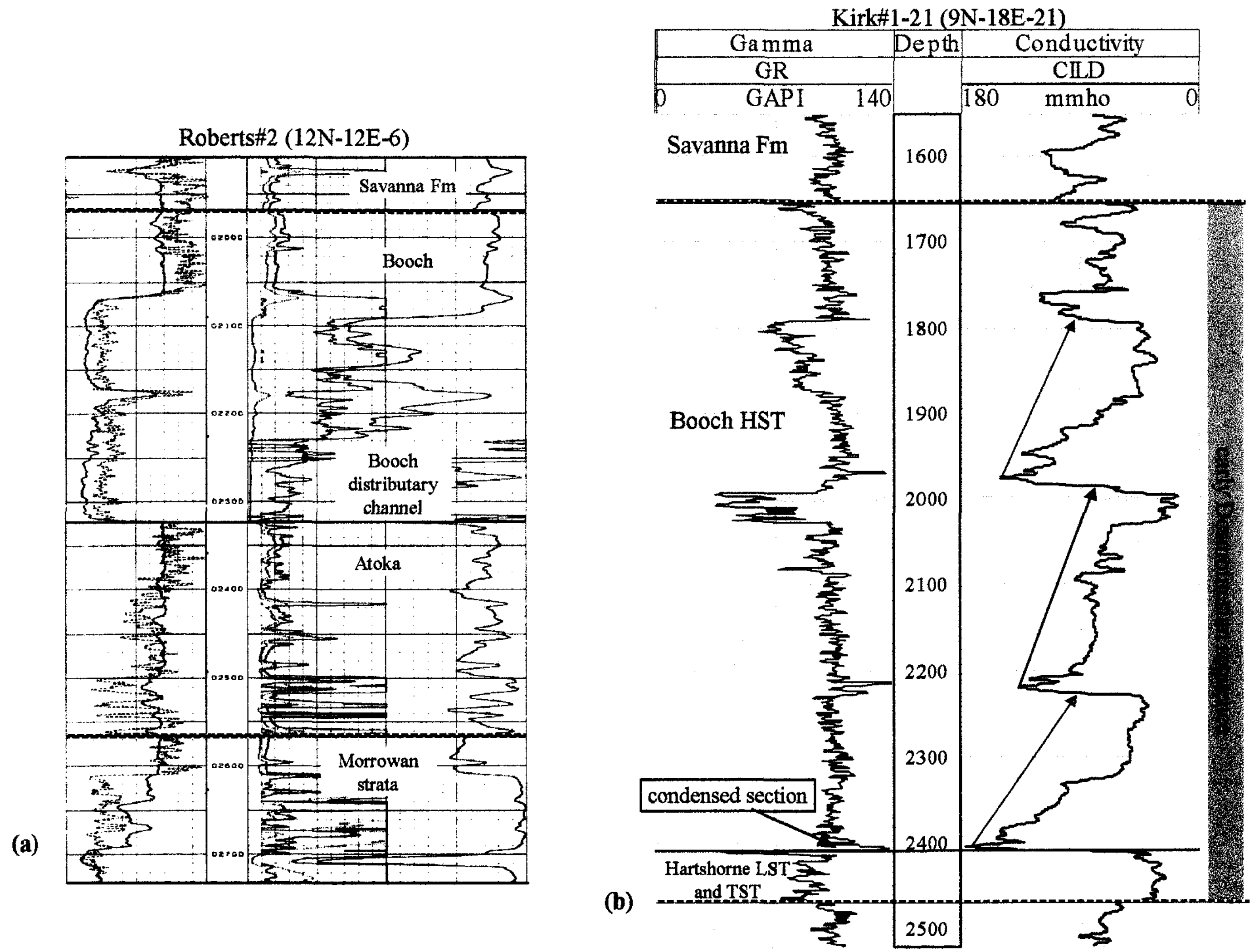

Figure 92. (a) an example from a well drilled in the northwestern part of the Arkoma Basin showing a thick booch distributary channel cutting into the underlying Atoka section. (b) an example showing the stacking of the Hartshorne LST and TST and the Booch HST parasequences on both gamma ray and conductivity logs. This package is considered in this study to represent an early Desmoinesian third order sequence.

CHAPTER 8

THE STRATIGRAPHIC FRAMEWORK FOR ATOKA FORMATION IN THE ARKOMA BASIN

The Arkoma Basin has been always defined as a foreland basin. Yet, the stratigraphic implications due to the evolution of a bulge, which is an integral part of the evolution of a foreland basin, were never addressed. Detailed correlations in this study revealed that the stratigraphy of the Atoka Formation in the Oklahoma part of the Arkoma Basin was controlled to great extent by a bulge formed in response to the orogenic loading of the northward-advancing thrust sheets of the Ouachitas.

A foreland basin system consists of four discrete depozones, referred to as the wedge-top, foredeep, forebulge, and back-bulge depozones (DeCelles and Giles, 1996) (Fig. 93). The latter two depozones form the bulge. The flexural deformation model predicts that loading on the foreland plate will result in a differential subsidence with asymmetric shape of the sedimentary fill as the foreland basin deepens toward the orogenic thrust belt (Angevine et al., 1990; Crampton and Allen, 1995). The model also predicts that a bulge will develop inboard from the basin, an upwarp formed due to loading on the continental plate. The amplitude of foreland basin subsidence is typically 20-40 times greater than the uplift of the forebulge, which is a minor upwrap on the edge of the bulge area (Crampton and Allen, 1995). Thus, compared to the basin subsidence, the forebulge is a subtle feature. Regional unconformities, stratal thinning, condensed zones, and shallow-marine deposits are typical features of forebulge and back-bulge depozones (DeCelles and Gilest, 1996).

The Ouachita thrust belt in Oklahoma may represent the frontal part of the advancing orogenic wedge-top. The remaining three depozones are integral parts of the Arkoma foreland basin system. The foredeep depozone is dominated by the thick deepwater strata. The forebulge depozone shows the highest rates of erosion along unconformities such as the Morrowan/Atokan and the middle Atokan unconformities. Shallow-water deposits and a thin sedimentary section characterize the back-bulge depozone to the north and west of the Arkoma Basin. During Atokan time, the foredeep depozone of the Arkoma Basin received over 14,000 feet of sediments, compared to few hundred feet on the back-bulge area to the northwest of the basin. Two stratigraphic cross sections show that all the sequences covered in this study thin significantly to the north and the west indicating that the formation of the bulge was active throughout the Atokan and early Desmoinesian (Figs. 94 and 95).

The tectonic evolution of the Arkoma Basin may consist of three phases based on the structural elements that controlled the subsidence of the basin and the associated stratigraphic changes. The earliest effects present in the Arkoma Basin that can be related to the development of the Ouachita orogeny and the collision of the Afro-South American and the North American plates may date back to the end of Morrowan time. The upwarp of the Morrowan carbonate shelf during the development of the Morrowan/Atokan unconformity represents a bulge covering a major part of the Arkoma

Basin, with a forebulge area to the south, where the extensive erosion of the Wapanucka carbonate shelf started (see Figs. 25 and 26 in Chapter 3), and in the eastern part of the Arkoma Basin resulting in the subcropping of the underlying Union Valley interval (see Fig. 36 in Chapter 3).

The second phase developed by the end of early Atokan time, as the flexure due to the loading of the Ouachita thrust belt resulted in the development of a series of major growth faults in the Arkoma Basin. South of these faults, thick turbidites were deposited in the foredeep of the Arkoma Basin. On the upthrown side of these faults, erosion was extensive marking the forebulge area. Farther north, the back-bulge area was a site of erosion and/or non-deposition. By the end of middle Atokan time, the third phase of the tectonic evolution of the Arkoma Basin included the compression exerted on the sedimentary section between the advancing edge of the Ouachita thrust belt, which became very close to the Arkoma Basin, and the back-bulge area to the north. This in turn, added a shear component to the subsiding areas of the Arkoma Basin in the south, where several synclinal features persisted during the late Atokan through at least early Desmoinesian times.

An approximate limit for the back-bulge has been delineated based on the change of thickness and stratigraphic criteria from the back-bulge area to both the forebulge and foredeep areas to the south and east in the Arkoma Basin (Fig. 96). These stratigraphic criteria were discussed in details in the previous chapters. These criteria are:

1- the unconformity on the top of the Morrowan section: the limit of the extensive erosion of the Wapanucka limestone in the southwest part of the Arkoma Basin, and the limit of the Wapanucka scarps where the underlying Union Valley interval subcrops to the northeast.

2- the lower Atoka sequence: a) the limits of development of the Foster strike valleys, the sandy facies of the Spiro and thick Cecil sandstones in the east, and the limy facies of the Spiro interval in the west. This limy facies may be the reworked sediments that were eroded from the Wapanucka platform on the bulge area farther north. b) the limit between development of thick lower Atoka HST delta to the northeast, and other thinner deltas to the west and northwest.

3- the middle-upper Atoka sequence: a) the forebulge erosion of the lower Atoka HST marking the unconformity at the base of the middle-upper Atoka sequence. b) the limit of middle Atoka LST. c) the limit of development of the thick upper Atoka TST and the HST delta in the east.

4- the lower Desmoinesian sequence: a) the limit of the development of thick Hartshorne incised channels in the south and east. b) the thickening of the Booch delta to the south and east.

The forebulge is a positive area that is commonly a site of erosion. Several workers have attributed basin-margin unconformities to forebulge uplift (Mussman and Read, 1986; Lash, 1988; Allen el al., 1991). Well-developed forebulges may be more pronounced in the early (flysch) stage of foreland basin development, when larger amounts of sediments are eroded from the foreland plate due to the greater elevation above sea level during lowstand (Crampton and Allen, 1995). In the Arkoma Basin, the erosional feature along the major San Bois syndepositional fault at the base of the middle Atoka lowstand systems tract is interpreted as forebulge erosion. Despite erosion of the underlying lower Atoka HST is evident on both sides of the growth faults, the eroded section on the upthrown side just to the north of the San Bois fault trend was much larger (see Fig. 50 in Chapter 4). Over 1000 feet of lower Atoka HST was eroded in the Madden#1 well in Fig. (94), assuming an average thickness of 1500 feet on both sides of the fault. This can be attributed to sustained high elevation above sea level on the crest of the forebulge.

In addition to the development of unconformities, the impact of the evolving bulge on the available accommodation space was significant. This is demonstrated by the comparison of the thick well-defined TST and HST parasequences of all the studied sequences in the east and south, with the thin sedimentary section in the back-bulge area in the northwestern part of the Arkoma Basin where the available accommodation space was limited. Also, the lowstand systems tracts in the studied stratigraphic section, which included the Foster sandstone of the basal Atoka LST, the thick turbidites of the middle Atoka LST, and the channels of the Hartshorne LST, were developed east and south of the back-bulge area where the continuously growing bulge limited their extension northwestwards. Meanwhile, the Cromwell sandstone of the Morrowan LST is present in that area indicating it predates the evolution of the bulge.

The sediment sourcing changed during the deposition of different systems tracts of the studied stratigraphic section. The importance of sediment supply direction on shaping the stacking of HST parasequences can be demonstrated by comparing the upper Atoka HST and the Booch HST deltas in the back bulge area to the northwest where accommodation space remained small during the deposition of both highstand systems tracts. The sediment source during the deposition of the upper Atoka HST was generally from the east. Its parasequences with several sandstone intervals in the east have become very thin and merged together forming a shaly interval in the bulge area westward (see Figs. 71 and 72 in Chapter 6). On the other hand, the sediment source for the Booch HST delta was from the north. Although the parasequences became thinner to the north, they remained distinguishable with deltaic sandstones on the top of each of them (see Fig. 90 in Chapter 7). Also, the thick distributary channels cutting into the underlying Atoka section may be attributed to the rising back-bulge (see Fig. 92a in Chapter 7).

