OKLAHOMA GEOLOGICAL SURVEY
OPEN-FILE REPORT 46-2004

Petroleum Geology of the Deepwater Jackfork Group and Atoka Formation,

With a Primer on the Petroleum Geology of Deepwater Depositional Systems

Presented by

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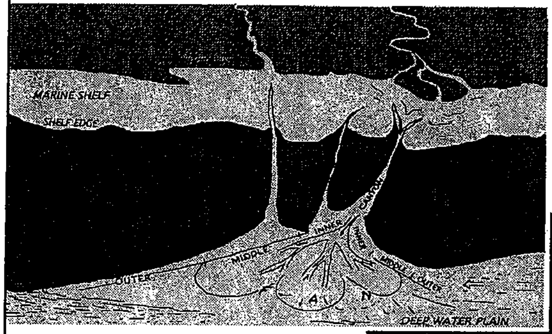
Unit 3: Geology of the Jackfork deepwater deposits with emphasis on exploration applications

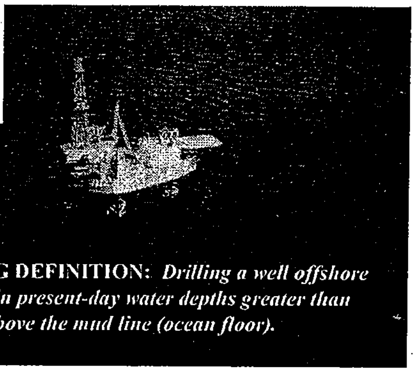
Unit 1: DEEPWATER (TURBIDITE) DEPOSITS & RESERVOIRS

GEOLOGIC DEFINITION: ***Clastic sediments transported beyond the shelf edge into deep water by sediment gravity flow processes and deposited on the continental slope and in the basin. They are later buried and become part of a basin fill.***

Engineering and geologic 'deep water' are usually the same, but for different reasons.



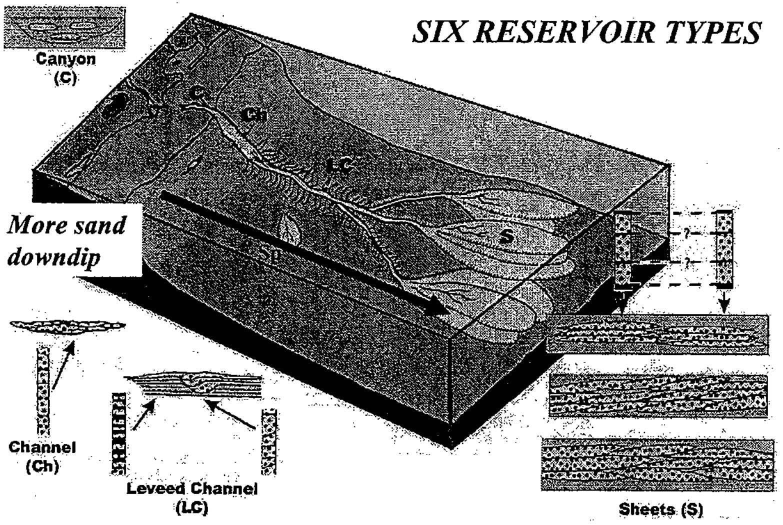
"DEEP WATER"



ENGINEERING DEFINITION: ***Drilling a well offshore into a basin fill in present-day water depths greater than 500m (1500ft) above the mud line (ocean floor).***

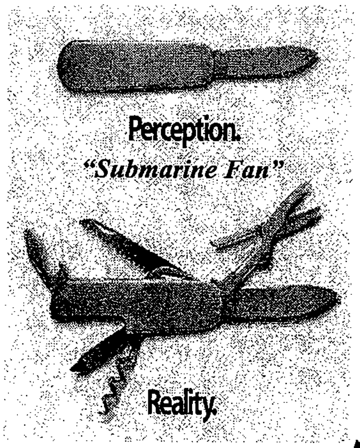
FINE-GRAINED, DEEPWATER ARCHITECTURAL ELEMENTS

SIX RESERVOIR TYPES

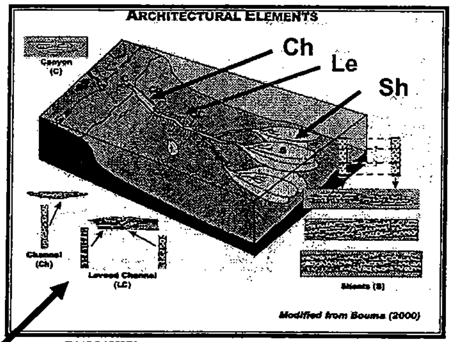


More sand downdip

Modified from Bouma (2000)



"Architectural elements" of a **submarine fan**



ARCHITECTURAL ELEMENTS

Ch

Le

Sh

Canyon (C)

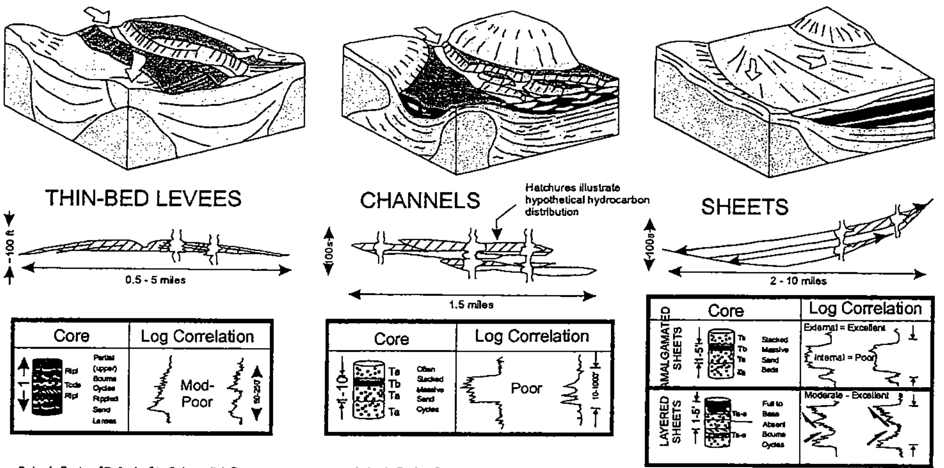
Channel (Ch)

Leveed Channel (LC)

Sheets (S)

Modified from Bouma (2000)

-Channels
-Sheets
-Levees



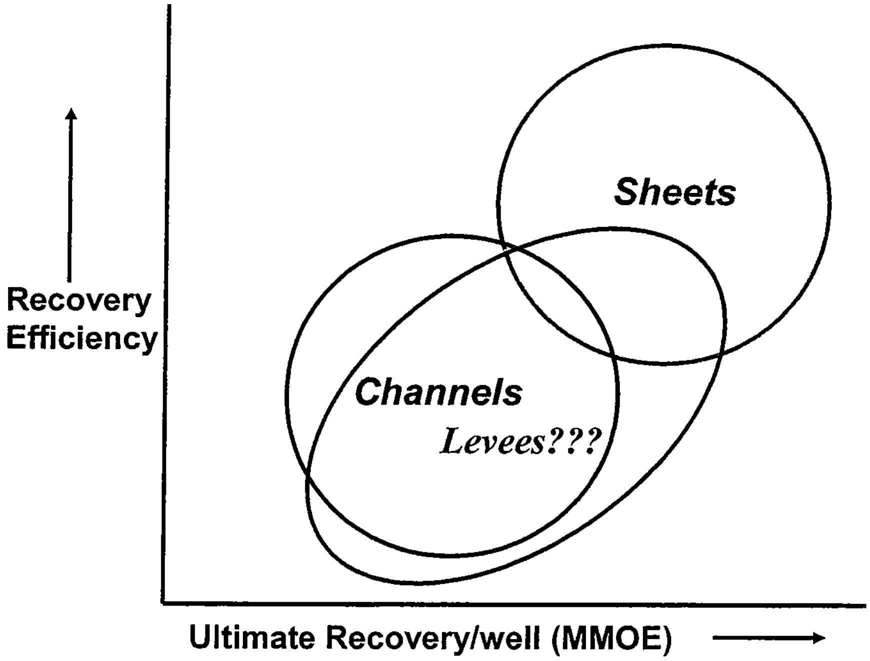
-Seismic Facies: "Gull-wing" to Subparallel, Poor to Fair Continuity
-Log Profile: Subdued, Serrate (to Fining-up)
-Log Correlatability: Moderate to Poor
-Thinly Bedded/ Laminated Sands/Silts (<4" beds)
-Insignificant Amalgamation

-Seismic Facies: Discontinuous, Subparallel
-Log Profile: Variable (to Fining-up)
-Log Correlatability: Poor
-Thick- to Thin-Bedded Sands
-Most Thick Sands (>5') Are Amalgamated

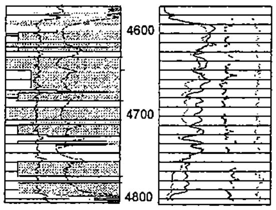
-Seismic Facies: Parallel (to Slightly Shingled), Laterally Continuous
-Variable to Coarsening-Up Log Profile
-Log Correlatability: Moderate - Excellent
-Mostly Thick Sand Beds (>4"); Boumas
-Most Thick Sands (>5') Are Amalgamated

(Chapin et al., 1994)

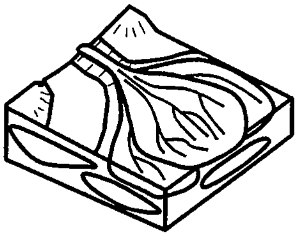
(sketched from Schwartz, 2003)



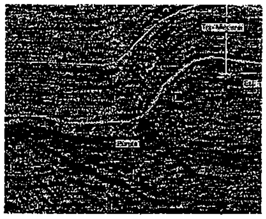
Tools for Deepwater turbidite reservoir characterization



Conventional logs

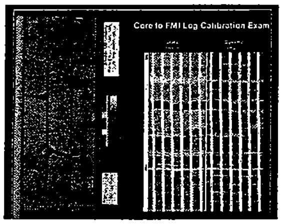


Conceptual model

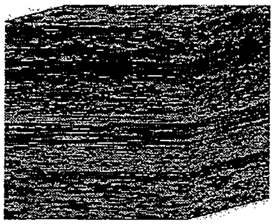


Seismic reflection

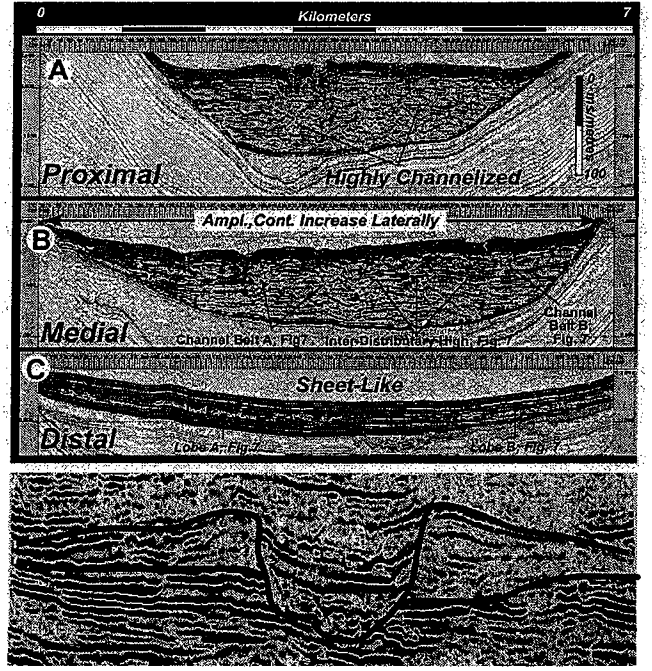
Outcrops



Cores & borehole image logs



Computer 3D geologic models



Downfan

Proximal
Channel fill

Medial
Channel fill

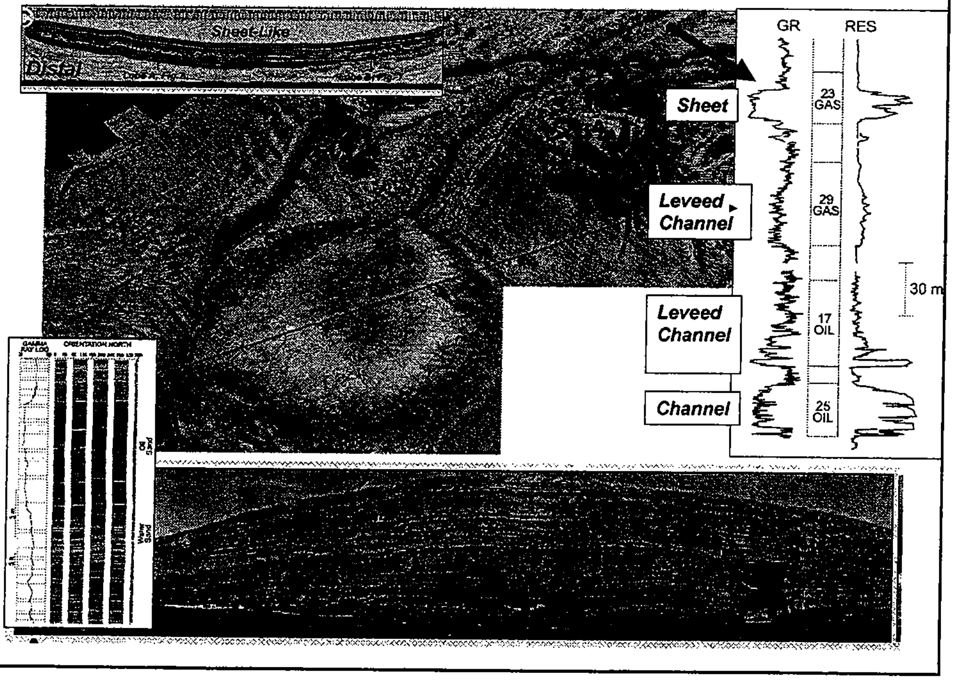
Distal
Sheet

Medial
Leveed
Channel

DEEPWATER (TURBIDITE) DEPOSITS & RESERVOIRS:

Sheet Sandstones & Reservoirs

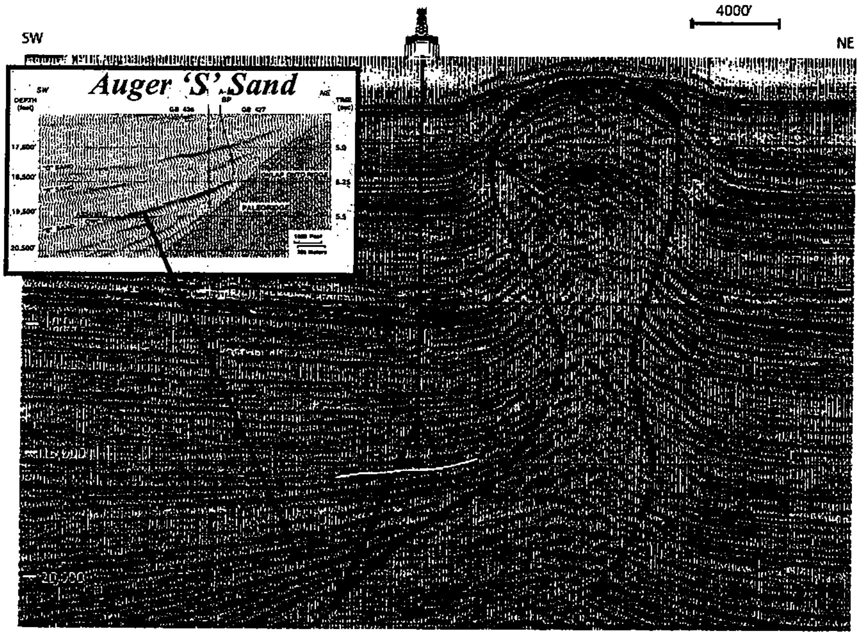
Sheet



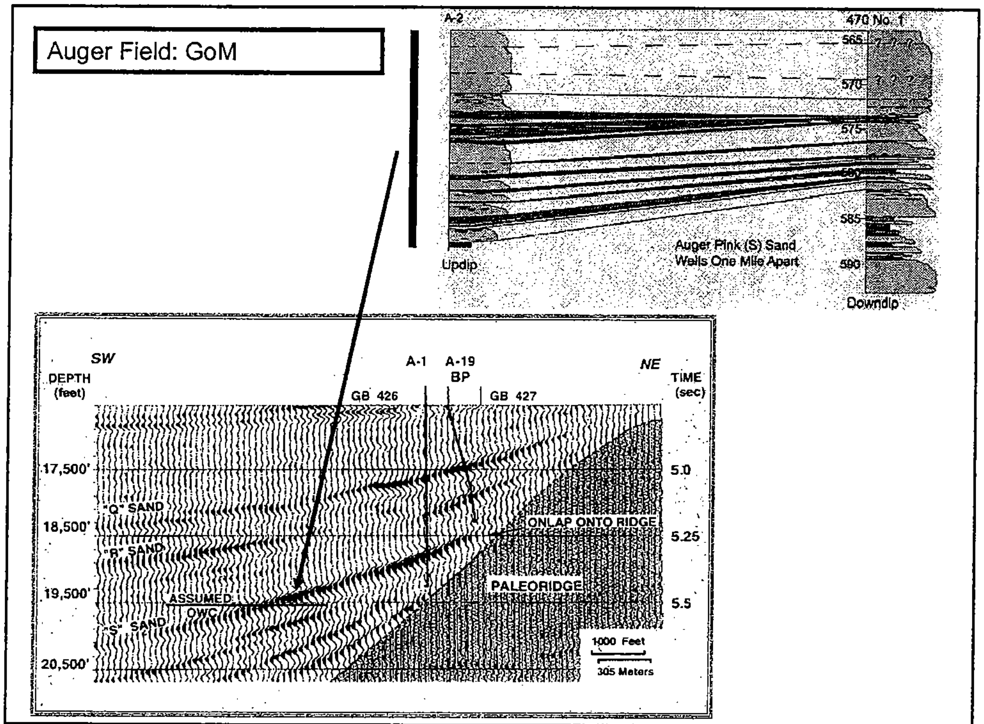
SHEET SANDSTONE EXAMPLES

S Sand, Auger Field; Gulf of Mexico (Kendrick, 1998)

-120MMBE assigned to S Sand
-As of 2000, 7 wells have produced 110 MMBE
-Field occurs within a salt-withdrawal mini-basin
-Combination fault-stratigraphic pinchout trap
-layered/amalgamated sheet sands , and shales extend across entire basin
-oil-bearing zones beneath water-bearing zones
-Excellent aquifer support
-Pulsed Neutron Capture (PNC) logs record replacement of oil by water during development; indicate that some shales isolate sands and others do not
-PNC data do not confirm that the 20ft. thick shale separating S1 and S2 sands is a barrier; however, other shales are barriers
-Different types of shales with different sealing potential?? Can these be recognized??

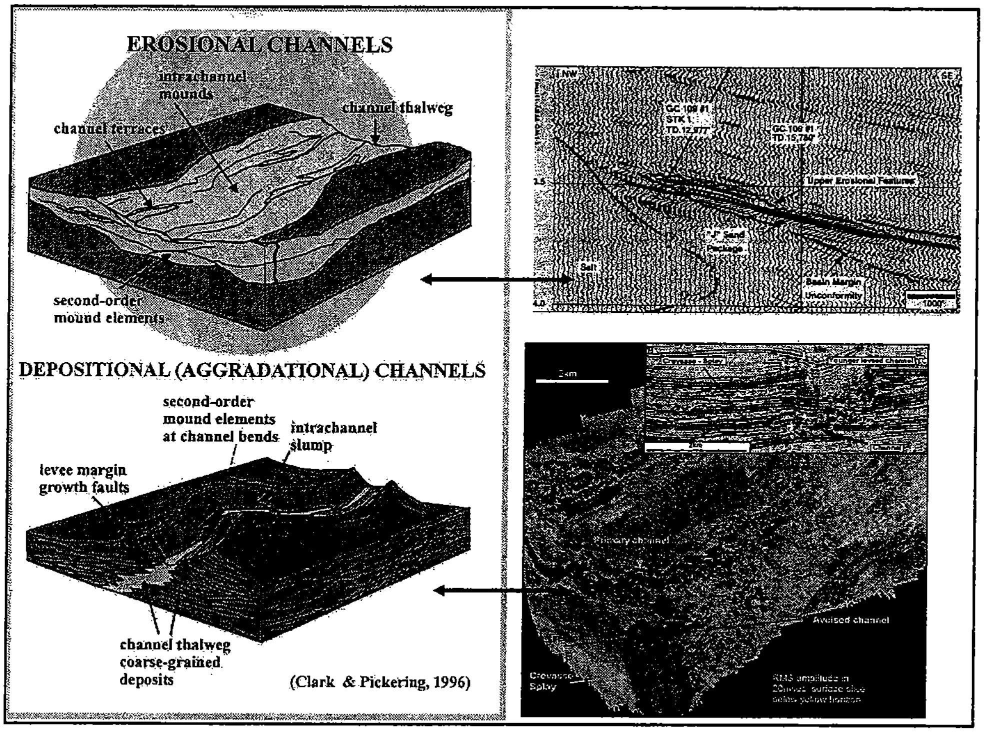


Auger Field: GoM



DEEPWATER (TURBIDITE) DEPOSITS & RESERVOIRS:

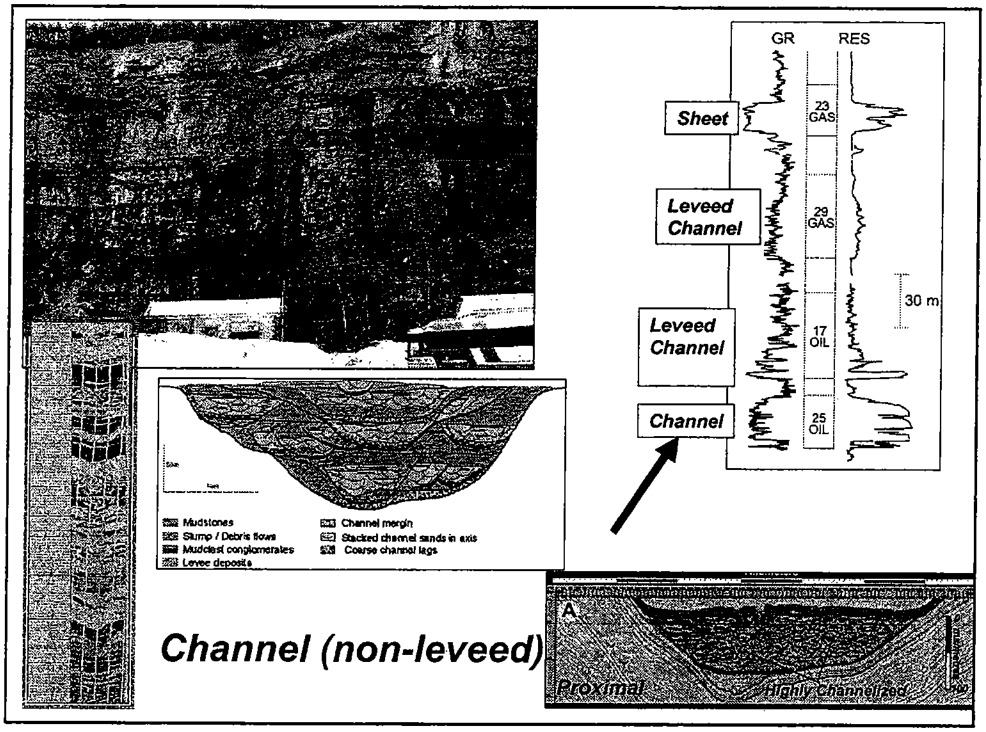
Channel fill sandstones & reservoirs



EROSIONAL CHANNELS

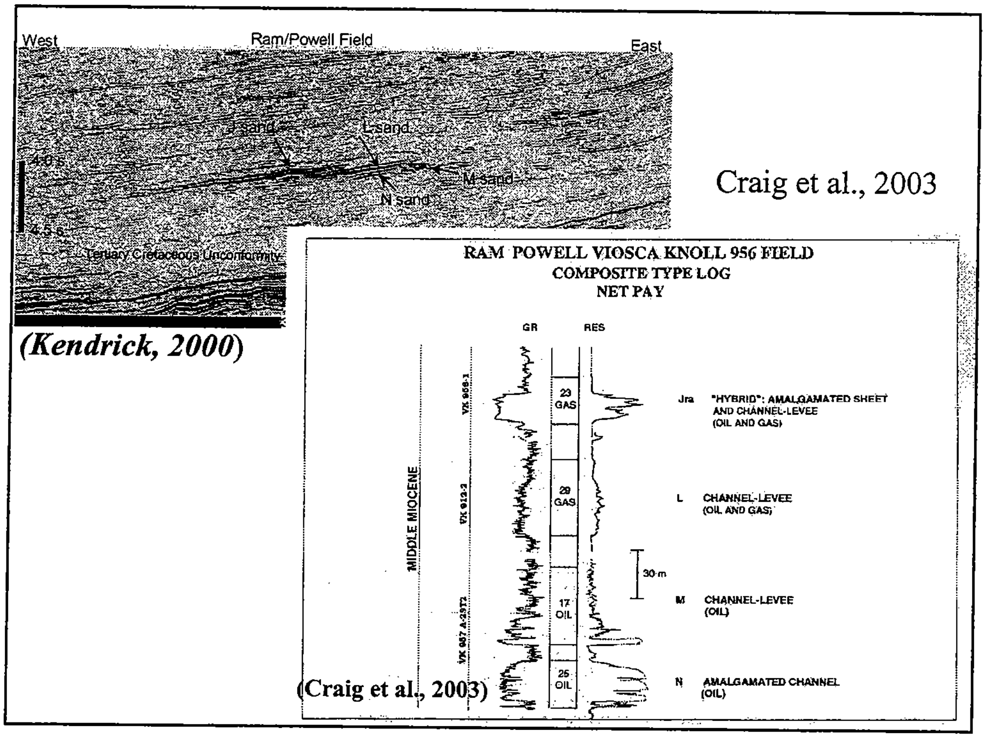
DEPOSITIONAL (AGGRADATIONAL) CHANNELS

(Clark & Pickering, 1996)



- ▦ Mudstones
- ▦ Slump / Debris flows
- ▦ Mudclast conglomerates
- ▦ Levee deposits
- ▦ Channel margin
- ▦ Stacked channel sands in axis
- ▦ Coarse channel lags

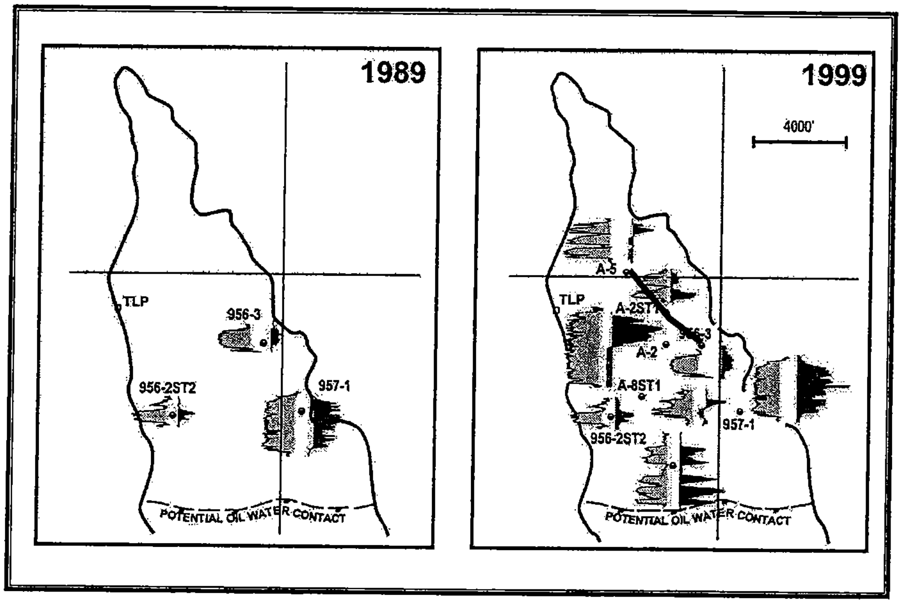
Channel (non-leveed)



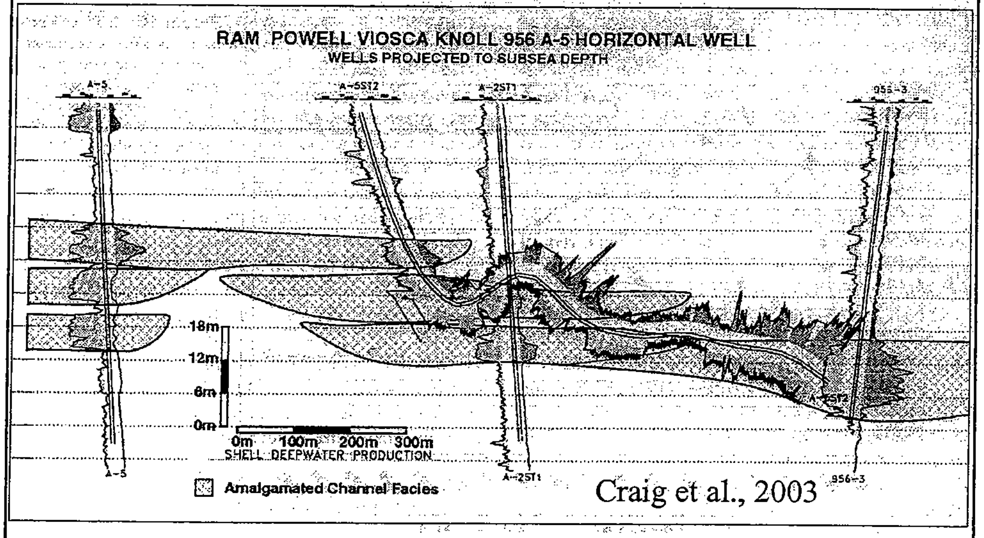
(Kendrick, 2000)

Craig et al., 2003

(Craig et al., 2003)

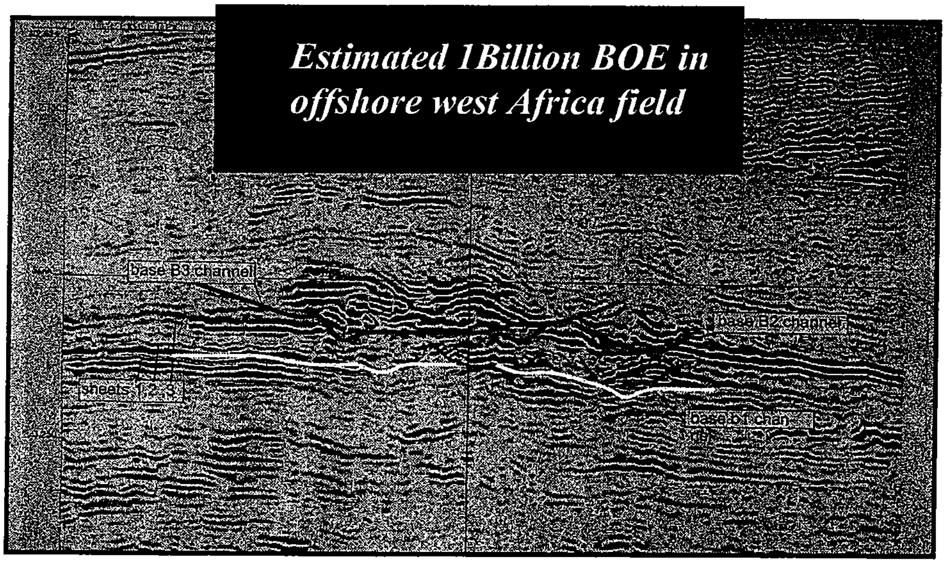


(Kendrick, 2000)



Craig et al., 2003

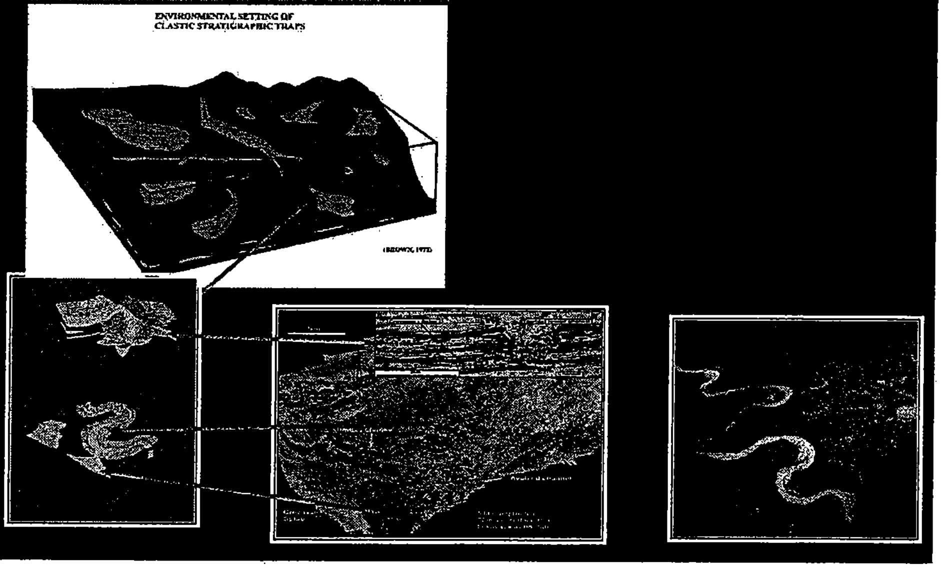
Estimated 1Billion BOE in offshore west Africa field