Despite the active tectonic history in the Arkoma Basin and the changes of both accommodation space and sediment source directions throughout the studied stratigraphic section, an overall picture of relative sea level changes during the deposition of the interpreted sequences can be drawn (Fig. 97). The stratigraphic section starting from the Morrowan through the early Desmoinesian represents four third-order cycles of relative sea level changes. The stratigraphic section including the Cromwell valley-fill through the Wapanucka prograding carbonate platform represents the Morrowan cycle. The basal Atoka LST, TST, and lower Atoka HST represent the lower Atokan cycle. The middle Atoka LST, and the upper Atoka TST and HST represent the middle-upper Atokan cycle.

Finally, the Hartshorne LST, TST, and the Booch HST represent the lower Desmoinesian cycle. Each cycle represents a third-order sequence bounded by unconformities. This picture demonstrates that the Atoka stratigraphy is an integral part of the sequence stratigraphic realm that continued throughout the Pennsylvanian time. Both the very active tectonic pattern and the huge sediment supply during the short Atokan time changed the morphology and the architecture of the basin but not the systematic cyclic nature of the stratigraphic section.

The lithostratigraphic Atokan sandstones have been arranged in different ways with names changing in different parts of the Arkoma Basin (Zachry, 1984; Sprague, 1985; Suneson and Hemish, 1994; Visher, 1996). One outcome of this study is the ability to arrange these lithostratigraphic sandstone units in Oklahoma based on sequence stratigraphic surfaces with chronostratigraphic significance. This arrangement is shown in Fig (98), which includes the names used frequently for the lithostratigraphic sandstones, their depositional systems tract, and their respective location in the Oklahoma part of Arkoma Basin.

The Atoka Formation outcrops both, at the northeast edge of Arkoma Basin in Oklahoma (Ozark uplift), and along the southern margin of the basin (Ouachita thrust belt). Although these outcrops have been studied, the literature does not state the division of the Atoka Formation to which these outcrops belong. Based on the stratigraphic criteria elucidated in this study, all the exposed Atokan section close to the Ozark uplift area is a thin upper Atoka section overlying much thicker lower Atoka section. The first penetrated interval in many wells drilled in the northeast corner of the Arkoma Basin covering township 12N and ranges from 24 to 27E, is the lower Atokan HST indicating that the upper Atoka section was almost completely eroded. This is in contrast to the outcrops in the southern margin of Arkoma Basin and frontal Ouachitas where very thick upper and middle Atoka strata are present with much thinner lower Atoka strata at the base of the section.

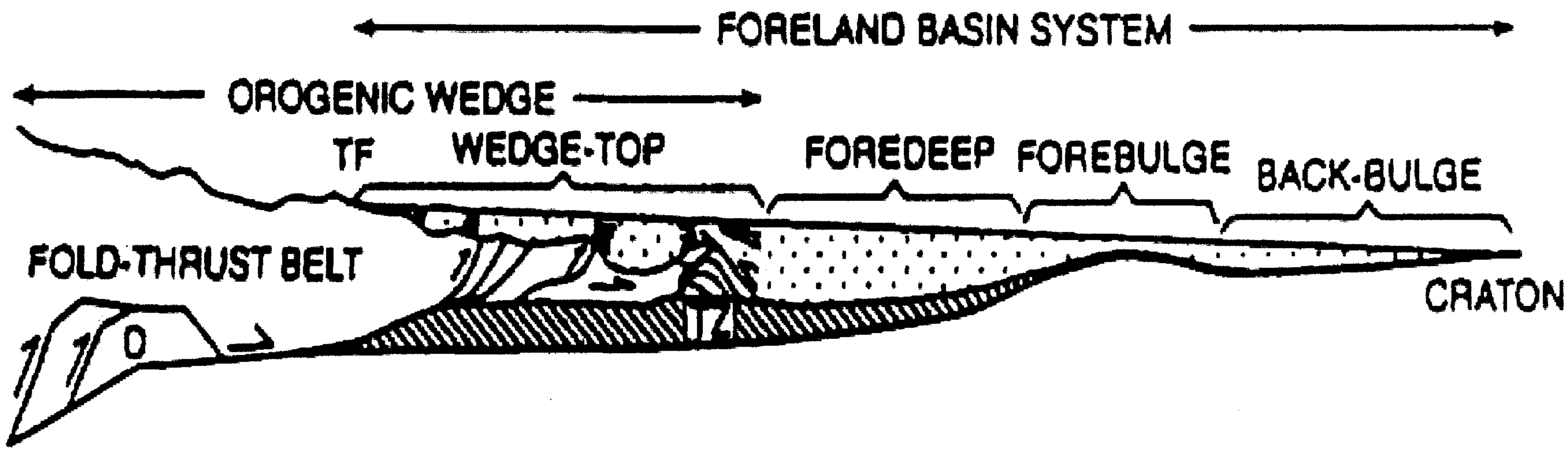

Figure 93. Schematic cross section depicting a foreland basin system, with the wedge-top, foredeep, forebulge, and back-bulge depozones (after DeCelles and Giles, 1996).

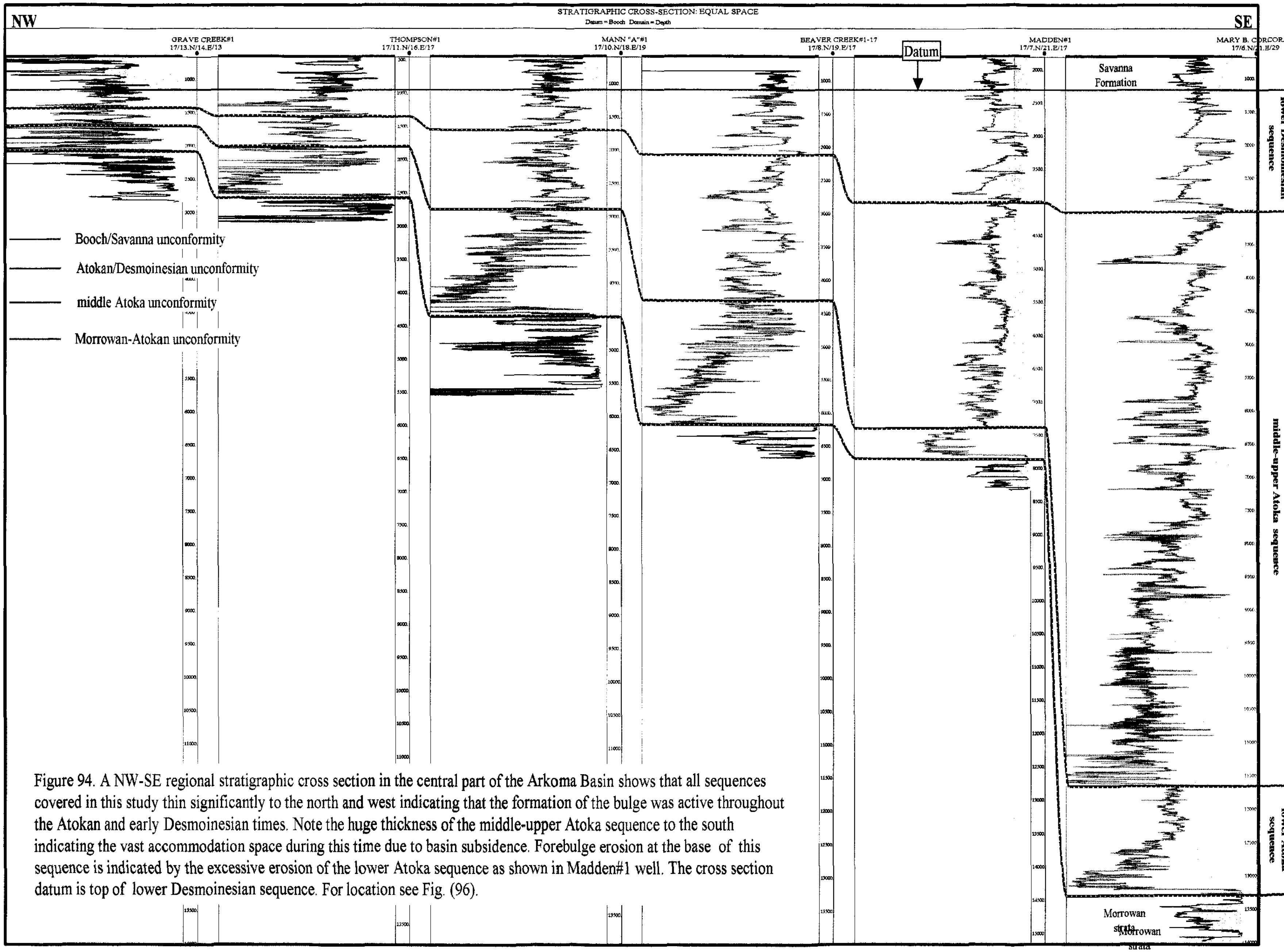

Figure 94. A NW-SE regional stratigraphic cross section in the central part of the Arkoma Basin shows that all sequences covered in this study thin significantly to the north and west indicating that the formation of the bulge was active throughout the Atokan and early Desmoinesian times. Note the huge thickness of the middle-upper Atoka sequence to the south indicating the vast accommodation space during this time due to basin subsidence. Forebulge erosion at the base of this sequence is indicated by the excessive erosion of the lower Atoka sequence as shown in Madden#1 well. The cross section datum is top of lower Desmoinesian sequence. For location see Fig. (96).