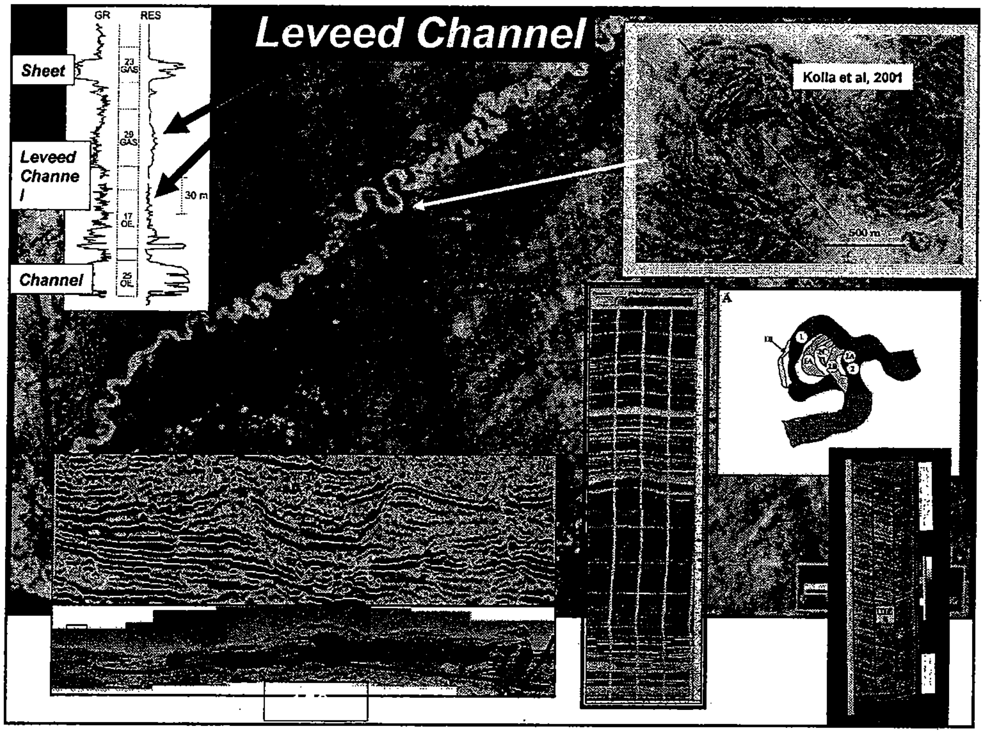


DEEPWATER (TURBIDITE) DEPOSITS & RESERVOIRS:

Levee-overbank deposits & reservoirs

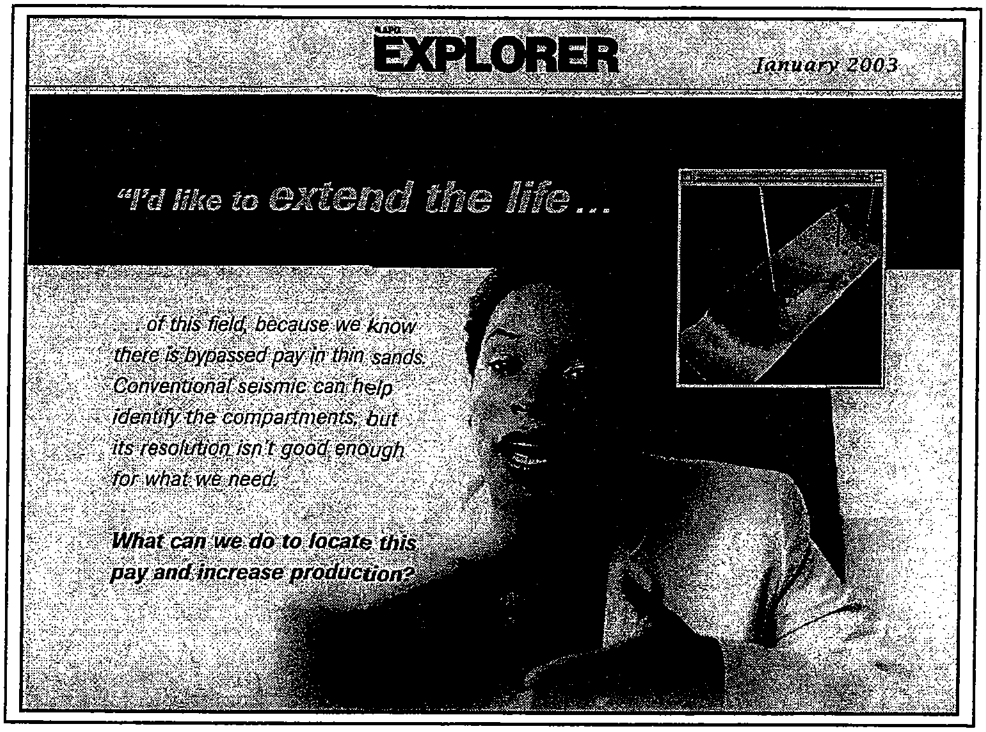
Leveed Channel deposits and reservoirs





Leveed Channel

Kolla et al, 2001



AAPG EXPLORER

January 2003

"I'd like to extend the life...

...of this field, because we know there is bypassed pay in thin sands. Conventional seismic can help identify the compartments, but its resolution isn't good enough for what we need.

What can we do to locate this pay and increase production?

Ram/Powell, L Sand, Gulf of Mexico (Clemenceau et al., 2000)

- L Sand comprised of *channel, proximal* and *distal levee* facies
- Channel is 1500-2000ft. wide, contains 25-100ft. water wet sand
- Gas charged, east levee extends 15,000 ft. to east of channel
- Reservoir is thin-bedded levee/overbank facies; individual sands are 0.04-1 inch thick!!
- Sand porosities = 15-32%(X=28%); k = <10-1000md (X=300)
- Single 2,500ft. horizontal well in proximal levee facies peaked at 8.8MBOPD & 108MMCFGD. This well has produced 4.8MMBO & 61.5BCF (15.4MMBOE from 9/97(?)-5/00.
- 4 day well test in 50ft. thick distal levee flowed 23MMCFGD and 2700BC/D with PTA perms of 143md.
- Good lateral continuity and pressure communication across entire 4000 acre proximal levee reservoir
- Channel and levee sands are NOT in communication, as determined from pressure data
- Gas sands give good seismic amplitudes, water sands do not
- Dip patterns differ in proximal and distal levee strata, as is the case in Mt. Messenger Fm. outcrops

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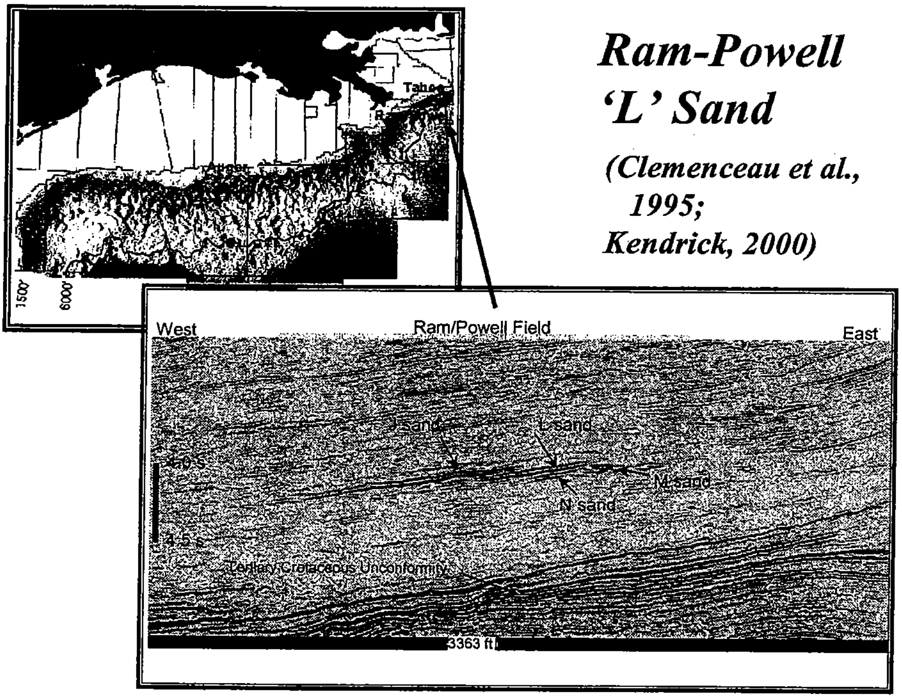
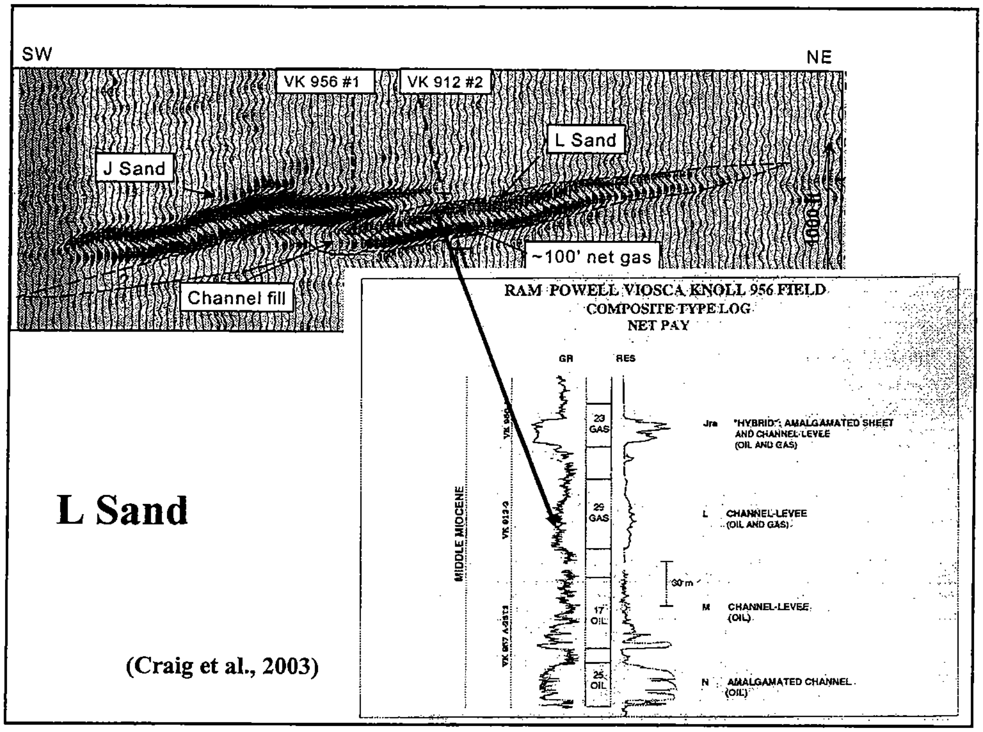
Ram-Powell 'L' Sand

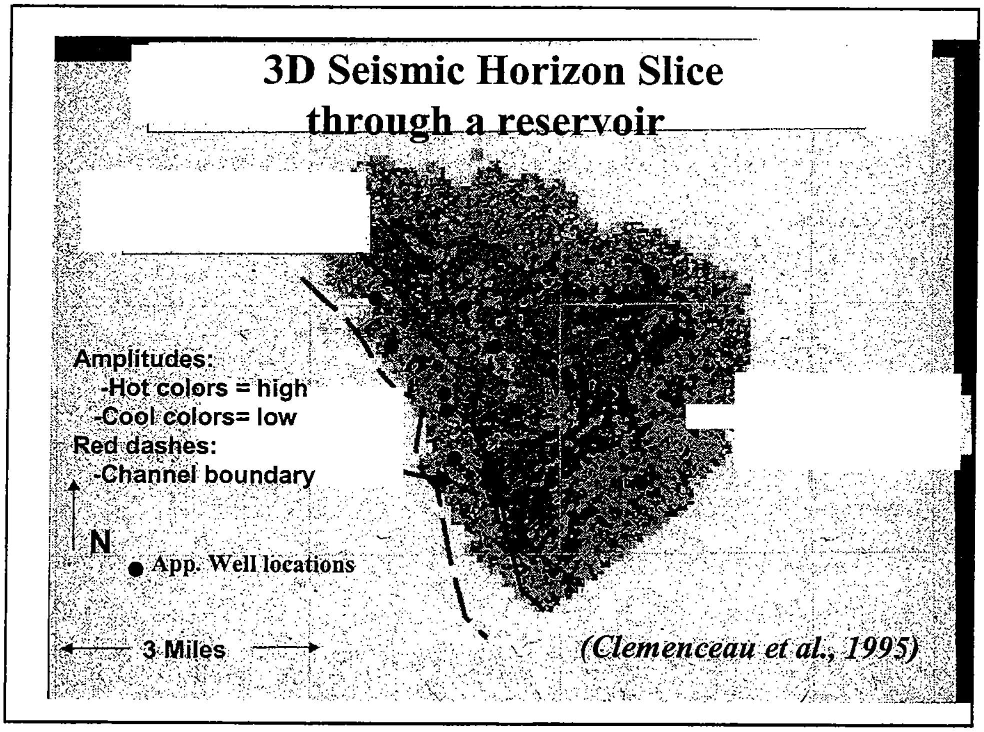
(Clemenceau et al., 1995; Kendrick, 2000)





L Sand

(Craig et al., 2003)

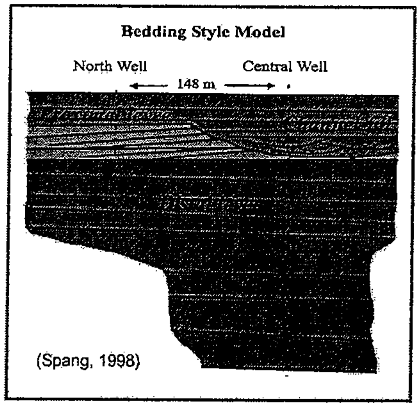


3D Seismic Horizon Slice through a reservoir

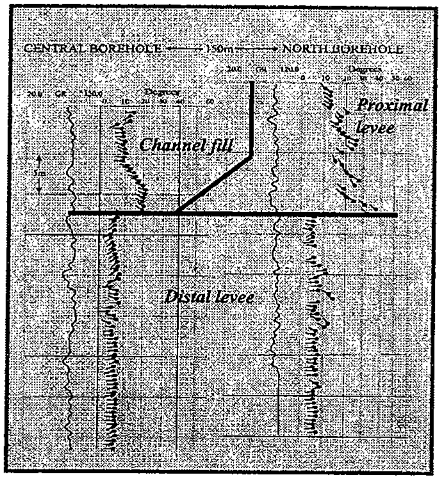
Amplitudes:
-Hot colors = high
-Cool colors= low
Red dashes:
-Channel boundary

(Clemenceau et al., 1995)

Mt. Messenger Fm., New Zealand Bedding style and Dipmeter example

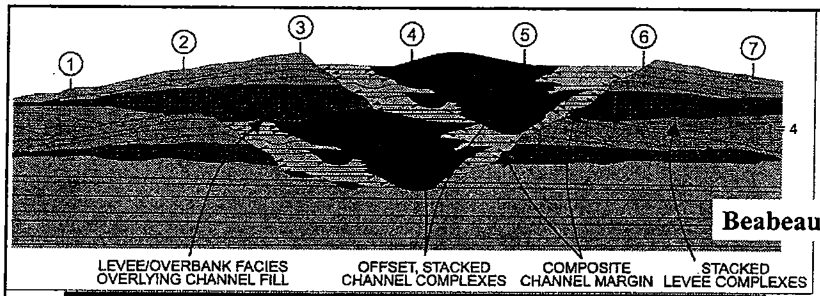


(Spang, 1998)



Dip Patterns

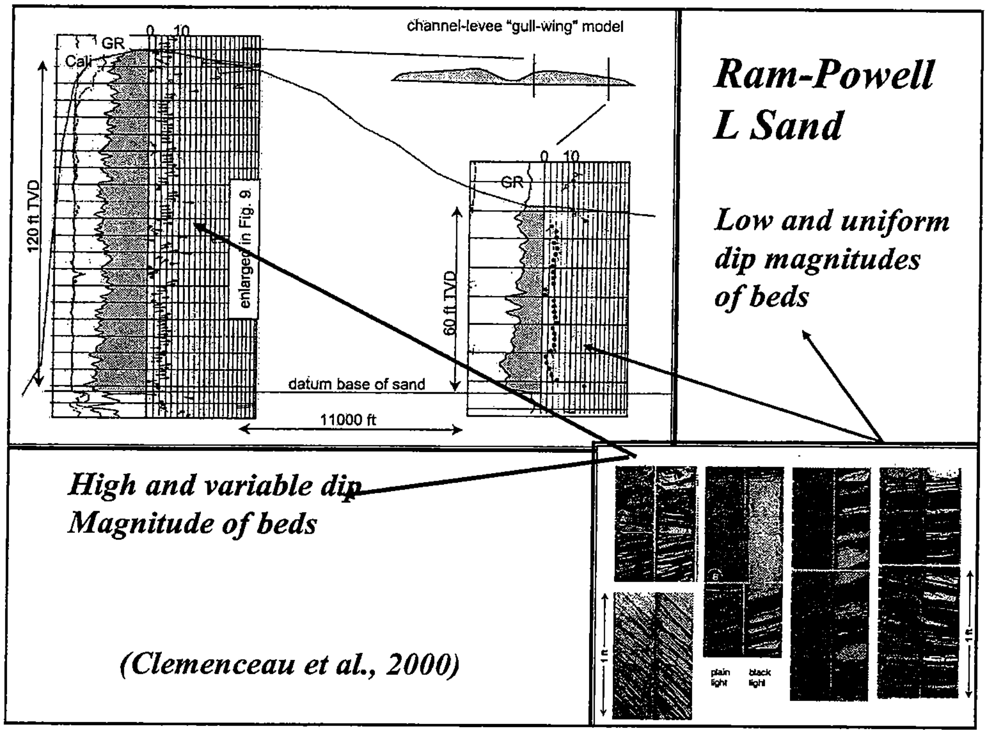
Channel-fill	**Proximal Levee**	**Distal Levee**
* Variable Dip	* Variable Dip & Azimuth	* Constant Dip & Azimuth
* Decrease Upward	* Relatively High Dip Angles	* Relatively Low Dip Angles
	High net/gross	Lower net/gross