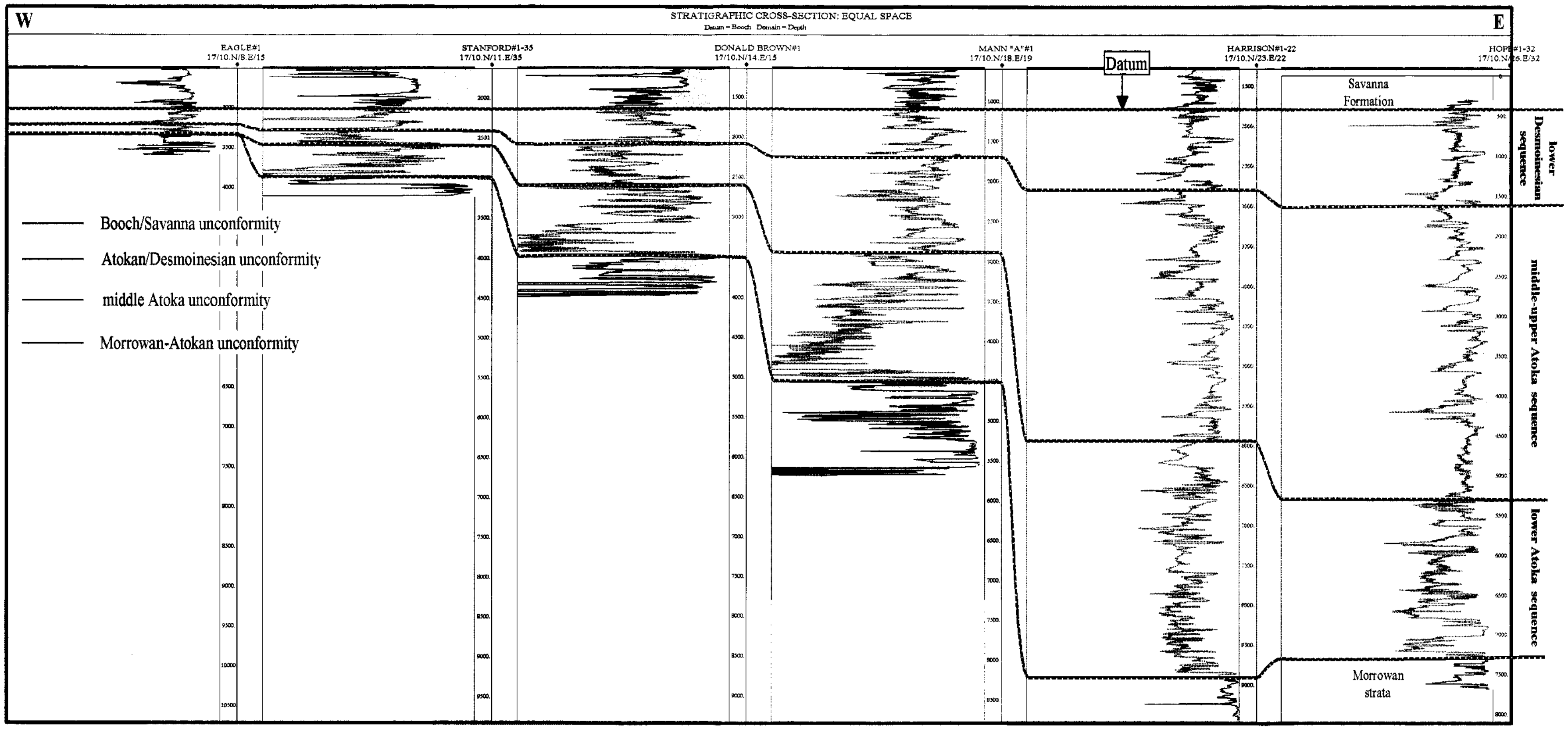

Figure 95. An E-W regional stratigraphic cross section in the northern part of the Arkoma Basin shows that all sequences covered in this study thin significantly to the west indicating that the formation of the bulge was active throughout Atokan and early Desmoinesian times. The middle-upper Atoka sequence in the north of the Arkoma Basin consists mainly of upper Atoka TST and HST. In the northwest corner of the basin, the lower Atoka sequence is completely eroded as shown in Eagle#1 well. The cross section datum is top of lower Desmoinesian sequence. For location see Fig. (96).

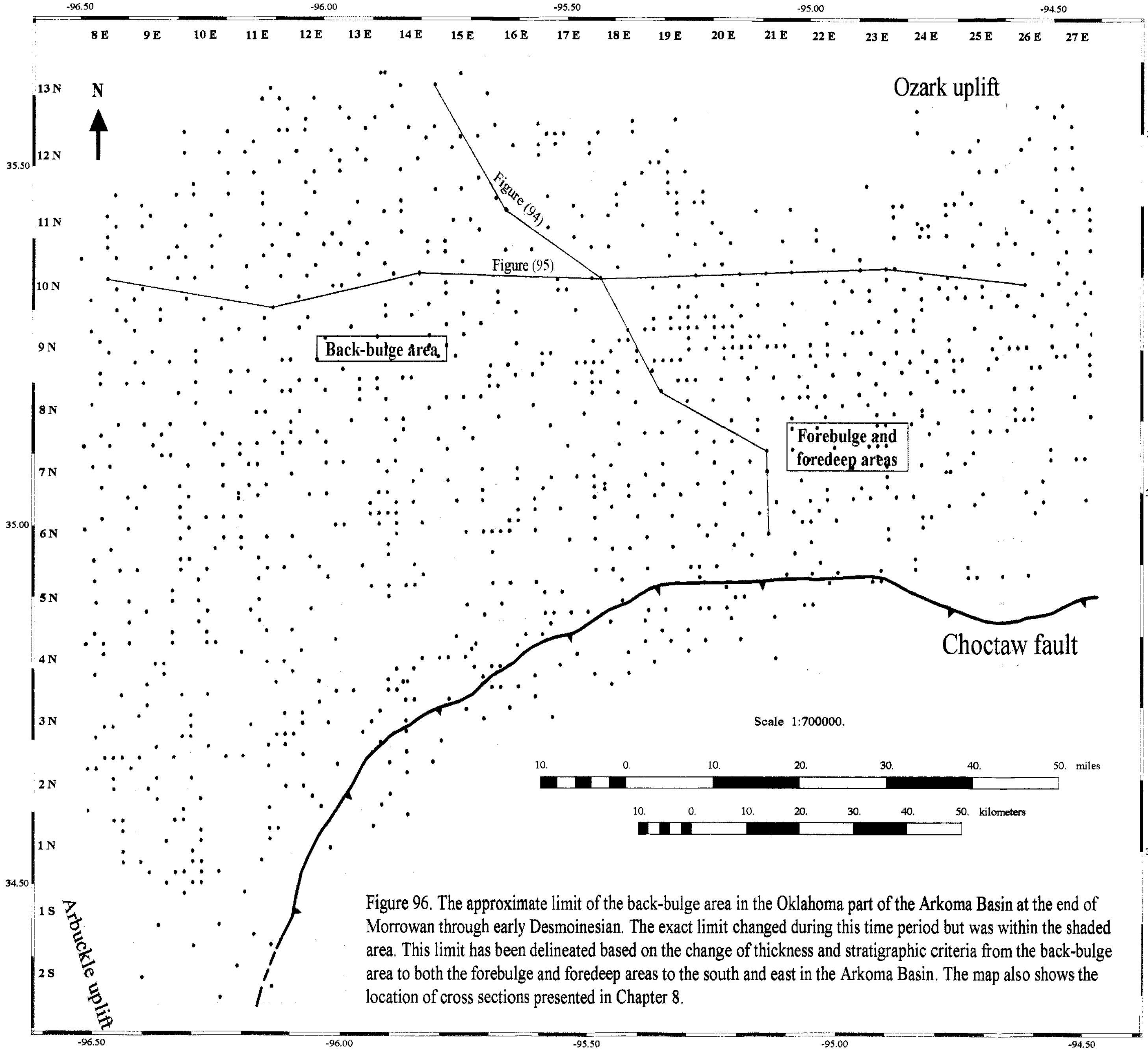

Figure 96. The approximate limit of the back-bulge area in the Oklahoma part of the Arkoma Basin at the end of Morrowan through early Desmoinesian. The exact limit changed during this time period but was within the shaded area. This limit has been delineated based on the change of thickness and stratigraphic criteria from the back-bulge area to both the forebulge and foredeep areas to the south and east in the Arkoma Basin. The map also shows the location of cross sections presented in Chapter 8.

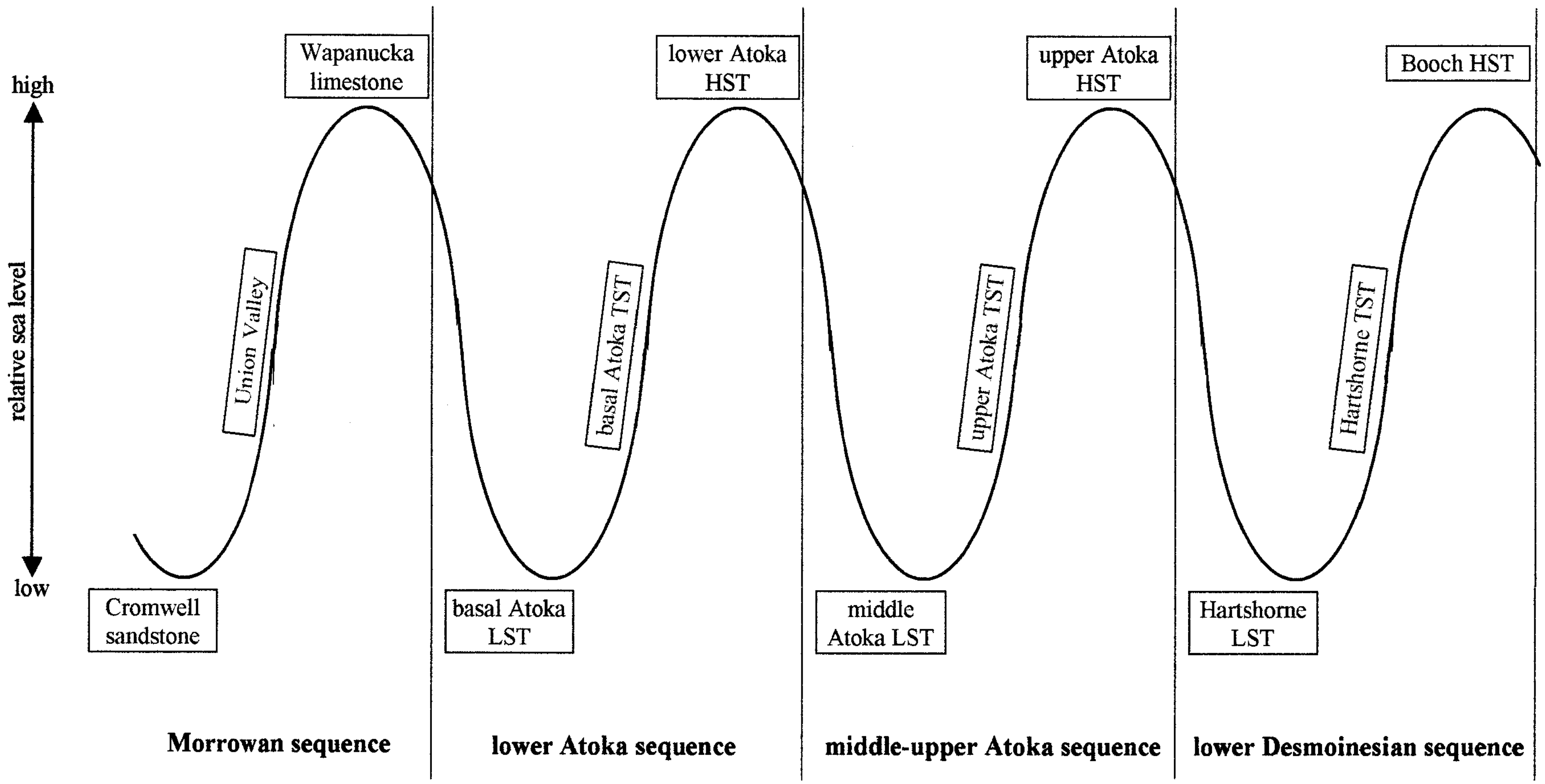

Figure 97. Relative sea level curve for the stratigraphic section from Cromwell sandstone to the Booch interval in the Oklahoma part of the Arkoma Basin. The section is composed of four cycles of relative sea level changes. Each cycle represents a third order sequence bounded by unconformities. This picture demonstrates that the Atoka stratigraphy is an integral part of the sequence stratigraphic realm that continued throughout Pennsylvanian time.

Series	Sequence	Systems tract	Western Arkoma basin	Eastern Arkoma basin
Atokan	middle-upper Atoka	HST		Carpenter
		TST	upper Gilcrease	Alma
		LST	Fanshawe Red Oak Panola Diamond Brazil	Fanshawe Red Oak Panola Diamond Brazil Basin floor fan sandstone
	lower Atoka	HST	lower Gilcrease Dutcher	Sells Jenkins Dunn (A-C)
		TST	Chapel Pope Spiro	Cecil Spiro
		LST	basal Atoka sandstone	Foster basal Atoka sandstone

Figure 98. Arrangement of the lithostratigraphic sandstone units based on their position with respect to sequence stratigraphic systems tracts and bounding surfaces. Names of the these sandstones are from scout tickets and literature. Some lithostratigraphic units are composed of several sandstones such as Alma and Carpenter which are equivalent in some cases to several parasequences. The limit between eastern and western Arkoma Basin is considered at range 18E.