Beabeauf, in press

LEVEE FACIES

Proximal levee:	Higher net sand; thin bedded; cut-and-fill; mud-lined scours; climbing ripples; good connectivity; high angle and variable dips of beds.
Distal levee	Lower net sand; thin bedded; interbedded sand/silt; good continuity; low angle and uniform dips of beds
Channel margins:	Complex: slumps, discontinuities, mud-lined; variable fluid communication in leveed channel reservoirs

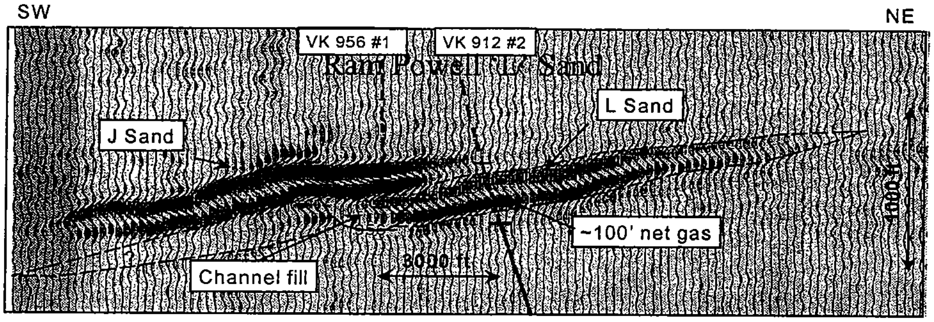


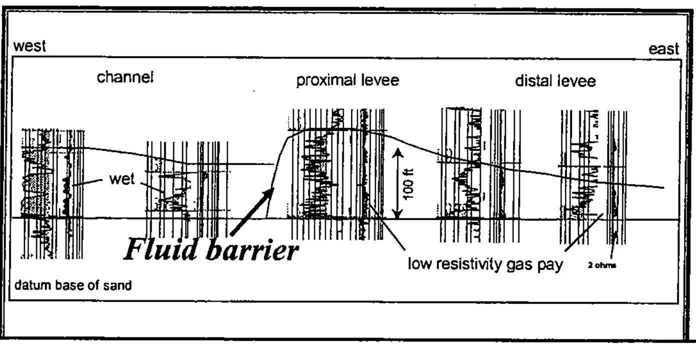
Ram-Powell L Sand

Low and uniform dip magnitudes of beds

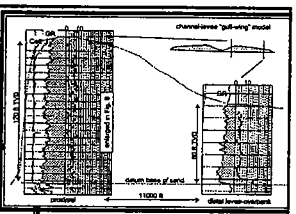
High and variable dip Magnitude of beds

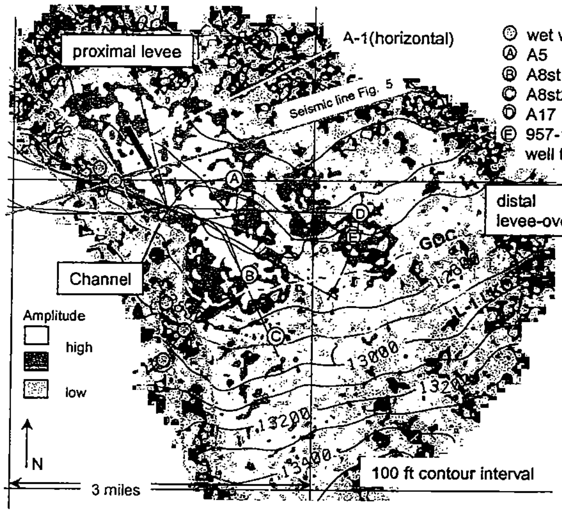
(Clemenceau et al., 2000)



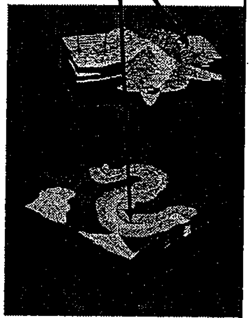


Drilling Strategy: Horizontal well in proximal levee beds, parallel to channel: "Well performance exceeded expectations with a peak flow rate of 105mmcfgd and 9600 bopd" (Clemenceau et al., 2000)





Horiz. well in proximal levee

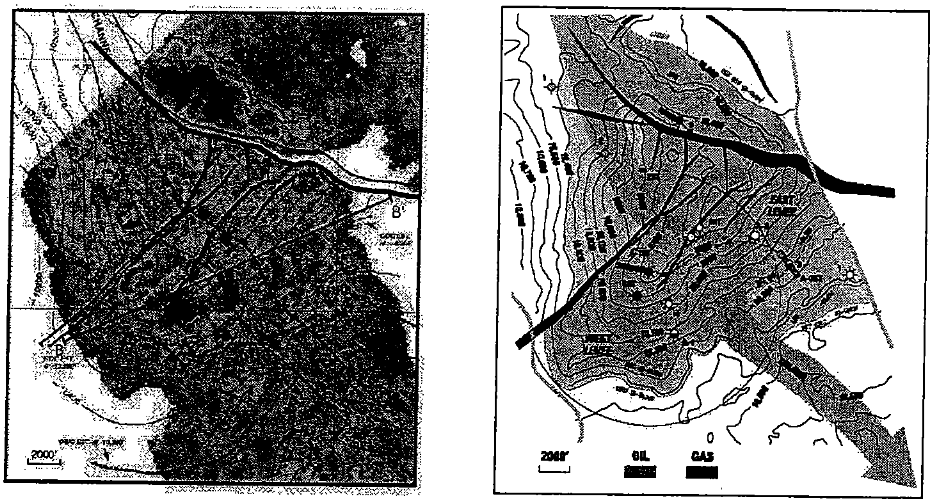


CHANNEL LEVEE/OVERBANK EXAMPLES

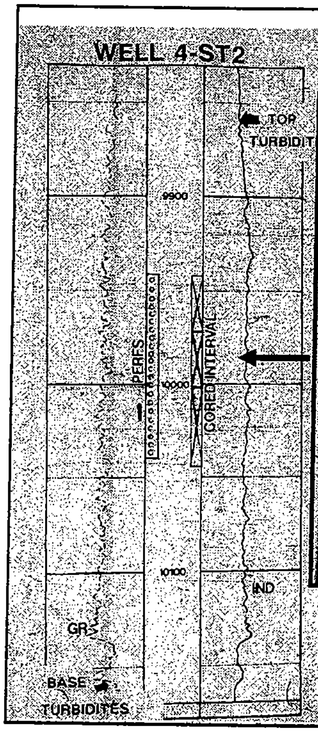
M4.1 Sand, Tahoe, Gulf of Mexico (Kendrick, 2000)

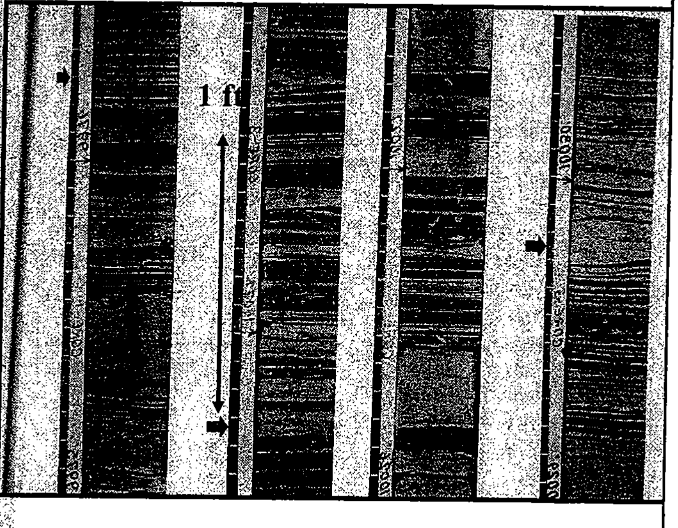
- **Upper Miocene**
- **Field is on faulted structural nose**
- **Characteristic 'gull wing' on seismic**
- **Channel is elongate dim area on horizon slice**
- **>17MMBE gas and condensate from 4 wells**
- **Single well flow rates from thin bedded levees tested 29MMCFGPD and 950BCPD**
- **Pressures in west levee depleted over time over entire stratigraphic interval; Pressures in east levee only depleted in upper part; lower part at original pressures, indicating disconnect with west levee.**
- **Oil-water contact is shallower in west, than east levee.**
- **Early production from upper levees provided optimism that was lost when production began from lower levee interval**

M4.1 Sand, Tahoe



(Kendrick, 2000)





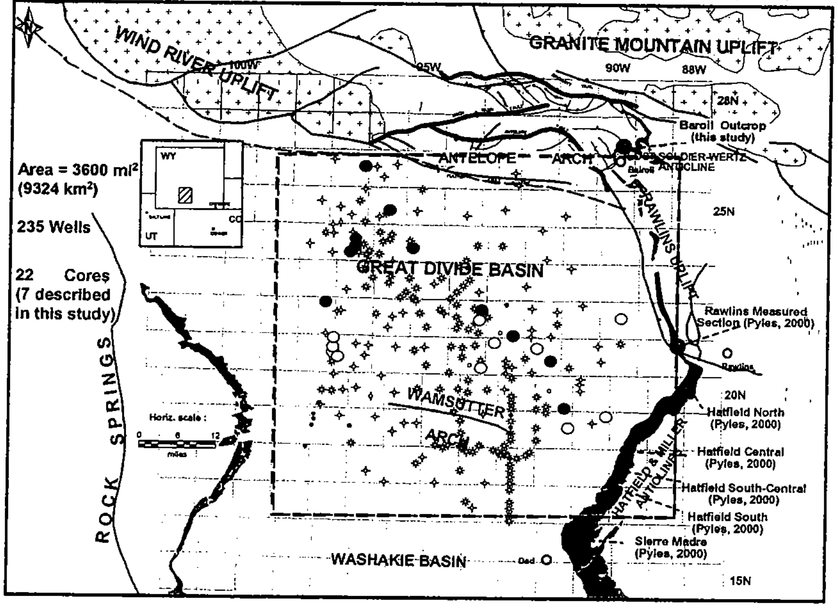
(Shew et al., 1994)

TWO EXAMPLES OF LOW PERMEABILITY TURBIDITE RESERVOIRS

Lewis Shale (Dad Sandstone)
- *-Upper Cretaceous age*
- *-Greater Green River Basin, U.S.*
- *-Gas*

Jackfork Group
- *-Pennsylvanian age*
- *-Oklahoma and Arkansas, U.S.*
- *-Gas*

Study Area & Data Available



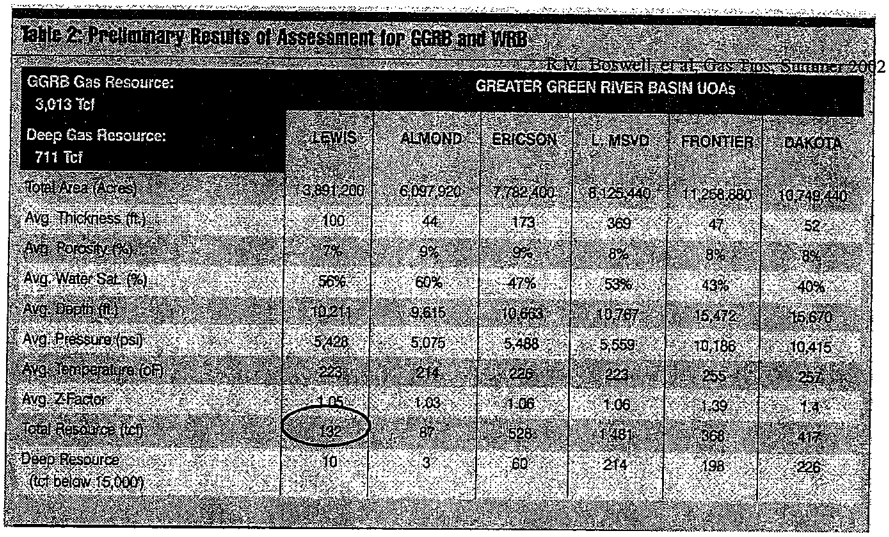
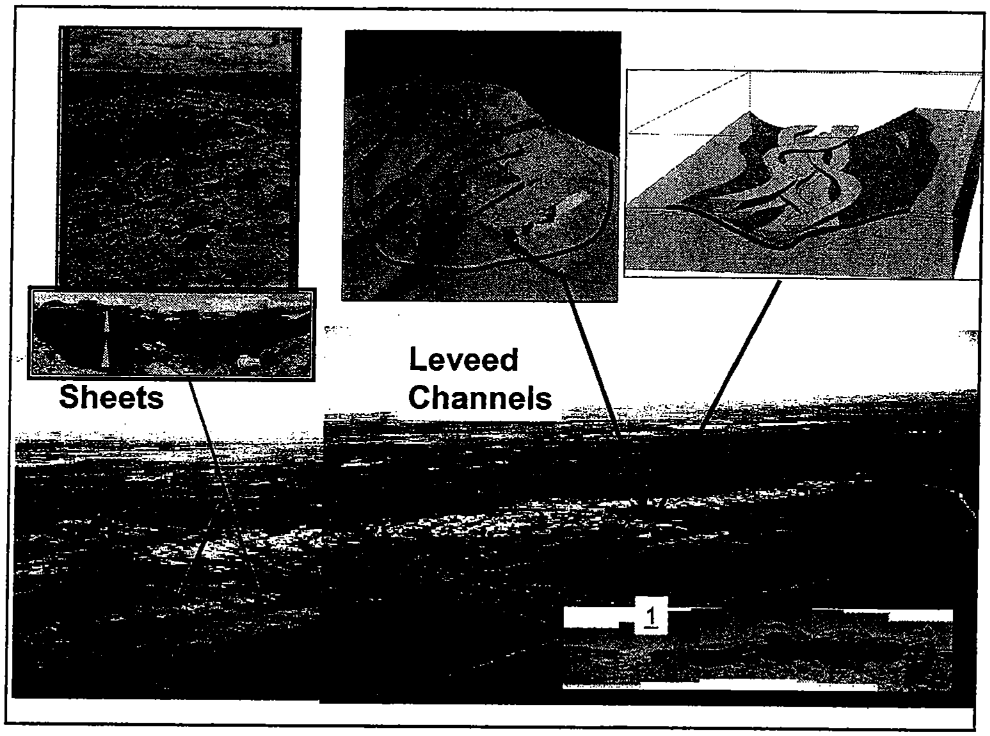
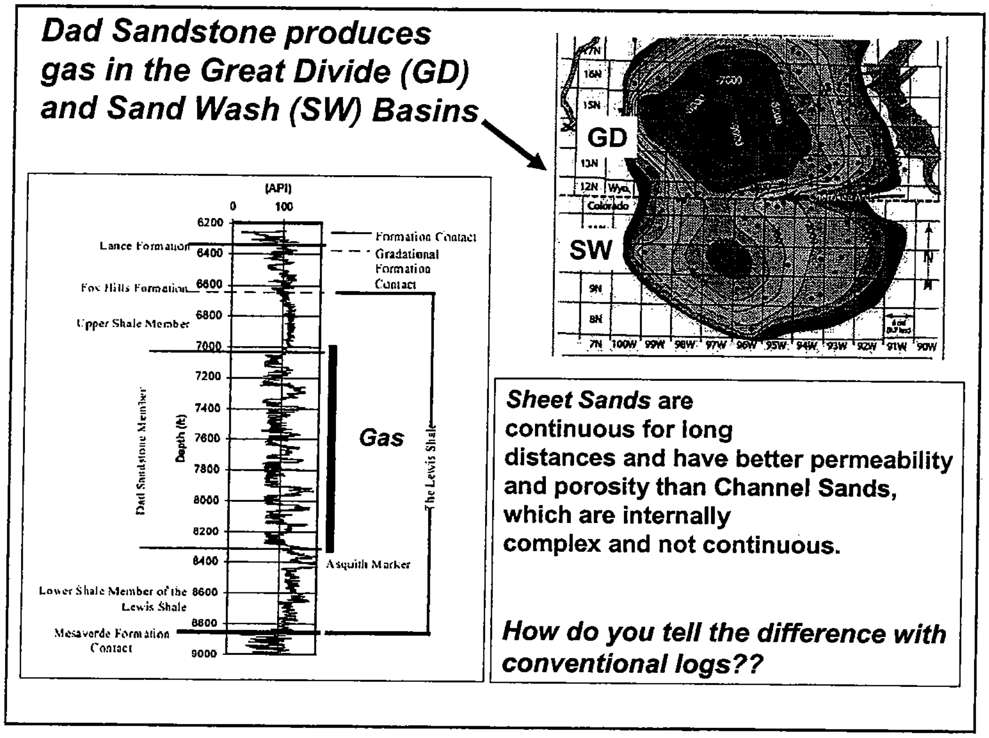