CHAPTER 9

SUMMARY AND CONCLUSIONS

1- The conductivity log was the principal tool used for correlations to interpret the sequence stratigraphic hierarchy of the Atoka Formation in the Arkoma Basin. Beside its availability in all the studied wells and its clear signature differentiating between clean and shaly rocks, it provides a good definition of distinguishable detailed patterns of different shale packages. The continuity of these packages was used to decipher the depositional systems tracts for several sequences and their bounding surfaces.

2- The Atokan section in the Arkoma Basin is divided into two third-order sequences: the lower Atoka, and middle-upper Atoka sequences. Each is bounded by regional unconformities. The Cromwell sandstone valley-fill, the Union Valley shale/limestone, and Wapanucka limestone are the Morrowan strata unconformably underlying the Atokan section. The Hartshorne and the Booch intervals are the Desmoinesian strata unconformably overlying the section.

3- The Morrowan/Atokan unconformity represents the lower bounding surface for the lower Atoka sequence. This unconformity lies at the top of the Union Valley interval in the northeastern part of the Arkoma Basin, and at the top of the Wapanucka limestone to the south and west. Differential erosion of the Union Valley shale resulted in development of strike valleys trending NW-SE in the eastern part of the Arkoma Basin. The development of these strike valleys, and the onset of extensive erosion of

Wapanucka limestone in the south of the Arkoma Basin are interpreted to occur in the forebulge area developed by the end of Morrowan time.

4- The lower Atoka sequence is composed of three systems tracts: the basal Atoka LST and TST, and the lower Atoka HST. The basal Atoka LST overlies the Morrowan/Atokan unconformity. It consists of thin basal Atokan sandstone, the sub-Spiro shale, and its time equivalent, the Foster sandstone, which was mainly deposited along the Wapanucka scarps within the strike valleys. The basal Atoka TST consists of the Spiro and Cecil sandstones. The latter represents the most transgressive sandstone in the sequence and is limited to the northern and eastern shelf areas of the Arkoma Basin.

5- The lower Atoka HST has a characteristic conductivity pattern that can be easily traced throughout the basin. This HST is composed of several aggradational to progradational parasequences and marks substantial development of deltas in the northeast, northwest, and western shelf areas of the Arkoma Basin. These deltaic sandstones carry the Arkansas nomenclature such as Dunn (A through C), Jenkins, and Sells in the eastern part of the Arkoma Basin. These lithostratigraphic units are time equivalent to the deltaic sandstones of the Dutcher and the majority of the Gilcrease sandstones in the northern and western parts of the Arkoma Basin.

6- The upper bounding surface of the lower Atoka sequence is the middle Atoka unconformity. In the deep parts of the Arkoma Basin, the lower Atoka prodelta shale is overlain by the middle Atoka LST with clear indications of submarine erosion. On the shelf, the unconformity is marked by erosion along the major syndepositional faults. The extensive truncation of the lower Atoka HST along the upthrown side of the San Bois fault can be attributed to its sustained high elevation above sea level because of its position on the crest of the forebulge. Farther north, the upper Atoka transgressive sandstone unconformably overlies the lower Atoka HST.

7-The middle-upper Atoka sequence is composed of the middle Atoka LST and the upper Atoka TST and HST. The middle Atoka LST is the thickest stratigraphic interval within the Arkoma Basin in Oklahoma, and is mainly confined to the southern and eastern parts of the basin. It is composed of a basin floor fan, slope fan and lowstand wedge. The sandstones within the basin floor fan were mistakenly correlated by previous workers with the Cecil sandstones of the lower Atoka section. The mud-rich slope fan contains several channel-levee complexes. The sediment feeder system for these complexes may have changed from a line source (shelf-fed) along the San Bois fault in the east, to point source feeding system in the west. The shaly lowstand wedge interval, in the south, becomes thicker and sandier (Fanshawe sandstone) to the northeast and in southwest corner of the Arkoma Basin.

8- The lack of recognition of the unconformity between the lower and middle Atoka sections may have resulted in disagreement regarding defining the age of the turbidites section in the Arkoma Basin and the frontal Ouachitas. It is likely that the thin lower Atoka section was completely eroded in areas in the frontal Ouachitas resulting in the merging of the two unconformities, which bound the lower Atoka third-order sequence, and forming one major unconformity that may span the late Morrowan through early Atokan times. The merging of the two unconformities coupled with the inability to identify the shaly lower Atoka interval, partially preserved up dip, may have mistakenly led some workers such as Sprague (1985) to consider the turbidite deposits in the frontal Ouachitas to be lower Atokan.

9- The upper Atoka section consists of several distinctive parasequences composing a transgressive and highstand systems tracts. These parasequences extend across the major syndepositional faults present in the southeastern part of the Arkoma Basin. The lower boundary of the upper Atoka section is a transgressive surface that overlies the middle Atoka LST in the southern and eastern parts of the Arkoma Basin, and the middle Atoka unconformity at the top of the lower Atoka sequence on the shelf of the basin.

10- The upper Atoka TST and HST are best developed in the eastern part of the Arkoma Basin with well-defined and thick parasequences in the southeast. The highstand parasequences with several sandstone intervals in the east become very thin and merge together forming a shaly interval marked at its base by the upper Atoka TST. This TST usually includes thin sandstones that unconformably overlie either the lower Atoka sequence or the Morrowan strata in the northwestern part of the Arkoma Basin.

11- Two criteria were used in this work to define the nature of the upper Atoka-Hartshorne contact: 1) the presence of a conductivity marker that represents the base of the major upper parasequence of the upper Atoka HST. 2) the characteristic fining upward pattern of the Hartshorne incised-channel deposits in the southern part of the Arkoma Basin. Based on these two criteria, a regional unconformity between the upper Atoka HST and the Hartshorne LST is identified where the channels of the latter incised into the upper Atoka HST at different levels. This unconformity is termed in this work as the Atokan-Desmoinesian unconformity.

12- The Hartshorne interval in this study has been divided into three units. The lower two units represent a lowstand systems tract, which is equivalent to the lithostratigraphic upper and lower Hartshorne members. The upper much-thinner unit is a transgressive systems tract capped by a condensed section in the western part of the Arkoma Basin.

13- The aggradational to progradational Booch parasequences constitute the highstand systems tract above the Hartshorne LST and TST. These three systems tracts compose a third-order sequence. This lower Desmoinesian sequence is bounded by the Atokan/Desmoinesian unconformity at its base and the Booch/Savanna unconformity at its top.

14- The Arkoma foreland basin system consists of three depozones. The foredeep depozone is dominated by the thick deepwater turbidites. The forebulge depozone shows the highest rates of erosion along unconformities such as the Morrowan/Atokan and the middle Atokan unconformities. Shallow-water deposits and thin sedimentary section characterize the back-bulge depozone in the northwestern part of the Arkoma Basin.

15- The tectonic evolution of the Arkoma Basin may consist of three phases based on the structural elements that controlled the subsidence of the basin and the associated stratigraphic changes. At the end of Morrowan time, the upwarp of the carbonate shelf formed a bulge covering a major part of the Arkoma Basin, with a forebulge area to the east and south. The second phase developed by the end of early Atokan time, when the flexure due to the loading of the Ouachita thrust belt resulted in the development of a series of major growth faults in the Arkoma Basin. South of these faults, thick turbidites were deposited in the foredeep of the Arkoma Basin. By the end of middle Atokan time, the third phase included the compression exerted on the sedimentary section between the advancing edge of the Ouachita thrust belt and the back-bulge area to the north. This in turn, added a shear component to the subsiding areas of the Arkoma Basin in the south, where several synclinal features persisted during the late Atokan through at least early Desmoinesian times.

16- The Atoka stratigraphy is an integral part of the sequence stratigraphic realm that continued throughout Pennsylvanian time. The stratigraphic section starting from the Morrowan through the early Desmoinesian represents four third-order cycles of relative sea level changes. The section including the Cromwell sandstone through the Wapanucka prograding carbonate platform represents the Morrowan cycle. The basal Atoka LST, TST, and the lower Atoka HST represent the lower Atokan cycle. The middle Atoka LST, and the upper Atoka TST and HST represent the middle-upper Atokan cycle. Finally, the Hartshorne LST, TST, and the Booch HST represent the lower Desmoinesian cycle. Each cycle represents a third-order sequence bounded by unconformities.

17- The outcropped Atokan section close to the Ozark uplift is composed of thin upper Atokan section overlying a much thicker lower Atokan section. The upper Atoka section is almost completely eroded in several wells in that area. This is in contrast to the outcrops in the southern margin of the Arkoma Basin and frontal Ouachitas where very thick upper and middle Atoka strata are present with much thinner lower Atoka strata at the base of the section.

18- Sandstones should not be used as a basis for correlation to infer the regional stratigraphy of a basin due to their discontinuous nature. In this study, the different lithostratigraphic sandstone units were arranged based on sequence stratigraphic surfaces with chronostratigraphic significance. This sequence stratigraphic model can aid as a predictive model for the distribution of sandstones throughout the Arkoma Basin.

19- The Arkoma foreland basin is a mature exploration province that still has opportunities for further prospecting. It can serve as a stratigraphic model for other foreland basins because of the following advantages: the wide range of sedimentary environments, the complex interaction of tectonics and sediment supply and the availability of thousands of well logs. The conductivity log is available for almost all the wells drilled in the basin. Few wells have sonic logs, which is the norm in many mature basins. The good correlation between the conductivity and sonic logs can be employed to create 2-D and 3-D pseudo-seismic models that may help in understanding the stratigraphy and exploring in other foreland basins.

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APPENDIX

WELL NAMES AND LOCATIONS
(TOWNSHIP-RANGE-SECTION)