Table 2: Preliminary Results of Assessment for GGRB and WRB

R.M. Boswell, et al. Gas Tips, Summer 2002

GGRB Gas Resource: 3,013 Tcf Deep Gas Resource: 711 Tcf	GREATER GREEN RIVER BASIN UOAs					
	LEWIS	ALMOND	ERICSON	L. MSVD	FRONTIER	DAKOTA
Total Area (Acres)	3,891,200	6,097,920	7,782,400	8,125,440	11,258,880	10,749,440
Avg. Thickness (ft.)	100	44	173	369	47	52
Avg. Porosity (%)	7%	9%	9%	8%	8%	8%
Avg. Water Sat. (%)	56%	60%	47%	53%	43%	40%
Avg. Depth (ft.)	10,211	9,615	10,663	10,767	15,472	15,670
Avg. Pressure (psi)	5,428	5,075	5,488	5,559	10,186	10,415
Avg. Temperature (oF)	223	214	226	223	255	257
Avg. Z-Factor	1.05	1.03	1.06	1.06	1.39	1.4
Total Resource (tcf)	132	87	528	1,481	368	417
Deep Resource (tcf below 15,000')	10	3	60	214	198	226

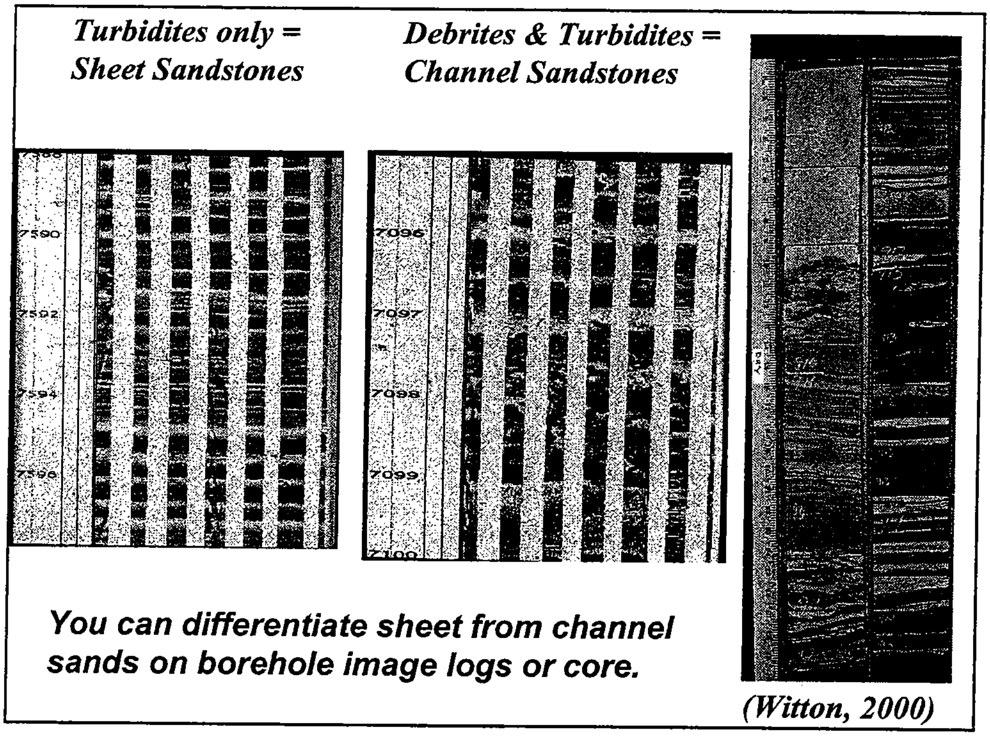




Dad Sandstone produces gas in the Great Divide (GD) and Sand Wash (SW) Basins

Sheet Sands **are continuous for long distances and have better permeability and porosity than Channel Sands, which are internally complex and not continuous.**

How do you tell the difference with conventional logs??

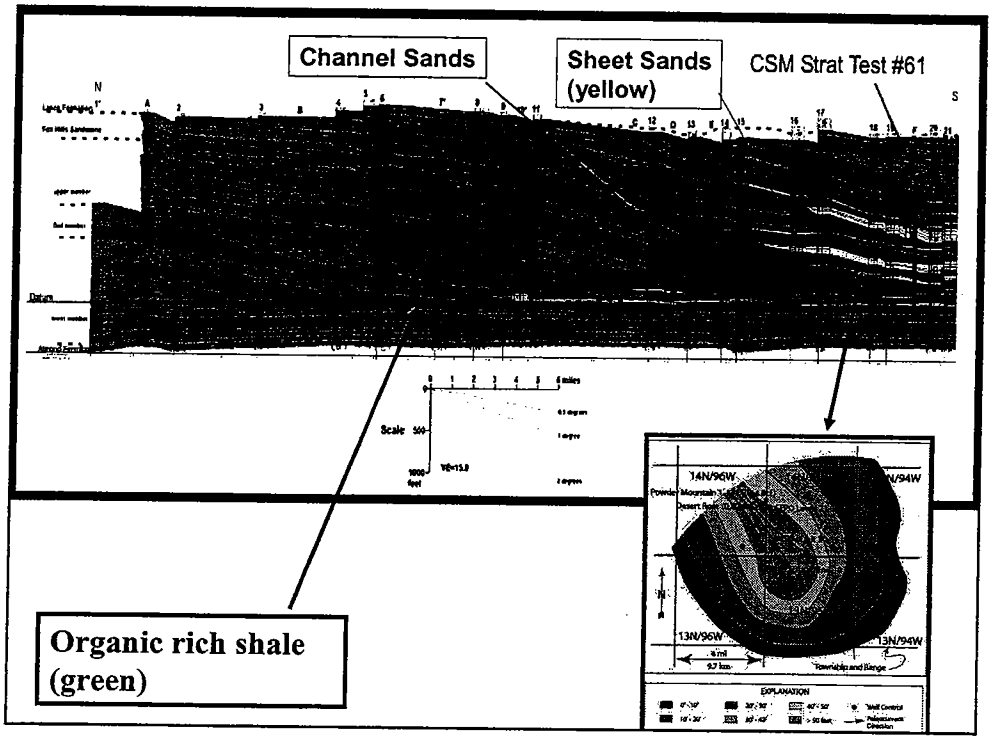


Turbidites only = Sheet Sandstones

Debrites & Turbidites = Channel Sandstones

You can differentiate sheet from channel sands on borehole image logs or core.

(Witton, 2000)



Channel Sands

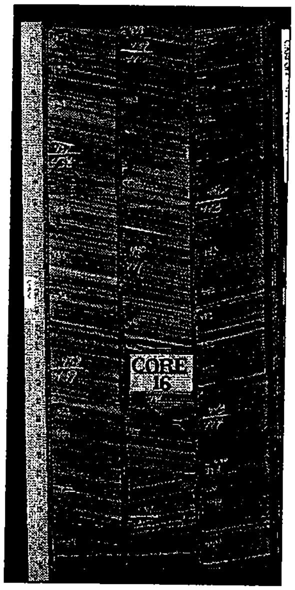
Sheet Sands (yellow)

CSM Strat Test #61

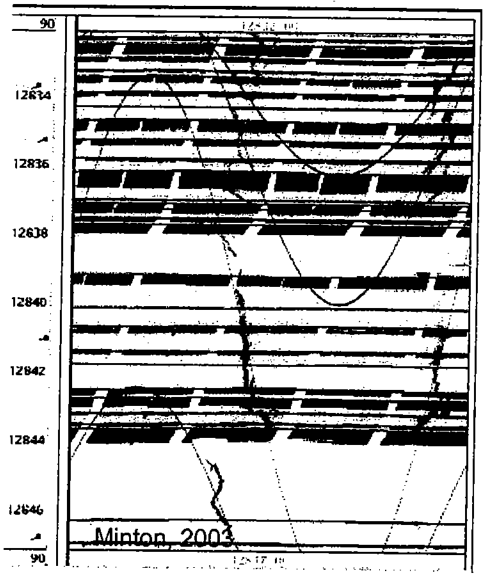
Organic rich shale (green)

Additional Potential:

Thin levee beds



Open fractures



Minton, 2003

TWO EXAMPLES OF LOW PERMEABILITY TURBIDITE RESERVOIRS

Lewis Shale (Dad Sandstone)

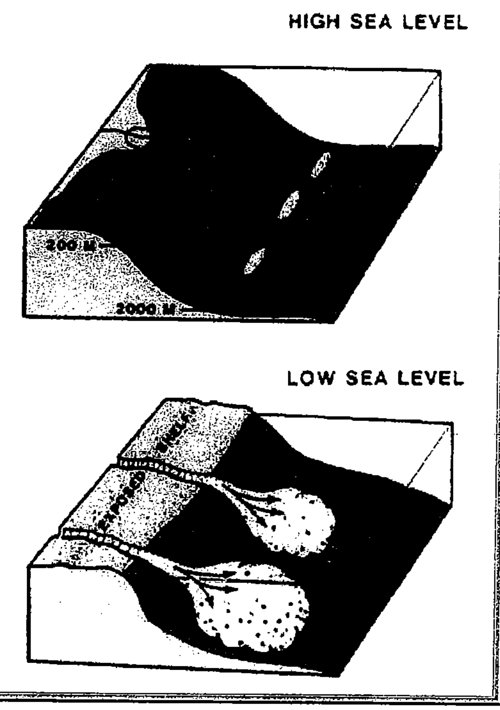
- *-Upper Cretaceous age*
- *-Greater Green River Basin, U.S.*
- *-Gas*

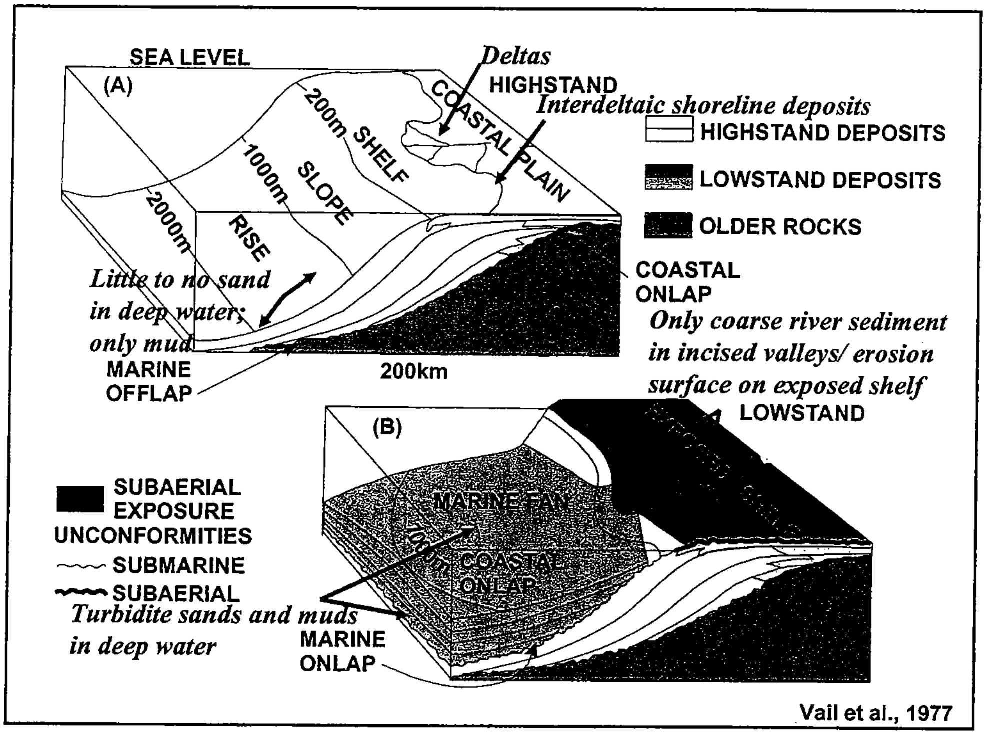
Jackfork Group

- *-Pennsylvanian age*
- *-Oklahoma and Arkansas, U.S.*
- *-Gas*

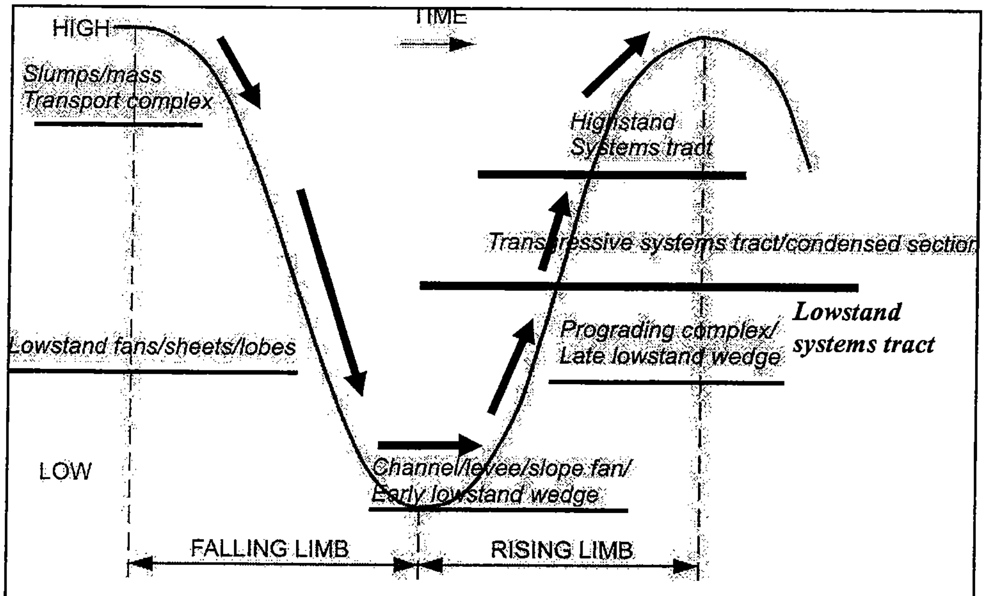
UNIT 2:

Stacking of elements; basics of sequence stratigraphy

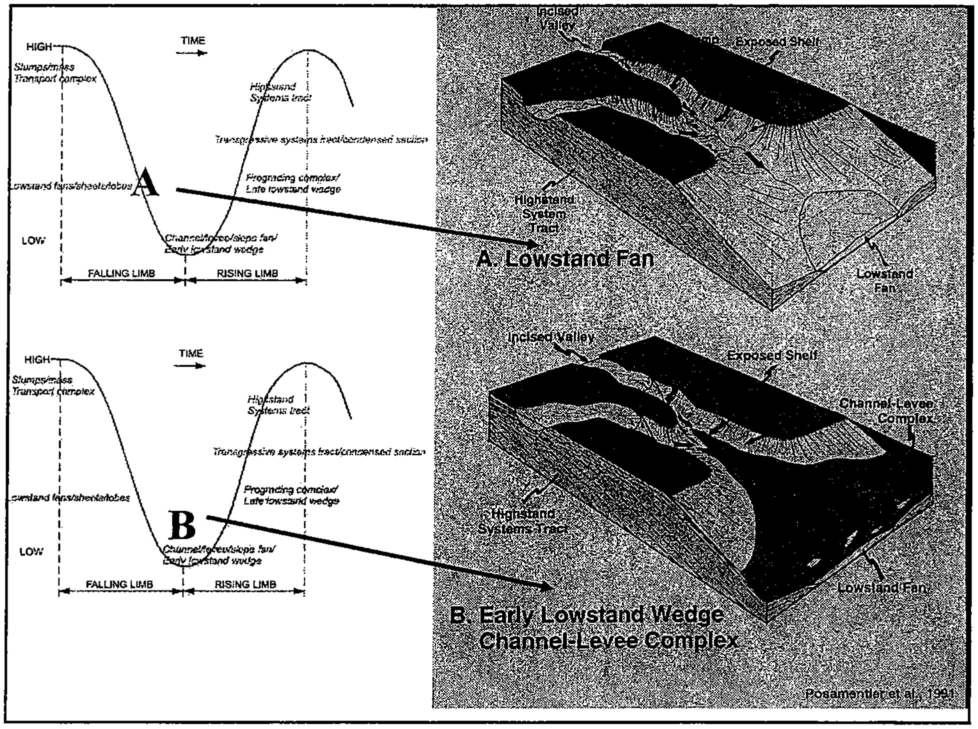




Vail et al., 1977



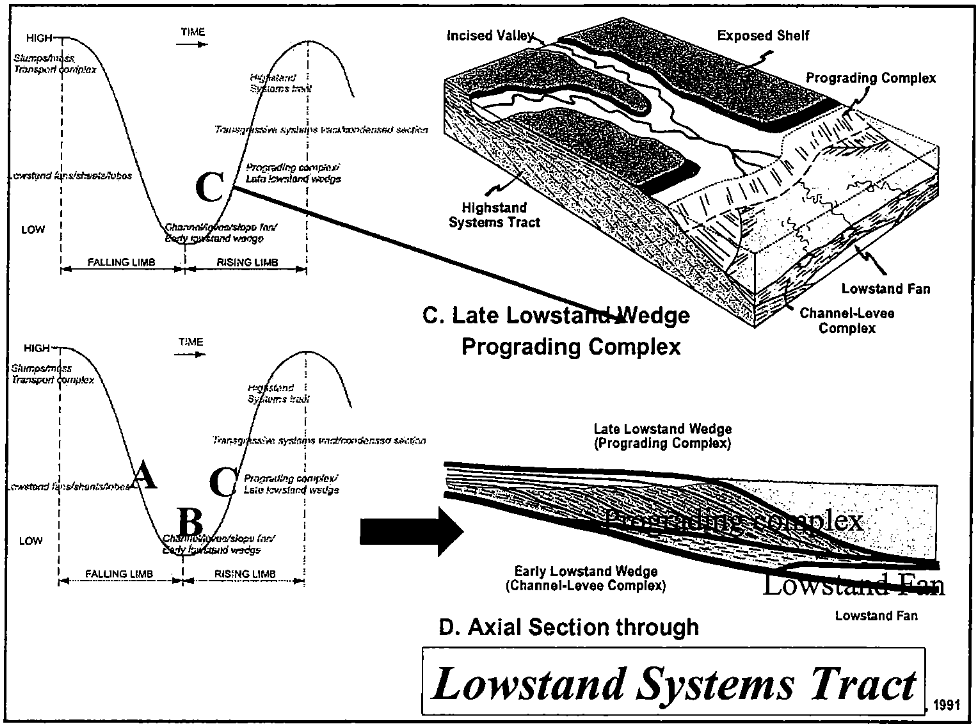
One complete sea level cycle



A. Lowstand Fan

B. Early Lowstand Wedge
Channel-Levee Complex

Posamentier et al., 1991



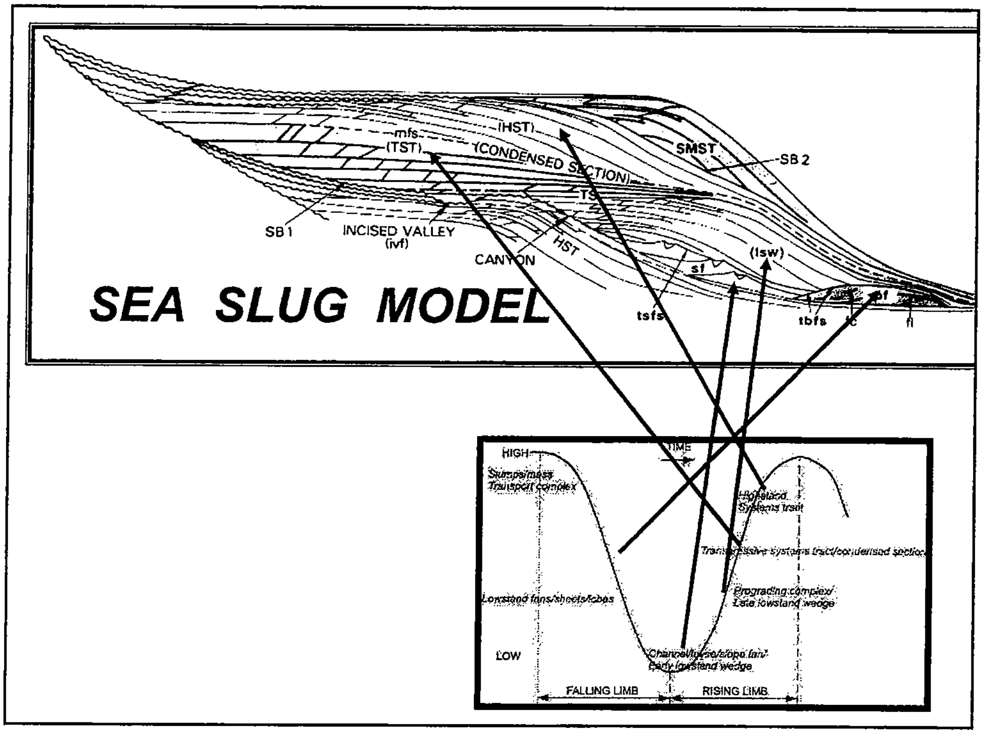
C. Late Lowstand Wedge
Prograding Complex

D. Axial Section through

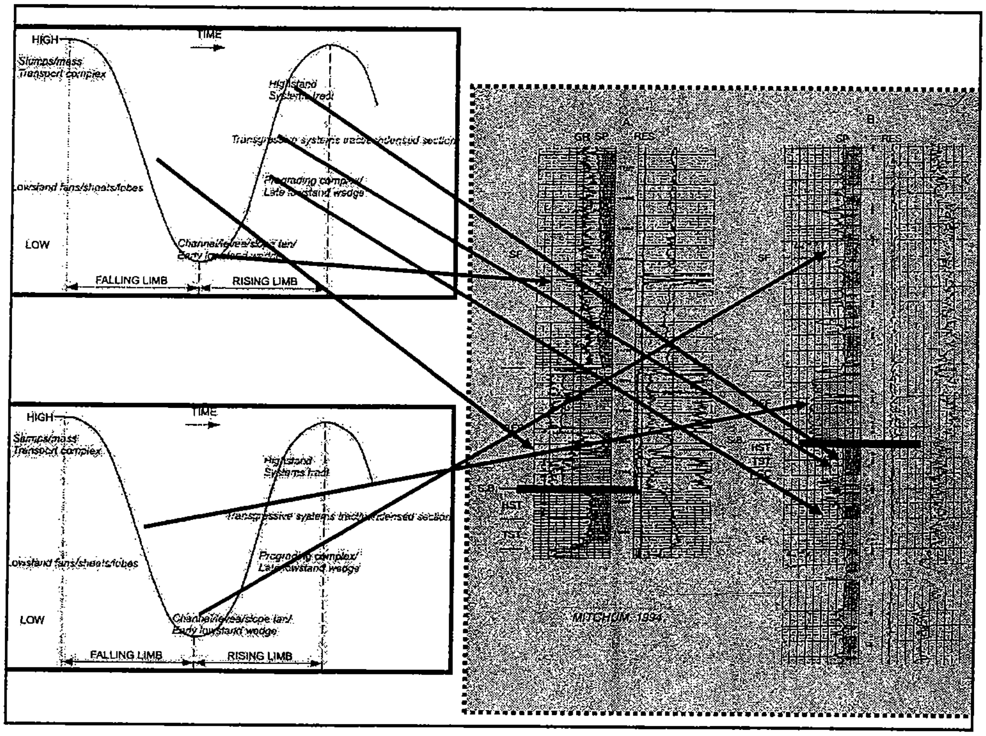
Lowstand Systems Tract

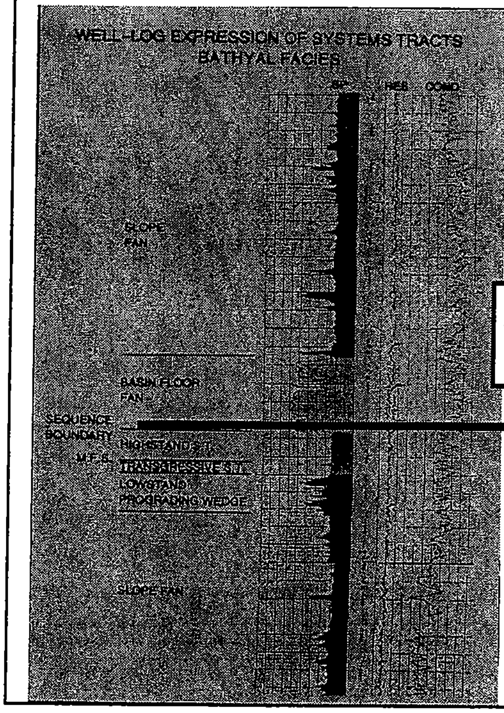
, 1991

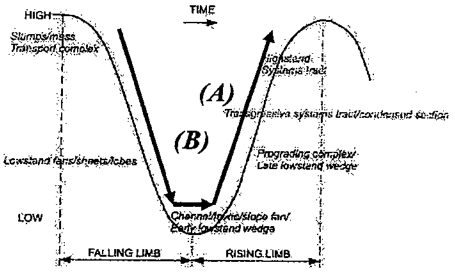
SEA SLUG MODEL



Movies







Deposition of lower part of an upper system

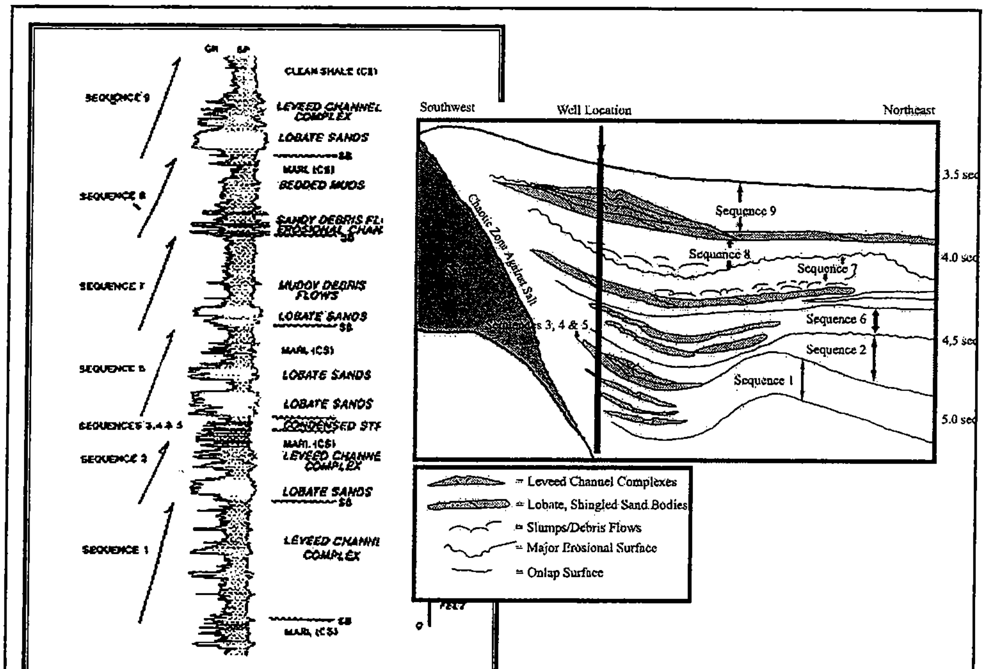
Deposition of upper part of a lower system (A)

STACKING PATTERNS

- A COMPLETE VERTICAL SEQUENCE CONSISTS OF:

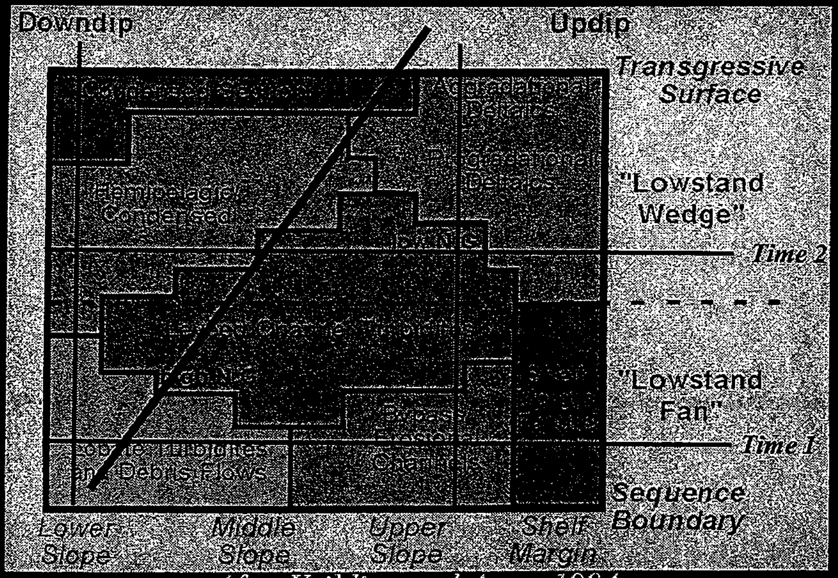
Sequence Boundary
-Highstand systems tract (thin shales in deep water)
-Transgressive systems tract, including condensed section (thin, organic rich or calcareous shales in deep water)
-Prograding complex or early lowstand wedge (mud-prone)
-Leveed channel complex, slope fan or early lowstand wedge
-Sheet sandstones, basin floor fan, or lowstand fan
-Mass transport complex
Sequence Boundary

- **COMPLETE VERTICAL SEQUENCE MAY NOT BE PRESENT;DEPENDS UPON POSITION OF DEPOSITION WITHIN BASIN**



(Yielding and Apps, 1994)

Facies in the Gulf of Mexico



After Yeilding and Apps, 1994

Global Sea level Curves

- Global cycle: relative rise and fall occurs on a global scale
- Global cycle charts illustrate different cycles at three orders"
  - First order
    - Precambrian to Early Triassic, 300 Ma
    - Middle Triassic to present, 225 Ma
  - Second order
    - 10 to 80 Ma duration—now considered as 9-10 Ma; stacked second order: 29-30 Ma
  - Third order
    - 1 to 10 Ma duration– now considered as 1-3 Ma
- These curves are asymmetric; again they are now considered to be coastal onlap curves

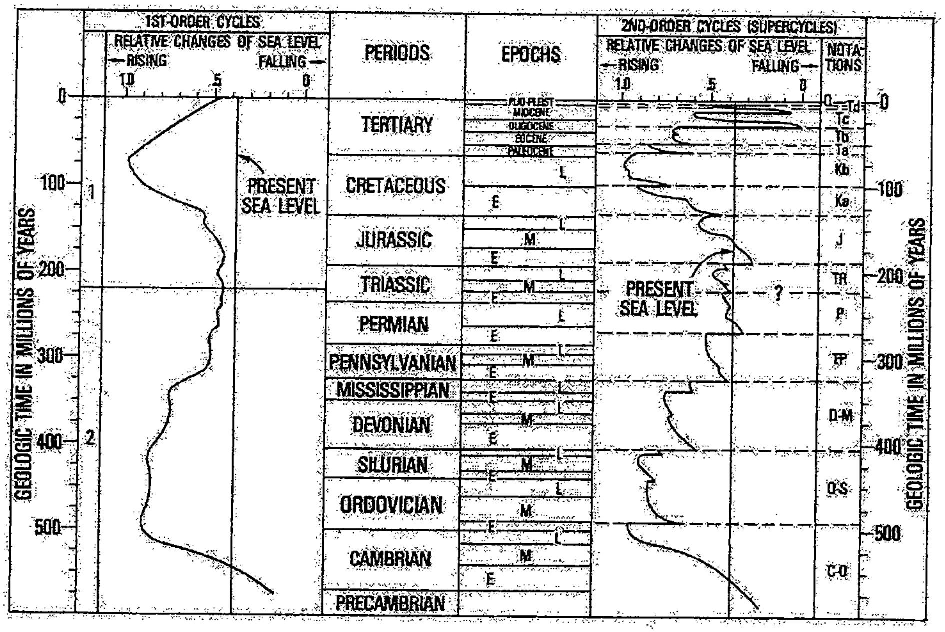
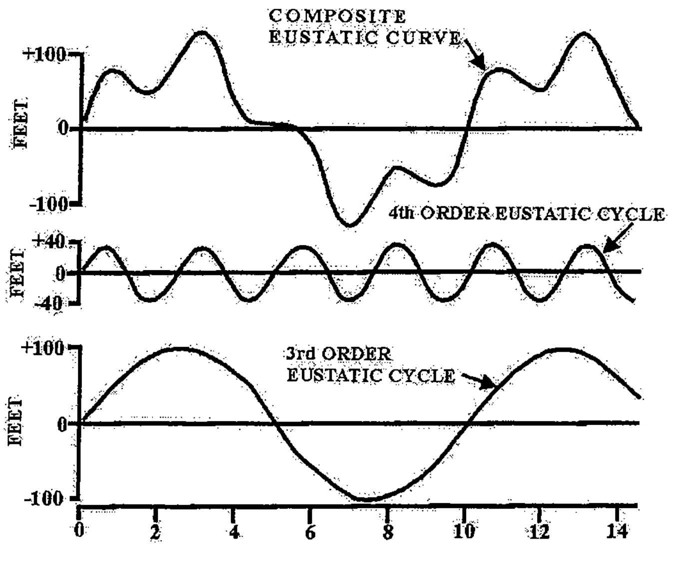


FIG. 1.—First- and second-order global cycles of relative change of sea level during Phanerozoic time.

INTERACTION OF 3rd AND 4th ORDER EUSTATIC CYCLES



Global Sea level Curves (cont.)

- Global cycle: relative rise and fall occurs on a global scale
- Global cycle charts illustrate different cycles at three orders"
  - First order
    - Precambrian to Early Triassic, 300 Ma
    - Middle Triassic to present, 225 Ma
  - Second order
    - 10 to 80 Ma duration—now considered as 9-10 Ma; stacked second order: 29-30 Ma
  - Third order
    - 1 to 10 Ma duration– **now considered as 1-3 Ma**

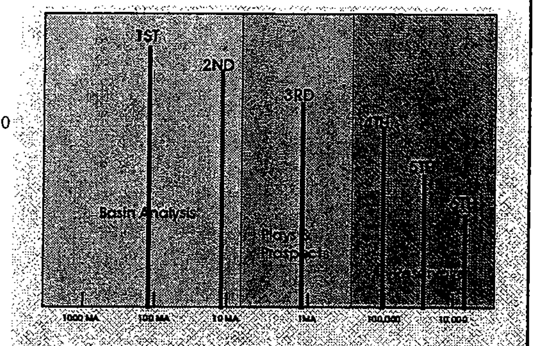
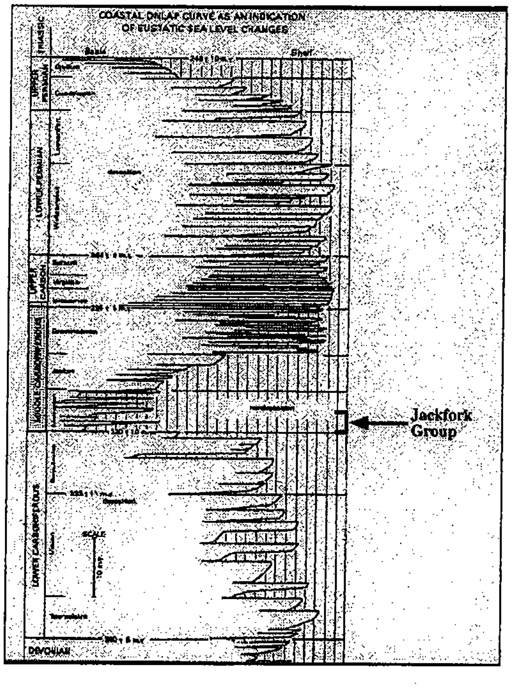
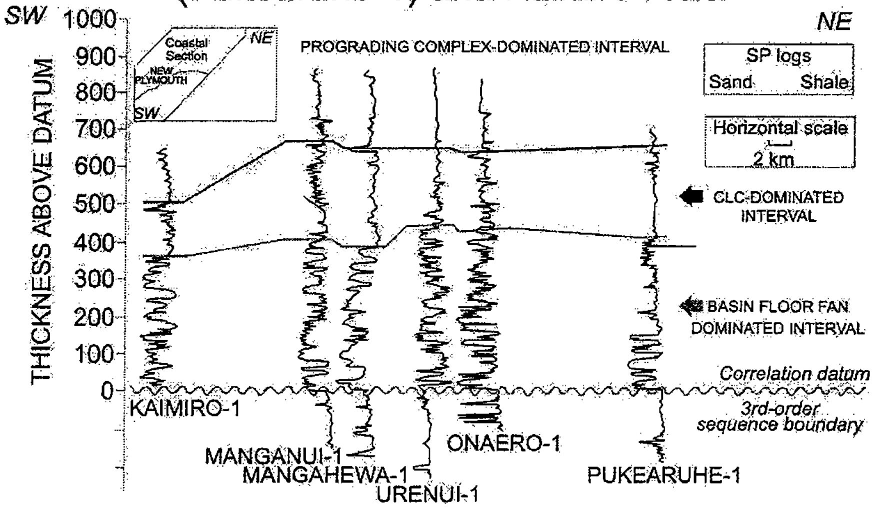


Figure 3-16 (a) Diagram showing the different frequencies (first through sixth order), and the typical scales for exploration and development (modified from Mitchum et al. 2002).



High Frequency Sequence Stratigraphy

SP log correlation between outcrop section (Pukearuhe-1) and Kaimiro Field



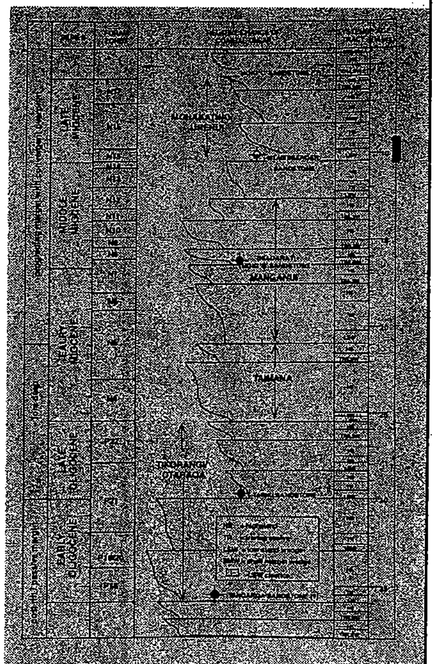
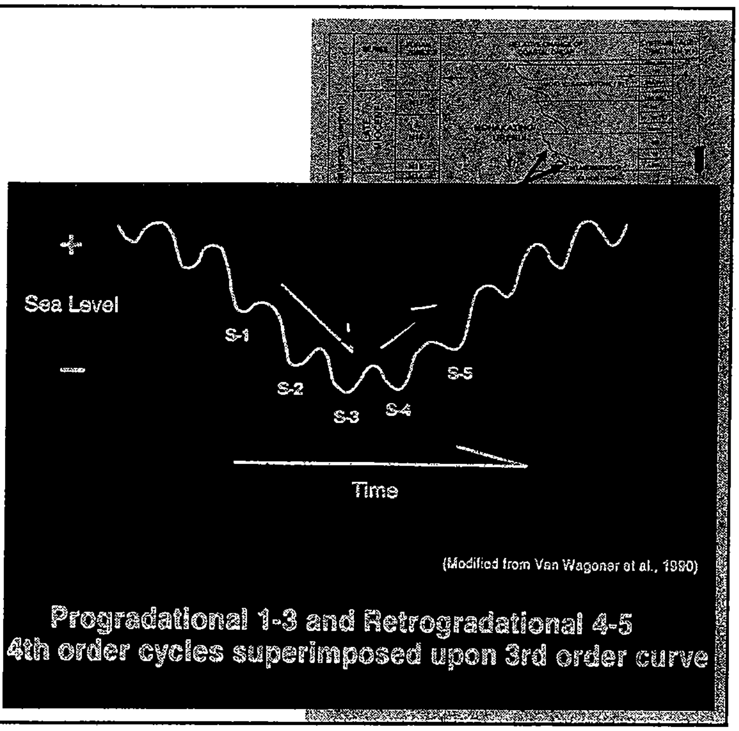
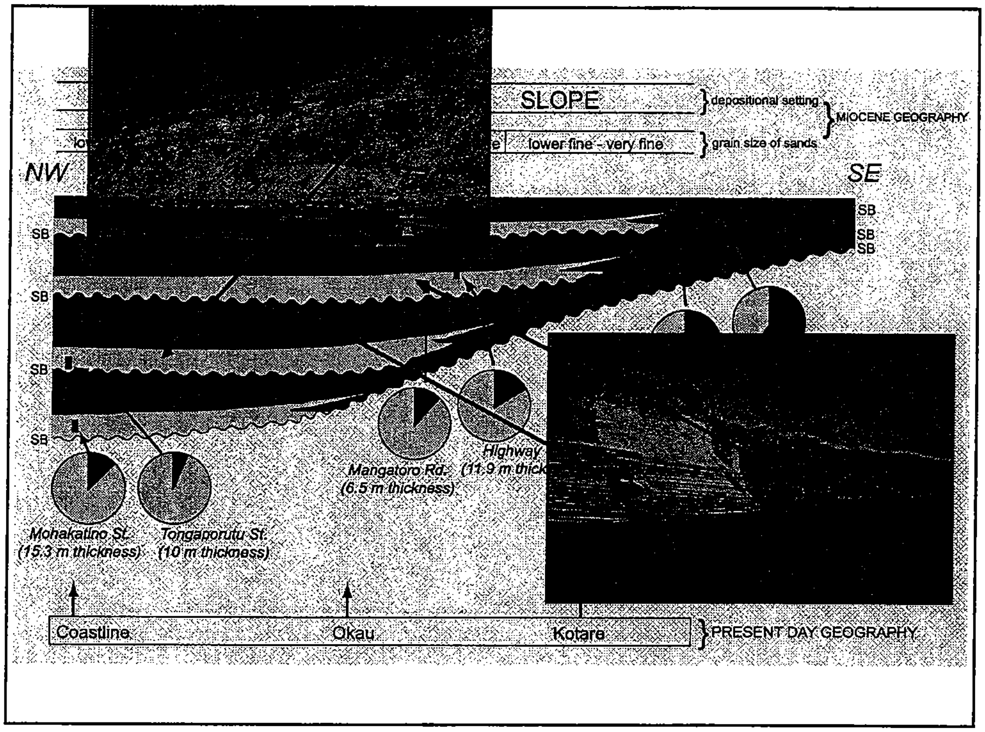


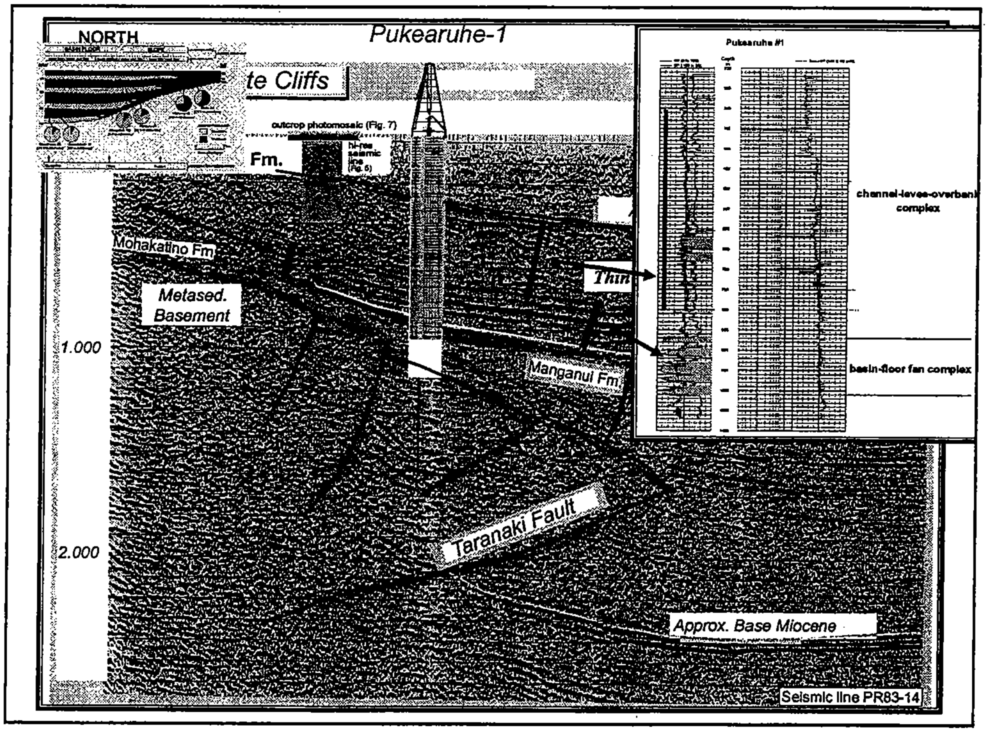
Figure 22. Taranaki Basin stratigraphy approximately located on Haq *et al.* (1987) chart. Kirk (1994)

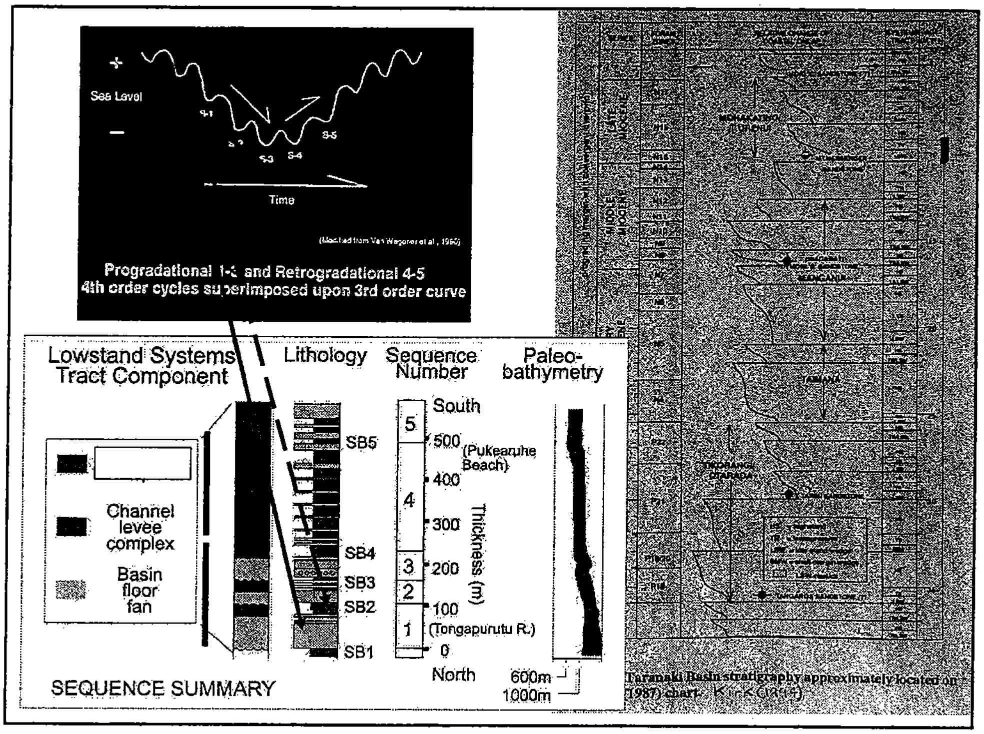


(Modified from Van Wagoner et al., 1990)

Progradational 1-3 and Retrogradational 4-5
4th order cycles superimposed upon 3rd order curve

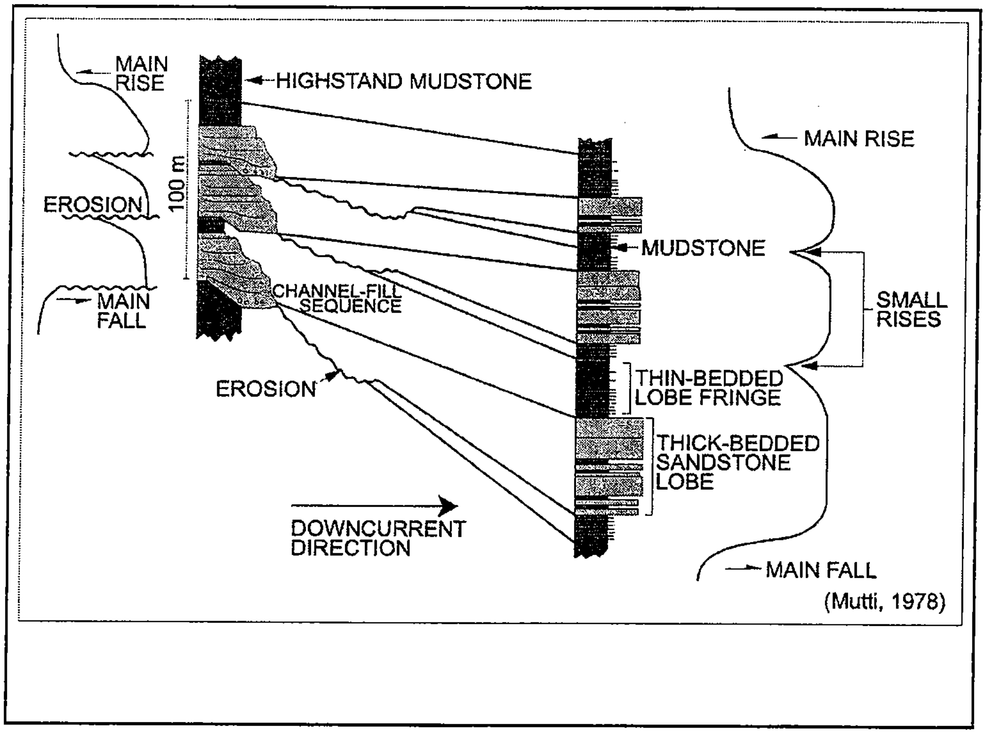

SLOPE
depositional setting
MIOCENE GEOGRAPHY
lower fine - very fine
grain size of sands
NW
SE
SB
SB
SB
SB
SB
SB
SB
Highway
(11.9 m thick
Mangatoro Rd.
(6.5 m thickness)
Mohakatino St.
(15.3 m thickness)
Tongaporutu St.
(10 m thickness)
Coastline
Okau
Kotare
PRESENT DAY GEOGRAPHY


NORTH
Pukearuhe-1
te Cliffs
outcrop photomosaic (Fig. 7)
Fm.
hi-res seismic line (Fig. 6)
Mohakatino Fm
Metased. Basement
1.000
2.000
Manganui Fm
Thin
Taranaki Fault
Approx. Base Miocene
Seismic line PR83-14
Pukearuhe #1
channel-levee-overbank complex
basin-floor fan complex