WELL NAME	LOCATION	WELL NAME	LOCATION
KING#1	13N/15E/9	STOCKS#1	12N/17E/24
ORENDORFF FRAZIER#1	13N/15E/24	J. MATTHEWS#1	12N/16E/1
GRAVE CREEK#1	13N/14E/13	HAGGAR"A"#1-6	12N/16E/6
MORRIS DISPOSAL TERMINAL#4	13N/14E/17	VOSS#1-13	12N/16E/13
BRYANT#230	13.N14E/30	ARCHER#1	12N/16E/16
DUCTHER#1	13N/13E/12	PLES MCCOY#1	12N/16E/24
MORRIS#2	13N/13E/12	BETTY SUE#1	12N/15E/9
PINE"B"#1	13N/13E/30	BREWER#1	12N/15E/11
SNIDER#1	13N/13E/32	LACKEY#1	12N/15E/17
ELLIS#1	13N/13E/35	RICHARD UNIT#1	12N/15E/35
RAINEY#122	13N/12E/22	MILLER#1	12N/14E/1
PINE#130	13N/12E/30	BROWN#1	12N/14E/4
MORTON#1	13N/12E/33	SHOCKLEY#1-11	12N/14E/11
BEETS#114	13N/11E/14	COLLINS#1	12N/14E/22
ANJET#93-A	13N/11E/22	MCGUIRE#1	12N/14E/29
WILLIAMS#1	13N/11E/24	PINE#3"SW"	12N/13E/3
STRANG#1	12N/27E/6	WEST#2	12N/13E/16
CATES#1-17	12N/27E/17	BURGESS#1A-19	12N/13E/19
BELAND HEIRS#1	12N/27E/29	PINE#2A	12N/13E/22
ARMER#1	12N/26E/3	PIERCE#1-30	12N/13E/30
UERLING#1	12N/26E/12	BIRD#2-A	12N/12E/4
GHOLSTON#1	12N/26E/21	ROBERTS#2	12N/12E/6
HOLMES#1-25	12N/26E/25	LAWSON#1-13	12N/12E/13
AUSTIN O'NEAL#1-29	12N/26E/29	BERRYHILL#1	12N/12E/17
TOUTZ HEIRS#1	12N/25E/21	THOMPSON#1	12N/12E/27
TOM & ECHO RIDER#1	12N/25E/29	WITHROW#B-1	12N/12E/33
POLASEK#1-5	12N/24E/5	RUBY#3	12N/11E/1
B. CHEEK#1	12N/24E/17	EASTOK-OKFUSKEE#6	12N/11E/9
GEORGE#1-25	12N/24E/25	LAMAR#1-A	12N/11E/17
CALAVAN#4	12N/19E/3	NAOMI STAFFORD#1	12N/11E/24
BUSE#1	12N/19E/21	KIRBY#28-12D	12N/11E/28
GRAHAM#1	12N/19E/29	ROBERTS#1	12N/10E/1
ROBBINS#1	12N/19E/30	BUCKEYE#1	12N/10E/6
SHINN#4	12N/19E/33	GUINN#1413"B"	12N/10E/14
F.H.#1	12N/19E/35	LINDSEY#4	12N/10E/18
CLAYTON#1-2	12N/18E/2	SPERRY#1	12N/10E/25
COX#1-7	12N/18E/7	COLONEL WOFORD#1	12N/10E/32
LOOSEN#1	12N/18E/11	GENEVIEVE#1-5	11N/27E/5
ROTT#1-36	12N/18E/36	HAWKINS#2	11N/27E/16
WOOD#1	12N/17E/7	KAY ROGERS#4	11N/27E/27
SUNG#1-8	12N/17E/8	PATES#1	11N/27E/29
EVERSOLE#1-9	12N/17E/9	ARKANSAS VALLEY FARMS#3	11N/27E/34
COMBS#1	12N/17E/13	CREWSON#1	11N/26E/1
HARDEN#1	12N/17E/17	GAGE#1-13	11N/26E/13

WELL NAME	LOCATION	WELL NAME	LOCATION
STOCKTON#1	11N/26E/20	BRANDON#1	11N/16E/17
PATES FARM#1-25	11N/26E/25	THOMPSON#1	11N/16E/17
BROWN#1	11N/26E/28	USA#1	11N/15E/4
PATES#35-A	11N/26E/35	RHEMA#1-20	11N/15E/20
PARKER#1	11N/25E/2	COLLUMS#1-22	11N/15E/22
GILBERT GREEN#1	11N/25E/4	GLENN#1-26	11N/15E/26
RANDOLPH#1-18	11N/25E/18	BUCK#1-31	11N/15E/31
HELMS#1-20	11N/25E/20	PATTON#1	11N/14E/1
LOWREY#1-33	11N/25E/33	BEVAN#2	11N/14E/8
B&F RANCH#2-23	11N/24E/23	KOCH#4	11N/14E/17
WILDHORSE#1-24	11N/24E/24	SIBERTS#1	11N/14E/29
MAYNARD#2-26	11N/24E/26	HAYNIE#1-35	11N/14E/35
FARGO#1-32	11N/24E/32	STECKEL BERG	11N/13E/9
WILD HORSE MOUNTAIN#1	11N/24E/32	WILLHITE#1	11N/13E/13
JACKSON UNIT#1	11N/24E/33	PINKSTON#1	11N/13E/20
HARVEY#1	11N/23E/8	TYLER-HUDSON#1-31	11N/13E/31
FEDRAL#1-23	11N/23E/23	MINYARD#134	11N/13E/34
CARLILE#1-24	11N/23E/24	ELMORE#1	11N/12E/3
WILLBORN#1-26	11N/23E/26	GUNNING#3	11N/12E/16
HOLT#132	11N/22E/32	TYLER-PIPPIN#1-25	11N/12E/25
COZART ESTATE#1	11N/21E/19	J.E. CHANCY#1	11N/12E/29
CARRIE T. HILL#1	11N/21E/23	PONNEQUIN#1-35	11N/12E/35
KNIGHT#7-A	11N/20E/7	PHAROAH#1	11N/11E/3
CALAVAN#1-18	11N/20E/18	RUBY JOHNSON#10-4	11N/11E/10
SKINNER#1	11N/20E/29	GRAYSON#1-22	11N/11E/22
REED#1	11N/20E/33	DUNSON#1	11N/11E/24
MONSANTO#1-4	11N/19E/4	HENDRIX#1	11N/11E/35
KUSLER#1	11N/19E/9	COWAN#2	11N/10E/1
F. H.#5-10	11N/19E/10	GROVES#1	11N/10E/5
MC BEE#1-13	11N/19E/13	MCMAHON#9	11N/10E/15
CARR#3-15	11N/19E/15	HIBLER#2	11N/10E/19
MATHEWS#2-22	11N/19E/22	KPC HICKORY RIDGE, LTD.#1	11N/10E/26
MC COULLOUGH#1	11N/19E/34	PALMER#34-1	11N/10E/34
COLEMAN#1-3	11N/18E/3	BONNIE THOMAS#1	11N/9E/1
STEWART#1	11N/18E/9	SILVERS#1	11N/9E/8
WINDSOR#4	11N/18E/16	F.M. HUMMINGBIRD#1	11N/9E/16
BRINSFIELD#20-11	11N/18E/20	HODGES#2-20	11N/9E/20
SIMPSON#1-25	11N/18E/25	OKEMAH#1	11N/9E/36
GRIFFITH#1	11N/17E/7	WILLIAMS#1-2	11N/8E/2
KOCH#15-11	11N/17E/15	DUKES#1	11N/8E/15
STORM#23-6	11N/17E/23	CAPEHART-MITCHAL#1-23	11N/8E/23
FUTRELL#1	11N/17E/30	ORR#27-1	11N/8E/27
STORM#34-6	11N/17E/34	EAST CROMWELL UNIT#401	11N/8E/34
CASSIE MIMS UNIT#1	11N/16E/7	ARKANSAS VALLEY FARMS#2	10N/27E/3

WELL NAME	LOCATION	WELL NAME	LOCATION
FORSGREN#1-15	10N/27E/15	MCCURTAIN SCOTT#1	10N/20E/23
WILSON#1	10N/27E/18	FUDGE#1-28	10N/20E/28
WILLIS#A-1	10N/27E/30	CARBONEX#1	10N/19E/1
BEATY#1	10N/27E/33	REED#1	10N/19E/9
CROWE#1	10N/26E/1	HOLCOMB#1-24	10N/19E/24
JAMES D. GALLOWAY#1	10N/26E/7	KETCHUM#1-27	10N/19E/27
COAN#3	10N/26E/16	WHITMAN#1-30	10N/19E/30
PAW PAW#1	10N/26E/24	BARNS#1-36	10N/19E/36
HOPE#1-32	10N/26E/32	E. G. GRIESEL#1	10N/18E/5
WILSON#1-36	10N/26E/36	HASKETT#A-1	10N/18E/16
ERNEST FOUTS#1	10N/25E/1	MANN "A"#1	10N/18E/19
BRANT#8-1	10N/25E/8	SUITER#1	10N/17E/1
BRANT#2-11	10N/25E/11	URQUHART"B"#1	10N/17E/20
GAMBLE#1-19	10N/25E/19	NIXON#A-1	10N/17E/24
LINKER#1-23	10N/25E/23	HAMMETT#A-1	10N/17E/28
REDLAND RANCH#10	10N/25E/33	URQUHART"A"#1	10N/17E/29
HALEY#1-2	10N/24E/2	SCHENEIDER#1	10N/16E/2
FARGO#1	10N/24E/4	ARTERBERRY#1	10N/16E/5
BIG COUNTRY#1	10N/24E/5	SHROYER#1	10N/16E/30
MAXWELL UNIT"C"#1	10N/24E/26	PRICE"H"#1	10N/16E/31
WOOD#1	10N/24E/29	HAGGARD#1-6	10N/15E/6
BLAYLOCK"C"#1-34	10N/24E/34	ADAMS#1-9	10N/15E/9
COWAN#1	10N/24E/36	T-BAR RANCH#219	10N/15E/19
TAYLOR#1	10N/23E/2	MONTGOMERY#1-22	10N/15E/22
SMITH#1-18	10N/23E/18	CECIL CRABTREE#1	10N/15E/30
WAYCOTT#1-19	10N/23E/19	PARKER BROTHERS#1-2	10N/14E/2
HARRISON#1-22	10N/23E/22	DONALD BROWN#1	10N/14E/15
MOORE#1	10N/23E/23	FINNEY#1-18	10N/14E/18
BALLARD#1-27	10N/23E/27	WEST OVERLOOK RANCH#21-1	10N/14E/21
GARLAND#2-32	10N/23E/32	S.W. RANCH#1-35	10N/14E/35
BROOKS#36-1	10N/23E/36	ERIN#1-A	10N/13E/4
HILL#1	10N/22E/5	LOAR#112	10N/13E/12
TYLER#1	10N/22E/10	IVAN HOLD#1	10N/13E/16
BEACH#26-A	10N/22E/26	CARTER#1	10N/13E/19
TATE#1	10N/22E/28	ESTOL#1	10N/13E/36
TIMMONS#1	10N/22E/36	VICTOR PAUL#14	10N/12E/6
PALMER#1	10N/21E/3	DOUGLAS#2	10N/12E/10
TERREL#1-14	10N/21E/14	HUDSON#1	10N/12E/16
WARD#C-1	10N/21E/20	LAWANDA#1	10N/12E/24
STORMENT#1	10N/21E/23	MODE#1	10N/12E/29
CHASTAIN#1	10N/21E/30	ADKINS#1	10N/11E/3
KECK#1	10N/20E/3	BURDEN#1-A	10N/11E/8
J. T. MCALESTER#1	10N/20E/16	SNELL HEIRS ESTATE#1-13	10N/11E/13
DRAKE#1	10N/20E/18	MAY#1-20	10N/11E/20

WELL NAME	LOCATION	WELL NAME	LOCATION
STANFORD#1-35	10N/11E/35	WADE WELLS#1	9N/24E/19
CRAMER#1-6	10N/10E/6	FESPERMAN#2-26	9N/24E/26
MAGNESS#1-10	10N/10E/10	STATE#1-32	9N/24E/32
SIMMONS#2	10N/10E/17	BLACK#1-35	9N/24E/35
BUTLER#1-30	10N/10E/30	BURRIS RANCH#1	9N/23E/5
WILSON#2-35	10N/10E/35	FOSTER#2	9N/23E/11
FOX#3	10N/9E/2	MOSBY#1	9N/23E/16
JANICE#1	10N/9E/9	BURRIS#2	9N/23E/19
WALKER#2	10N/9E/13	HAYES#3-23	9N/23E/23
PALMER LAND COMPANY#1-20	10N/9E/20	COMER#1-32	9N/23E/32
JARED#2-30	10N/9E/30	SPRING MOUNTAIN#1	9N/23E/35
PAPOOSE UNIT#34-2	10N/9E/34	WAYCOTT#1-3	9N/22E/3
PANTHER#1	10N/8E/2	BLAYLOCK#1-16	9N/22E/16
PEDERSON#1	10N/8E/6	ATKINS#1-24	9N/22E/24
EAGLE#1	10N/8E/15	KERR MCGEE"D"#2	9N/22E/28
SHELIA#1	10N/8E/23	TATE#2	9N/22E/30
RIFE-REED TRUST#1	10N/8E/29	DONNA KENNEDY#1	9N/22E/31
LINDLEY#1-35	10N/8E/35	FREDERICK#4-33	9N/22E/33
HENRY TRIMBLE#2	9N/27E/3	SHORT#1	9N/22E/35
LEAR-VLEET#1-5	9N/27E/5	GOWIN UNIT#1	9N/21E/2
JOE RICHISON#3	9N/27E/7	NEAL ET AL#1-6	9N/21E/6
GRAY#1-16	9N/27E/16	FLANAGAN#1	9N/21E/15
BATES#1-20	9N/27E/20	DIXON#19-2	9N/21E/19
PERKINS#2-27	9N/27E/27	MEMINGER#1-27	9N/21E/27
HARDIN#1	9N/27E/32	JOHN WELLS#1-28	9N/21E/28
PECAN RIDGE#1	9N/26E/3	ZEHNDER#1	9N/21E/29
TIBBITTS#7-1	9N/26E/7	MEANS#1-35	9N/21E/35
PETTIGREW#1	9N/26E/16	FRAZIER#1-3	9N/20E/3
MCDONALD#1-23	9N/26E/23	KIRK#1-7	9N/20E/7
HUCKOBEY#1	9N/26E/31	CONKLIN#18	9N/20E/8
REMORA#1	9N/26E/32	MCCLARY#1-11	9N/20E/11
NORA UNIT#1	9N/26E/35	TATE#1-15	9N/20E/15
BRANSCUM#1	9N/25E/1	QUICK#3-16	9N/20E/16
PHEBE#1	9N/25E/4	JOHNSON#2-17	9N/20E/17
FOXWOOD#3	9N/25E/6	QUICK#1	9N/20E/20
INDIAN NATIONS#3	9N/25E/10	FENTON#1	9N/20E/22
BRIDGES#20-A	9N/25E/20	BIG#1	9N/20E/24
BOLEN#1-26	9N/25E/26	ROYE ROYE#1	9N/20E/25
BAILEY UNIT#1	9N/25E/34	WILSON#1	9N/20E/26
JOHNIE REMER UNIT#1	9N/25E/36	BROWN#27-4	9N/20E/27
FOXWOOD#2	9N/24E/2	JESS BRYCE#1	9N/20E/28
E. D. BURRIS#1	9N/24E/5	BRAY#1	9N/20E/30
CORLEY#1-8	9N/24E/8	BAILES#33-5	9N/20E/33
NELSON#2	9N/24E/18	PERRY#1	9N/20E/35

WELL NAME	LOCATION	WELL NAME	LOCATION
TYLER#1	9N/19E/2	WOODROW WILSON#1	9N/14E/21
TYLER#1	9N/19E/3	LAWSON#1	9N/14E/23
BIGGER#1-17	9N/19E/7	SKINNER#1-25	9N/14E/25
PARKS#"F"1	9N/19E/9	HOPKINS#1	9N/13E/1
CASON#1A-11	9N/19E/11	CLAUDENE CAMPBELL#19	9N/13E/8
WHITEFIELD#2-13	9N/19E/13	JANEWAY#1	9N/13E/14
HALL BUTLER#1-14	9N/19E/14	ETHEL#1	9N/13E/24
ROGERS#D-1	9N/19E/15	COOKE#1-31	9N/13E/31
WREN#1-A	9N/19E/16	PRICE#1	9N/12E/4
HANLEY#1-18	9N/19E/18	WALLEYE ISLAND#1-8	9N/12E/8
GOLLON#1-23	9N/19E/23	FIFE#1	9N/12E/14
QUICK"C"#1	9N/19E/26	V.V.HARRIS#1	9N/12E/27
BEAR CREEK#1	9N/19E/31	LILE#1	9N/12E/30
TUCKER#1-32	9N/19E/32	HARRIS#1-3	9N/11E/3
UNDERWOOD#1	9N/19E/33	KEENE#1	9N/11E/7
MCKIBBONES#1	9N/19E/34	ROBISON"A"#1-15	9N/11E/15
BARBEE#1-13	9N/18E/13	PROCTOR#1-25	9N/11E/25
ADDITION#1	9N/18E/15	KACY ANNE#1	9N/11E/32
KIRK#1-21	9N/18E/21	BARGER#1-4	9N/10E/4
SEABOLT#1-22	9N/18E/22	JONATHAN CALE	9N/10E/14
HAMLIN#1	9N/18E/26	KRISTIN#1	9N/10E/20
TREASURE COVE#29-A	9N/18E/29	MCKEE#3	9N/10E/29
VERDEN"A"#3	9N/18E/31	MEADORS#1-36	9N/10E/36
TETER#1	9N/18E/35	PAPOOSE UNIT#3-7	9N/9E/3
ARDETH-SALLAS#1-3	9N/17E/3	OLIPHANT#1	9N/9E/7
BELT#1-24	9N/17E/24	MEADORS#1-21	9N/9E/21
VOILS#1-30	9N/17E/30	HARJO#8	9N/9E/26
1ST NATIONAL BANK&TRUST#1	9N/17E/34	CHAPMAN ESTATE#30-4	9N/9E/30
BROW#1	9N/17E/35	LODESTAR"A"#5	9N/8E/1
JANEWAY"A"#3	9N/17E/36	ALDRIDGE#1	9N/8E/8
SNEED"A"#1	9N/16E/4	ROGERS#5	9N/8E/16
G. H. JAMES#1	9N/16E/21	STAFFORD#22-2	9N/8E/22
CLARK BASS#1-25	9N/16E/25	COOK#1-33	9N/8E/33
MCDUFF#2-32	9N/16E/32	SPRADLEY#2	8N/27E/3
URQUAHART#236	9N/16E/36	HARGROVE#1-6	8N/27E/6
EWENS#1	9N/15E/4	IBISON#1	8N/27E/10
MARTIN UNIT#1	9N/15E/7	HALES#1-15	8N/27E/15
DYAS#1	9N/15E/11	FARRAR#1-29	8N/27E/29
FARROW#1-16	9N/15E/16	CASEY UNIT#1	8N/26E/1
KIMBERLING#1	9N/15E/19	WOMACK-WALTERS#1	8N/26E/9
CREEK TRIBE#1	9N/15E/29	TANKERSLEY#1	8N/26E/10
CONNERS#1	9N/15E/36	CAPELL#1	8N/26E/19
FISHER#2-4	9N/14E/4	BURTON#1	8N/26E/21
FISHER#114	9N/14E/14	HILL#1	8N/26E/31

WELL NAME	LOCATION	WELL NAME	LOCATION
BLASDEL#1	8N/26E/33	CHAD#1	8N/20E/24
HICKMAN#1-2	8N/25E/2	TUCKER#1	8N/20E/34
DANIEL#4	8N/25E/6	SPEARS#1-6	8N/19E/6
GREAT NATIONAL#1-10	8N/25E/10	GEORGIANNA#1	8N/19E/10
HICKMAN#1	8N/25E/19	BUTLER#2	8N/19E/11
TAYLOR"A"#1-32	8N/25E/32	GARRETT#1	8N/19E/12
COX#1-34	8N/25E/34	BEAVER CREEK#1-17	8N/19E/17
TACKETT UNIT "B"#1	8N/24E/1	BOWERS#1-23	8N/19E/23
RED BANK CREEK#1	8N/24E/3	WOODMORE#2	8N/19E/34
BOKOSHE#1	8N/24E/6	WACNON#A-2	8N/18E/4
CLARK#1	8N/24E/9	H.U. EAKLE#3-7	8N/18E/7
VIRGINIA#1-12	8N/24E/12	BLAND#1	8N/18E/16
ARLIE TACKETT#15-1	8N/24E/15	HIGGINS#1	8N/18E/23
DEW#1	8N/24E/19	CARL ZARTMAN#1-33	8N/18E/33
JOHNSON#1-24	8N/24E/24	EAKLE"A"#2	8N/17E/1
COCHRAN UNIT#1	8N/24E/32	BADSEN#1	8N/17E/10
LEON WATSON#1	8N/24E/32	M.G. EAKLE#1-12	8N/17E/12
LIZZABELL#2	8N/23E/3	RICHARDSON#1	8N/17E/13
MCBEE#1	8N/23E/7	ROBERTS#2	8N/17E/26
GRAHAM-MCBEE#4	8N/23E/12	WILLIAMS#1	8N/17E/31
LETHA BRIDGEMAN#3	8N/23E/16	METHODIST-EPISCOPAL#1-2	8N/16E/2
KENNEDY UNIT#2	8N/23E/19	O.H.SMITH#1-4	8N/16E/4
BESHERS#2	8N/23E/22	CANADIAN#2-7	8N/16E/7
BIRCKEL UNIT#2	8N/23E/29	SCHENEIDER#1	8N/16E/23
CLUCK#1	8N/23E/33	LAKE EUFALA#1-30	8N/16E/30
GOULD UNIT#2	8N/23E/35	ORBISON#1-1	8N/15E/1
STEELCO#2	8N/22E/5	ORBISON#2-12	8N/15E/12
D.R. CONDO#3	8N/22E/10	ORBISON-WEEKS#1-14	8N/15E/14
HIGHTOWER#2-X	8N/22E/18	PIERICE#2	8N/15E/16
HIGHTOWER#1	8N/22E/19	MCALESTER#1-18	8N/15E/18
U.S. GOVERNMENT#2	8N/22E/21	GRIFFIN#1	8N/15E/33
MCCAFFERTY UNIT#2	8N/22E/26	A.J.#1	8N/14E/4
PAULINE ALLEN#1-29	8N/22E/29	EARTHMAN#1	8N/14E/5
HOBBS#1-33	8N/22E/33	SHIRLEY#1	8N/14E/23
FOWLER"D"#1	8N/21E/6	PEARSON UNIT#1-29	8N/14E/29
SIBYL#1	8N/21E/9	DAVID TRAVIS#1	8N/14E/32
KERR-MCGEE#1	8N/21E/12	MOORES#1-2	8N/13E/2
MCMONIGLE#1	8N/21E/22	WELLS#3-4	8N/13E/4
HIGHTOWER#2-24	8N/21E/24	JOHNSON#2-9	8N/13E/9
BURGE#3	8N/21E/31	PENDLEY#1-11	8N/13E/11
HOUSE#1	8N/21E/35	LAYMAN#1-13	8N/13E/13
C.M. HODGES#1	8N/20E/9	WARREN G. BOGLE#1-16	8N/13E/16
SPESSARD#1	8N/20E/12	TUCKER#1	8N/13E/25
BRYANT#20-1	8N/20E/20	LOTT#3-29	8N/13E/29

WELL NAME	LOCATION	WELL NAME	LOCATION
LUCAS#1	8N/12E/3	COFFIELD#1	7N/24E/23
ROBERTS#1	8N/12E/5	ROY REED#1-29	7N/24E/29
MONROE#1	8N/12E/7	REED TRUST#1-35	7N/24E/35
HARRIS#1	8N/12E/11	ROY REED TRUST#2-35	7N/24E/35
GANN#B-1	8N/12E/20	WASSON#2	7N/23E/3
DEEP BYNAM#1	8N/12E/30	HAMMOND UNIT#1	7N/23E/4
RAMAY#1	8N/12E/31	REED#2-9	7N/23E/9
TURNER-PARKS#1	8N/12E/34	ROY REED"E"UNIT#1	7N/23E/15
WAMPUS CAT#1	8N/11E/3	ROY REED#F-5	7N/23E/16
SANDERS#1-12	8N/11E/12	STOUT#2-17	7N/23E/17
MAXWELL#1-21	8N/11E/21	REED#4-21	7N/23E/21
DIAMOND"A"#1-22	8N/11E/22	ROY REED#B-2	7N/23E/27
NANCY G.	8N/11E/35	LOWERY UNIT#2	7N/23E/34
C.N. GRIDER#1	8N/10E/5	HORTON#2	7N/22E/5
SMITH#1	8N/10E/12	KRAFTY#18	7N/22E/8
PERRYMAN#5	8N/10E/17	SADDLEBACK#1	7N/22E/15
PROCTOR#1	8N/10E/28	ARKANSAS KRAFT#1-19	7N/22E/19
POWELL#6	8N/10E/35	HENRY HILL "A" UNIT#1	7N/22E/25
GREENLEE#1-5	8N/9E/5	HORTON#1	7N/21E/2
FIXICO#1-12	8N/9E/12	SLOAN UNIT#2	7N/21E/6
BLACKBURN#1-26	8N/9E/26	PANTHER HOLLOW#2	7N/21E/14
GRIGGS#1	8N/9E/29	MADDEN#1	7N/21E/17
JESS CAMP#1	8N/9E/34	FERRELL#1-29	7N/21E/29
FLINT#1-1	8N/8E/1	GEORGE#9	7N/21E/36
CHAMBERS NEW#1-4	8N/8E/4	CLADYS MATHEWS#3	7N/20E/8
COHEA#1	8N/8E/17	WALKER"L"#1	7N/20E/10
MKB#1	8N/8E/26	HULSEY MOUNTAIN#1	7N/20E/20
BRANTLEY#1-33	8N/8E/33	BURRIS#1	7N/20E/24
MURPHY#1	7N/27E/3	JANKOWSKY#1-27	7N/20E/27
WILLIAM K. VEAZEY#1	7N/27E/28	JANKOWSKY#1-33	7N/20E/33
HANCOCK#1-29	7N/27E/29	BUFORD GUTHRIE#2	7N/19E/1
TUCKER#1	7N/26E/4	A. H. COX#2	7N/19E/5
GOODWIN#1	7N/26E/5	CARTER SNOW#2	7N/19E/13
HOLTON#1	7N/26E/6	QUINTON#2	7N/19E/20
JERRY ANGEL#1	7N/26E/23	PETE PARKS#3	7N/19E/32
ROBBS UNIT#1	7N/26E/26	BROWNE#1	7N/19E/36
LEFLORE LAND & CATTLE#1	7N/25E/8	OLSON#1	7N/18E/1
HANNA#1	7N/25E/10	BREEDLOVE#1-9	7N/18E/9
THOMPSON#1	7N/25E/12	CANFIELD UNIT#1	7N/18E/20
DOWNES#1-17	7N/25E/20	TREKELL#4	7N/18E/25
GARNER TRUST#1-30	7N/25E/30	WHITE#7	7N/18E/31
HOFFMAN UNIT#1	7N/24E/3	WHITE#12	7N/18E/31
GUNTER#3	7N/24E/6	WHITE FUEL#6	7N/18E/34
ROY REED EST.#1-9	7N/24E/9	BROWNE#1(9)	7N/17E/9

WELL NAME	LOCATION	WELL NAME	LOCATION
DEBORAH HUGHES#1	7N/17E/13	ECKLES#1-26	7N/10E/26
WHITE"Q"#1	7N/17E/25	GUNTHER#1	7N/10E/31
JOHN L. MARTIN	7N/17E/27	LYDA#4-1	7N/9E/4
WALLACE#1	7N/17E/30	CHAPMAN#1	7N/9E/10
HUGHES ROYALTY#2	7N/17E/36	PATTI BEAR#1	7N/9E/11
BROWNE#1	7N/16E/21	ROBINSON#1	7N/9E/25
BROWNE#1	7N/16E/28	JOHNSON#1-29	7N/9E/29
COCHRAN#1	7N/16E/36	HARVEY#1	7N/8E/3
COLLIER#1-3	7N/15E/3	JANIS#1	7N/8E/6
SHELTON"A"#2-7	7N/15E/7	NFJ#1	7N/8E/15
MCALESTER#1-23	7N/15E/23	HAYS#1	7N/8E/17
GUINN WELL#1-30	7N/15E/30	PHILLIPS#1	7N/8E/28
BUG TUSSLE#1-35	7N/15E/35	MOORE#1-36	7N/8E/36
MURRIN#1-1	7N/14E/1	DUNN#1	6N/27E/16
EVERETT#1	7N/14E/6	HARLOW#1-3	6N/26E/3
WARD "D"#1	7N/14E/18	WALTON#1-8	6N/26E/8
SANDERS#2-22	7N/14E/22	ROY REED#1	6N/26E/15
B&W-WARD#1-28	7N/14E/28	HULL#1	6N/26E/21
GRAHAM#1	7N/13E/14	RUNESTONE#1	6N/25E/9
CRANDELL#1-18	7N/13E/18	ROBERT S.KERR#1	6N/25E/17
HITCHCOCK#1-24	7N/13E/24	HAWKINS#1-7	6N/24E/7
STATE#1-35	7N/13E/35	JEAN SHADWICK#1-14	6N/24E/14
MADDEN#1-36	7N/13E/36	NOBLE THOMPSON#1	6N/24E/20
LOTT#1	7N/12E/2	MITCHELL#1	6N/24E/21
CARPENTER#1	7N/12E/5	C.C. JACKSON#1	6N/24E/29
OWEN#1-14	7N/12E/14	ROY REED#G-3	6N/23E/3
SHIRLEY JEAN#1	7N/12E/19	LEFLORE#2	6N/23E/6
STIPE#1-33	7N/12E/33	KANE#2A	6N/23E/8
STACY#1	7N/12E/35	R.W.REED#1	6N/23E/11
JEREMY-D#1	7N/11E/1	PARKS#B-3A	6N/23E/27
SARAH#1-4	7N/11E/4	BUTTRILL#1-34	6N/23E/34
B. BEAR#1	7N/11E/6	LEWIS UNIT#3	6N/22E/4
LANKFORD#1	7N/11E/7	FOSTER#1	6N/22E/7
FOLLANSBEE#2	7N/11E/12	LYONS UNIT#2	6N/22E/9
ANDERSON#1	7N/11E/16	CHARNEY UNIT#2	6N/22E/12
ANDERSON#1	7N/11E/17	RIDER UNIT#2	6N/22E/17
KAMPERMAN#1-27	7N/11E/27	KENT UNIT#2	6N/22E/19
KAMPERMAN#1-29	7N/11E/29	MYTON#8	6N/22E/22
ECKLES#1	7N/11E/31	FIELDS#131	6N/22E/31
ANITA#1	7N/11E/31	YANCEY#2-9	6N/21E/9
CHARLES#1-33	7N/11E/33	WILLIAM GALLAGHER UNIT#2	6N/21E/14
WILLIS#1-3	7N/10E/3	WHITE#2	6N/21E/18
COX#1-14	7N/10E/14	CECIL UNIT#5	6N/21E/24
SHED#1-18	7N/10E/18	MARY B. CORCORAN#1-29	6N/21E/29

WELL NAME	LOCATION	WELL NAME	LOCATION
WARD#1-1	6N/20E/1	MENEFEE#1	6N/13E/11
GIBSON#19	6N/20E/9	J.N. MILLER#2-12	6N/13E/12
SWART#1-20	6N/20E/20	ASHLEY#1	6N/13E/14
YOUNG&COOPER#1-26	6N/20E/26	HENRY#1-18	6N/13E/18
PIERCE#1-30	6N/20E/30	LEO#1	6N/13E/25
NETCALFE#1-34	6N/20E/34	ENGLEMAN#1-36	6N/13E/36
CLAYTON BROWNE UNIT#2	6N/19E/3	LEE#1	6N/12E/13
DOVIE WEAVER"A"#2	6N/19E/6	L. C. NULL#119	6N/12E/19
WEAVER#3	6N/19E/16	BLIGH-LUCY MORGAN ESTATE#1	6N/12E/33
GOLIGHTLY#1	6N/19E/24	SARAH BEAR#1	6N/11E/7
ADAMS UNIT C#2	6N/19E/33	ELLEN#1-19	6N/11E/19
WHITE"B"#2	6N/18E/3	FARRELL#1	6N/11E/22
MARY WHITE#48	6N/18E/8	LINDLEY#1-30	6N/11E/30
SCRUGGS#1-14	6N/18E/14	RICHARDSON#1	6N/11E/33
USA ANDERSON-PRITCHARD#2	6N/18E/25	EDWARDS#1-9	6N/10E/9
FAZEKAS#1-32	6N/18E/32	JACKIE#11-1	6N/10E/11
BILLY HECKMAN#2-34	6N/18E/34	KIRBY#18-1X	6N/10E/18
EMMA WHITE#3	6N/17E/1	LONDON#1	6N/10E/23
OWENS#E-1	6N/17E/8	WILBANKS#2-27	6N/10E/27
WHITE"F"#1	6N/17E/13	BENCH#1-31	6N/10E/31
MARY LOU#1-25	6N/17E/25	CARRIE#1	6N/9E/1
BROWNE#1	6N/17E/28	STAFFORD#1-6	6N/9E/6
LAKE EUFULA#1-2	6N/16E/2	SKINNER-DAVIS#5	6N/9E/12
WARD#A	6N/16E/9	SHERRY#1-24	6N/9E/24
BALDWIN-PETTITT#1	6N/16E/11	MILLER#1	6N/9E/36
DAVIS KEMP#1	6N/16E/16	BRYANT#1	6N/8E/9
DURANT#1	6N/16E/17	LOVE#1	6N/8E/13
KEITH#1	6N/16E/19	ADAMS#1-18	6N/8E/18
OPAL#1	6N/16E/20	COX#1	6N/8E/27
E.C. MCKINZIE#1	6N/16E/23	PALMER STAR#1	6N/8E/32
LALMAN ESTATE#1-2	6N/15E/2	WARD#1	5N/26E/20
BULLARD#1-5	6N/15E/5	WEBB#1	5N/25E/18
SILVA#1	6N/15E/21	SHORT UNIT#1	5N/25E/19
ROUSE#1	6N/15E/23	STACEY UNIT#1	5N/25E/20
MINNIE#2	6N/15E/24	C.H.PEBSWORTH#1	5N/25E/23
PHIPPS#136	6N/15E/36	U.S.A. UNIT#1-WELL#1	5N/24E/7
SHERIA STRONG#1	6N/14E/4	S.L.SUTTON#1	5N/24E/18
USELTON#1-6	6N/14E/6	WISTER LAKE#16-1	5N/23E/16
MILLER#3-7	6N/14E/7	3904 JV-P HOLLAN#1	5N/23E/20
ARNOT ESTATE#2	6N/14E/15	NEVIL#1-21	5N/23E/21
ROSS#1	6N/14E/18	BLACKJACK RIDGE#1-17	5N/22E/8
LENDRA#1-19	6N/14E/19	WILSON#1-15	5N/22E/15
JAYNELLE#1	6N/13E/3	SIERRA#1-18	5N/22E/18
BANKS ESTATE#1	6N/13E/10	INGLE#1	5N/22E/21

WELL NAME	LOCATION	WELL NAME	LOCATION
TALIHINA#1-31	5N/22E/31	J. VERNON BLACK#1	5N/12E/28
GARNER#1-2	5N/21E/2	WILDHORSE#1	5N/11E/1
ALFORD"A"#1-15	5N/21E/15	OLIVER#1-3	5N/11E/3
SMITH ENGLISH#A-1	5N/21E/36	BIVINGS#1-9	5N/11E/9
FOSTER#1-1	5N/20E/1	REDMAN#1	5N/11E/21
DEAR#1	5N/20E/8	WILBANKS#1	5N/11E/29
CINDY#1-21	5N/20E/21	LOFTIS#33-1	5N/11E/33
RAYMOND SMITH#1	5N/20E/26	CITIES SERVICES#1	5N/10E/4
NICHOLSON A#1-22	5N/20E/27	TUCKER#8-A	5N/10E/8
H&H CATTLE CO"A"#131	5N/20E/31	JENSON#1	5N/10E/20
COX#1-28	5N/20E/33	SPIKER#1-28	5N/10E/28
JANEWAY#1-11	5N/19E/11	MCDOUGAL#1	5N/10E/32
OTHO ENIS#1-12	5N/19E/12	DEXTER CLENNEY#1	5N/9E/1
HEITNER#1-13	5N/19E/13	PHILPOT ENTERPRISES#1	5N/9E/6
VIRGINIA WALKER UNIT#1	5N/19E/32	JAMES NIX#2	5N/9E/14
ERLAINE WHEELER#251	5N/19E/36	TREAT#3	5N/9E/23
RAUNIKER#2-8	5N/18E/8	COGDILL#1-29	5N/9E/29
ROBINSON#2-12	5N/18E/12	STOVER#1-2	5N/8E/2
KILPATRICK#3	5N/18E/16	PUNLUSTE"A"#5-W	5N/8E/8
STATE"C"#2	5N/18E/28	PERRY A-49W	5N/8E/20
PICARO#2-36	5N/18E/36	F.R. HARRISS#4	5N/8E/24
VAUGHN#1	5N/17E/12	ANGLIN PROPERTIES#1	5N/8E/36
PAULINE BOWMAN#5	5N/17E/20	ELLIS#1	4N/21E/4
PETTIT#5-31	5N/17E/31	LADY LUCK#1-28	4N/21E/28
HARE#1-33	5N/17E/33	SMALLWOOD#1-3	4N/20E/3
DELIA HOLT#1	5N/17E/35	WINDING STAIR#2-14	4N/20E/14
COOK"K"#1	5N/16E/14	BEAR SUCK KNOB#1-7	4N/20E/18
GEORGE B. HALL#1	5N/16E/17	CLEMONS#1	4N/19E/8
GEORGE PEDEN#2	5N/16E/24	HOLSTEN#1	4N/19E/11
SMITH#2-30	5N/16E/30	JAMES A#1-16	4N/19E/16
WOODS PROSPECT UNIT#2	5N/16E/36	COLONY#1-23	4N/19E/23
DOUGLAS#13-1	5N/15E/13	PINE CREEK#1-30	4N/19E/30
ANDERSON#1-28	5N/15E/28	REVERE#1-1	4N/18E/1
MELVIN#1	5N/15E/35	MABRY TRUST#1-5	4N/18E/5
CHOCTAW STATE#1-4	5N/14E/4	DOLLINS#1-13	4N/18E/13
CRAWLEY#1	5N/14E/10	9001 JV-P WORKMAN#1	4N/18E/22
CRAWLEY#1	5N/14E/16	TNT#1-34	4N/18E/34
LEHNHARD UNIT#1	5N/14E/17	HARTSHORNE#3	4N/17E/6
WINNIE GIBSON#1	5N/13E/4	BLUE MOUNTAIN#1	4N/17E/22
HOPKINS#1	5N/13E/13	TOMLIN UNIT#1	4N/17E/29
MASON#1-15	5N/13E/15	MOSE WATTS#36-1	4N/17E/36
CHILDERS UNIT#1	5N/13E/24	SMALLWOOD UNIT#2	4N/16E/10
HARDIN#3-1	5N/12E/3	LEWIS#4-12	4N/16E/12
ORR"B"#1	5N/12E/11	BUDDY SHERRILL#16-1	4N/16E/16

WELL NAME	LOCATION	WELL NAME	LOCATION
LOVELESS#1-30	4N/16E/30	DROMGOLD#1	3N/16E/4
DROMGOLD"D"#35-1	4N/16E/35	J.A. COLLINS#6-3	3N/16E/6
ELLIS#1-8	4N/15E/8	NORTON#11-1	3N/16E/11
MARY MARGARET#1	4N/15E/15	SWEETIN"A"#1	3N/16E/17
MARY MARGARET#2	4N/15E/15	J.A. GODDARD#1-3	3N/15E/1
CABLE#1-19	4N/15E/19	WILLIAMS#1-7	3N/15E/7
HACKLER#1-21	4N/15E/21	ISBELL#1-16	3N/15E/16
WHITING#2	4N/15E/25	SWEETIN#1	3N/15E/23
WEST UNIT#1	4N/15E/27	CRUTCHFIELD#1	3N/14E/6
VAN DYKE#1	4N/15E/35	BIGGERS#A-1	3N/14E/8
CRABTREE#B-1	4N/14E/22	ECHELLE#2-9	3N/14E/9
HARRIS I#2	4N/14E/24	PITTSBURG#2	3N/14E/20
ROMINE#1	4N/14E/28	DON SCOTT#2-29	3N/14E/29
MCCLAIN"30"FED.COM.#1	4N/14E/30	CHRISTMAN#1	3N/14E/36
PEARL#1-A	4N/14E/32	CRUTCHFIELD#1	3N/13E/1
DAVIS"Q"#1	4N/14E/32	NAVAL DEPOT#1	3N/13E/5
AEC WEINGARTEN#1-36	4N/13E/36	CALDWELL#1-14	3N/13E/14
PHILLIPS#1	4N/12E/6	CRESCENT OIL#1-22	3N/13E/22
ARMY AMMO#12-1	4N/12E/12	CORONADO UNIT#A-1	3N/13E/28
DUKE#1	4N/12E/17	SNIDER#1	3N/13E/35
BAIN#A-1	4N/12E/30	NAVY UNIT#1	3N/12E/1
DUNN#1-34	4N/12E/34	MCCLUNG#2-10	3N/12E/10
W. E. LACKEY#1	4N/11E/3	C. SMITH#4-17	3N/12E/17
SNYDER#1-18	4N/11E/18	VAUGHN#5-20	3N/12E/20
CORONADO#1-22	4N/11E/22	SHIELDS#1	3N/12E/23
MCNUTT#1	4N/11E/24	QUADE#9-30	3N/12E/30
SELLERS#2	4N/11E/35	CUNNINGHAM#1-13	3N/11E/13
THORNTON#1-4	4N/10E/4	PASQUALI#1	3N/11E/20
WOODALL#1-A	4N/10E/9	LEMONS#4-25	3N/11E/25
PRIEST#1-10	4N/10E/10	WATTERSON#26-1	3N/11E/26
JASON#1	4N/9E/2	CUNNINGHAM#2	3N/11E/34
WILSON#1	4N/9E/11	MORAN#2-36	3N/11E/36
TATUM#1	4N/9E/21	SELLS#1	3N/10E/4
BALLINGER#1-22	4N/9E/22	CHILES DOME#5	3N/10E/18
NOEL#2	4N/9E/27	CHILES DOME#6	3N/10E/19
HAMILTON#2	4N/9E/32	VAN HALEN#1-30	3N/10E/30
ASHER#1	4N/8E/5	REARDEN#33C-2	3N/10E/33
J.B. PRINCE#B-2	4N/8E/7	N.B. HUNT#1	3N/9E/1
MINNIE O#1	4N/8E/9	HAMILTON#1-8	3N/9E/8
MOFFAT#1-89	4N/8E/12	HAMILTON#18-1	3N/9E/18
HOPE-BUSBY#1	4N/8E/16	BLUTARSKY#1-25	3N/9E/25
HARRIS#22-29	4N/8E/29	BADLEY"C"#1	3N/9E/33
RETHERFORD#1	3N/18E/5	CLEMONS#1	3N/8E/2
LONGREACH A#1	3N/17E/19	MASHIER#21-1	3N/8E/21

WELL NAME	LOCATION	WELL NAME	LOCATION
WHISENHONT#1	3N/8E/22	MAYER#6-17	1N/10E/17
MAYER#1	3N/8E/29	BATTLES#1-19	1N/10E/19
GLADYS ROSE#1	2N/14E/5	JONES#1-29	1N/10E/29
JACK AINSWORTH#1	2N/14E/11	AXTON#1	1N/10E/30
RUBY"A"#1	2N/14E/17	JONES "A"#1-32	1N/10E/32
VAUGHN-DUVALL#1-3	2N/13E/3	WATKINS#1-34	1N/10E/34
SELF#1-12	2N/13E/12	MAYER#3-1	1N/9E/1
J.J. CHASTAIN UNIT WELL#2	2N/13E/25	M&R RANCH UNIT#1	1N/9E/2
PINE MOUNTAIN#1-35	2N/13E/35	COGBURN#1	1N/9E/15
MOWDY#1-5	2N/12E/5	DEMOND PARKER#1-30	1N/9E/30
NEWBERRY#12-1	2N/12E/12	DANIEL#1	1N/9E/32
MCENTIRE#1	2N/12E/20	EFFIE MAE#1-35	1N/9E/35
O.V. HAWKINS#1	2N/12E/28	R.A. DAVIS#1	1N/9E/36
CLOTHFELTER#1	2N/12E/34	LOGSDON#2	1N/8E/2
WILSON#6-1	2N/11E/6	HOCKETT#1-3	1N/8E/3
CLAUD MOWDY#1	2N/11E/10	BILLS#1-11	1N/8E/11
THOMAS#1-24	2N/11E/24	ELVIS#1-23	1N/8E/23
CROW#1-34	2N/11E/34	HUDSON#1-26	1N/8E/26
BARNES#1-2	2N/10E/2	PAXTON#1	1S/11E/7
RUSHING#1	2N/10E/18	CURTIS NOEL#1	1S/11E/32
PRIDE#1-29	2N/10E/29	JONES#1	1S/10E/5
MORGAN#1-2	2N/9E/2	MOWDY#1	1S/10E/6
GREEN#1	2N/9E/6	MANNING#1-27	1S/10E/27
ROBINS#16-A	2N/9E/16	RILEY#2-3	1S/9E/3
CRANE#2-20	2N/9E/20	MAYER#1	1S/9E/12
CRANE#1-28	2N/9E/28	MURPHY#1-28	1S/9E/28
POLER#2-36	2N/9E/36	CHITWOOD#1-3	2S/11E/3
PARKS#1-2	2N/8E/2	HARAWAY#1-27	2S/11E/27
ELLIS#1-3	2N/8E/3	GRAHAM#1	2S/10E/6
M.G. KELLOGG#1	2N/8E/4	CARR ESTATE#1-13	2S/10E/13
WOOLEY#7-1	2N/8E/7	THOMAS#1-34	2S/10E/34
NEWPORT#8-1	2N/8E/8	BOWMAN#19-1	2S/9E/19
MURPHY#1	2N/8E/12		
STALLCUP#1-15	2N/8E/15		
SANDO#22-7	2N/8E/22		
NORRIS#1A-31	2N/8E/31		
HUNT#1-5	1N/14E/5		
J.C. LAFEVERS#10-2	1N/13E/10		
ATOKA WILDLIFE#1	1N/12E/23		
MCENTIRE ESTATE#10-A	1N/11E/10		
MCENTIRE#11A	1N/11E/11		
MCENTIRE#1-15	1N/11E/15		
MILLER UNIT#1	1N/11E/28		
PATRICK#1	1N/10E/8		