Progradational 1-3 and Retrogradational 4-5
4th order cycles superimposed upon 3rd order curve

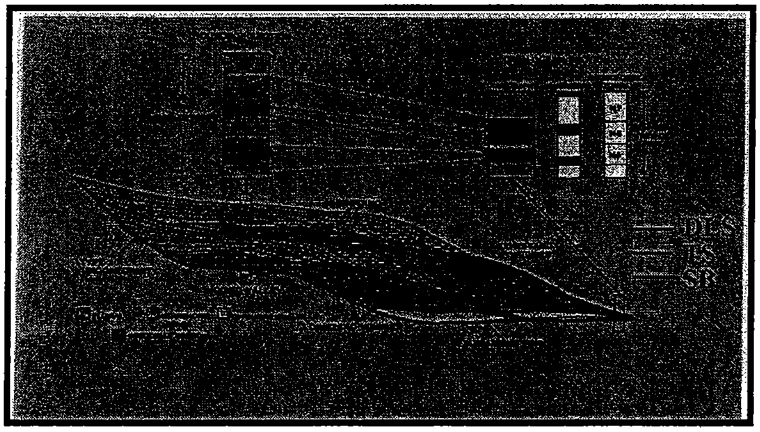
Taranaki Basin stratigraphy approximately located on 1987) chart. Kirk (1995)



(Mutti, 1978)

<u>Condensed section</u> is represented by a *long time interval* in which only mud and organics are deposited, giving rise to a *thin, organic-rich shale interval*

Depth-distance Cross Section



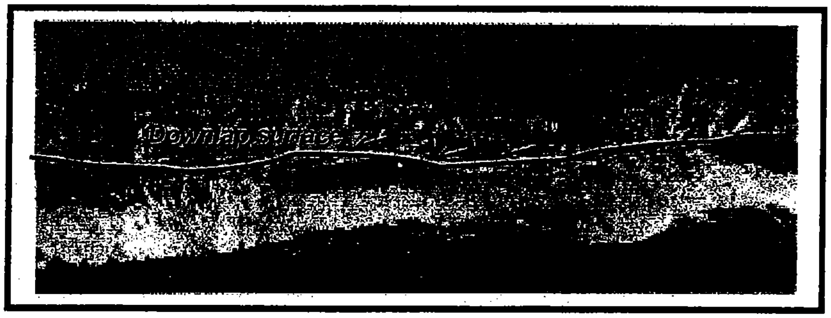
The cross section is showing distribution of condensed sections (DLS) that provides physically link between deep-sea sedimentary sections and continental margin sections

RECOGNITION OF CONDENSED SECTIONS

- Generally condensed sections are associated with maximum water depths occurs at the time when the sum of the rate of eustatic rise and the rate of subsidence is at a maximum during a depositional sequence
- Hemipelagic and pelagic sediments may be deposited over a large area of the shelf, initiating the formation of a condensed section
- Condensed sections can be recognized in core, outcrop and subsurface by using a variety of tools, including facies analyses of outcrop and well logs, biostratigraphic analyses, and seismic stratigraphy

Outcrop Expression of Condensed Sections

- In outcrops, condensed sections are generally identified at the base of prograding clinoform of the HST creating a DLS

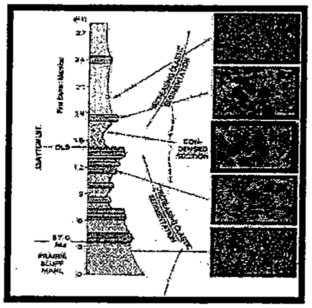


Tucker, M. E., 1996. Lower Cretaceous, French Alps.

Prograding beds are downlapping onto deep water shale

Core Expression of Condensed Sections

- In cores, condensed sections are generally characterized by abundant and diverse microfossils assemblages, authigenic minerals (glauconite, phosphorite and siderite), organic matter, and bentonites as well as greater concentrations of platinum elements such as iridium

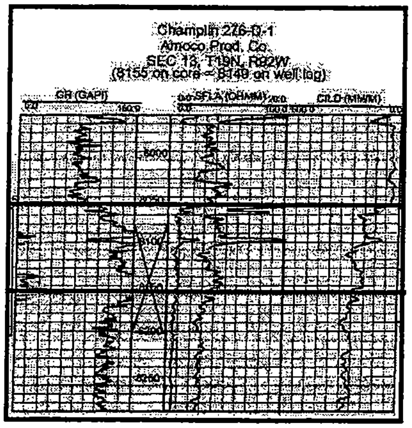


Condensed sections are generally characterized by low terrigenous content and richer glauconite and organic matter content than the rocks above and below

Baum et al, 1984. Braggs section in Lowndes, Alabama

Well Logs Expression of Condensed Sections

- High gamma ray values are generally associated with condensed sections due to radioactive element-bearing sediments (potassium, thorium, uranium)



"Asquith marker" associated with organic matter rich in the Lewis Shale Formation is interpreted as a condensed section

Pyles, 2000.

Seismic Expression of Condensed Sections

- On seismic sections, condensed sections are generally identified at the base of prograding clinoform of the high-stand systems tracts, which show a characteristic downlap pattern onto the underlying sediments

Walcott, R. I., 1978. Seismic section of the east coast of the South Island of New Zealand

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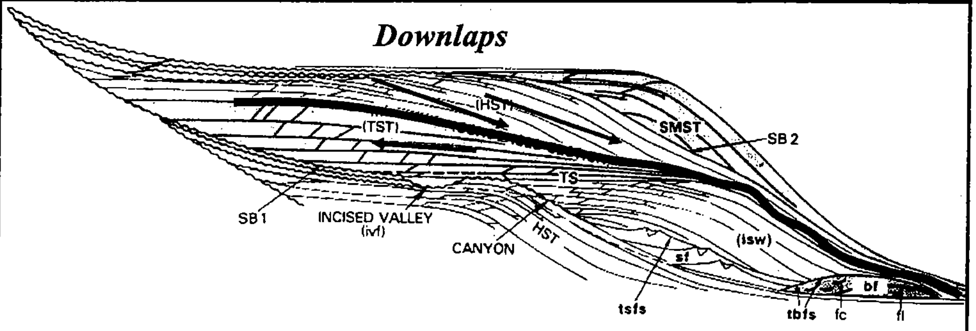
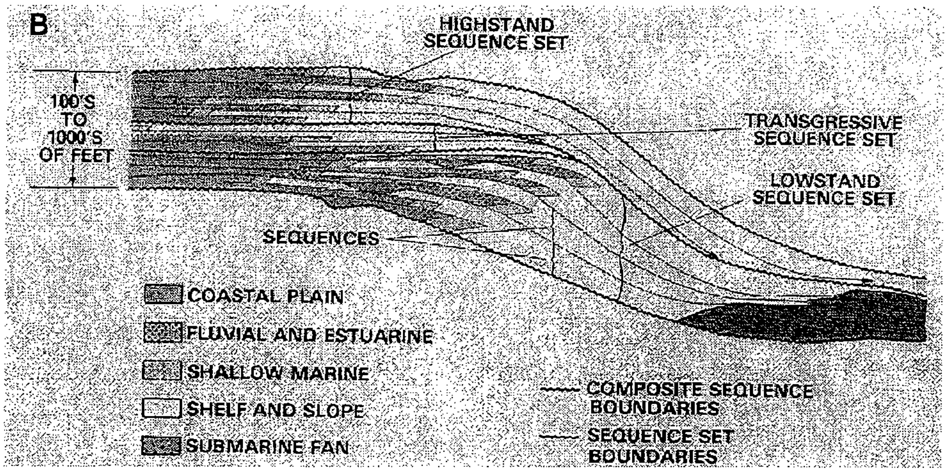
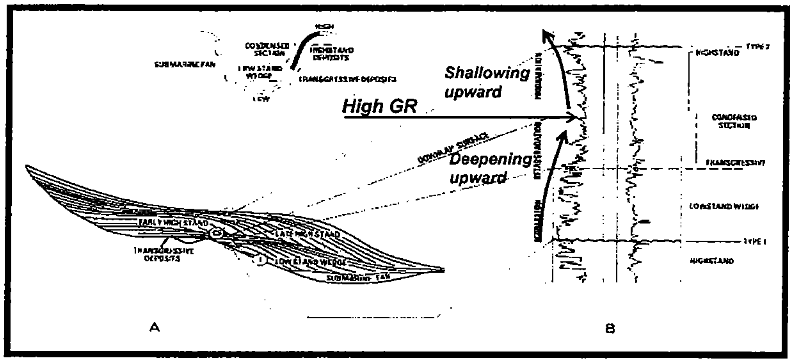
SEA SLUG MODEL





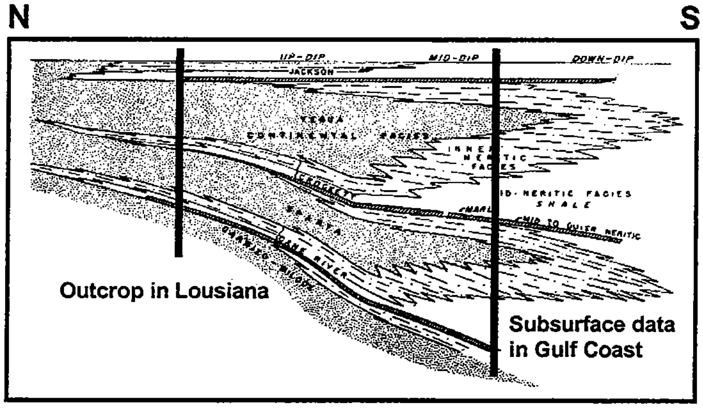
Mitchum and Van Wagoner, 1991

Well Logs Expression of Condensed Sections



The condensed section is generally detectable on electric and gamma ray logs as the point where progradational of highstand sediments begins above the retrogradational stacking of the transgressive-systems tracts

CONDENSED SECTIONS : KEY TO REGIONAL CORRELATION



Murray, 1961
(Modified after
Lowman, 1949)

Three condensed sections within the sediments deposited between the top of the Wilcox Group to the base of the Vicksburg Stage were long used as a basis regional correlation within the Gulf basin

Unit 3:

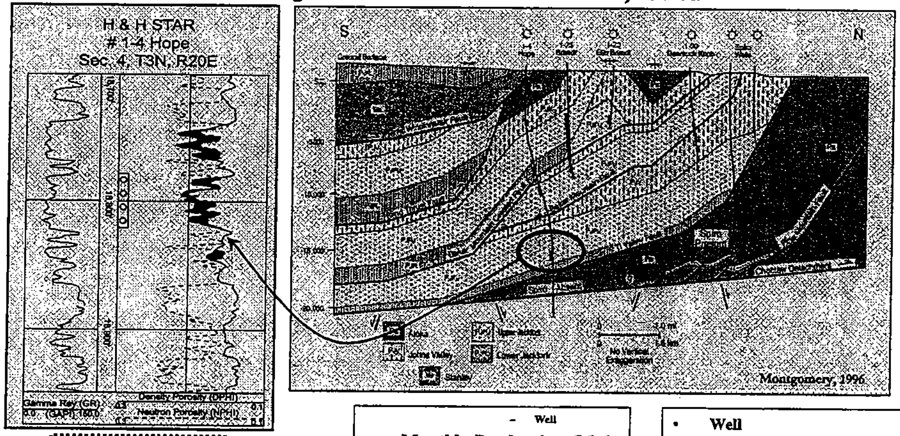
Geology of the Jackfork deepwater deposits with emphasis on exploration applications

TWO EXAMPLES OF LOW PERMEABILITY TURBIDITE RESERVOIRS

Lewis Shale (Dad Sandstone)
- *-Upper Cretaceous age*
- *-Greater Green River Basin, U.S.*
- *-Gas*

Jackfork Group
- *-Pennsylvanian age*
- *-Oklahoma and Arkansas, U.S.*
- *-Gas*

***Jackfork Group:** Porosities 8-17%; matrix permeabilities <1md; Hydraulically fractured; IP's >1.5MMCFGPD; EUR 2-8bcf/well; Drainage areas <160 acres at 7.5-12,000 ft.*

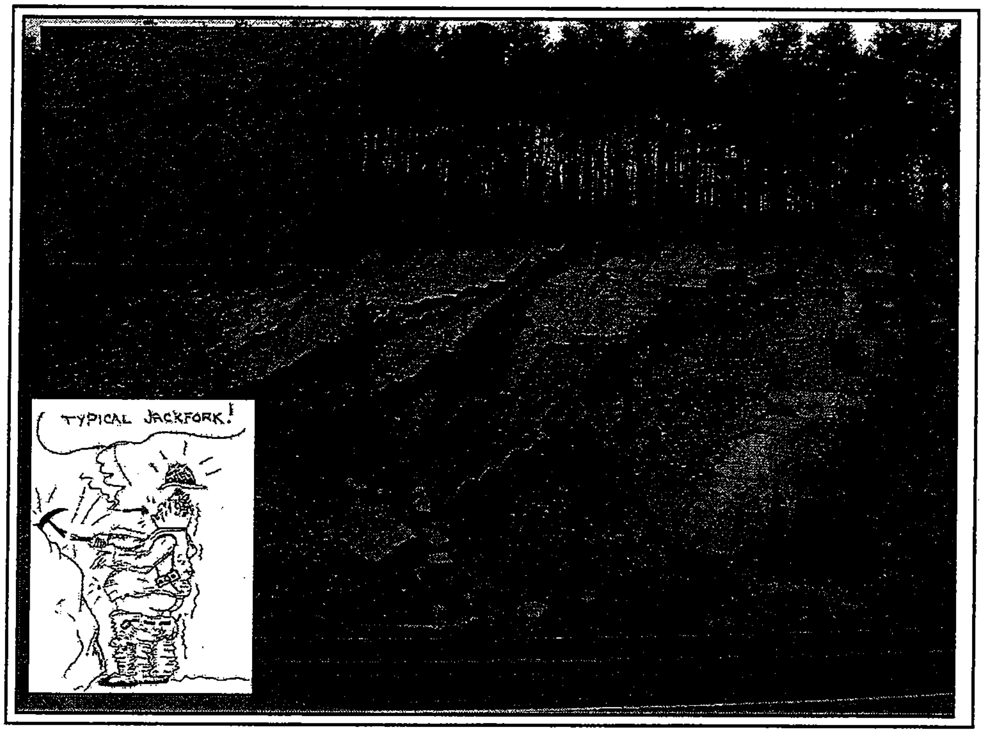


Montgomery, 1996

I.P. = 5.7 MMCTGPD
"Lower Jackfork"

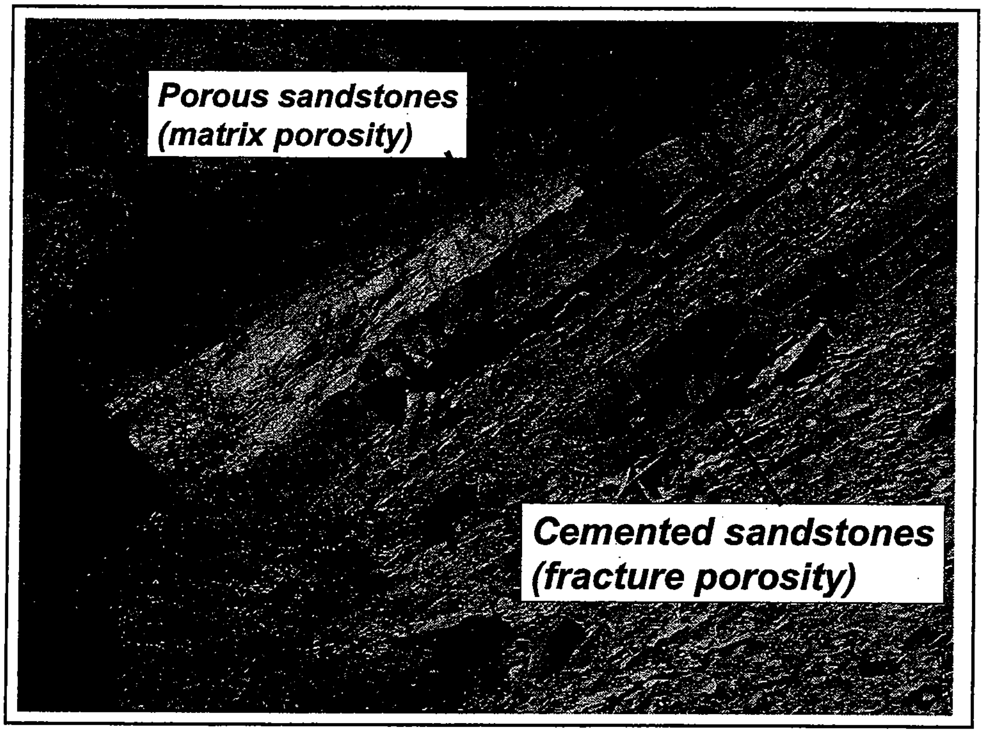
- Well
- Monthly Production (Mcf)
- GHK/Amoco Ratcliff 1-33
  - 200,000+
- GHK Thompson 1-4
  - 350,000+

- Well
  - Monthly Production (Mcf)
- GHK Morgan 1-5
  - 900,000
- GHK Guggenheim 1-6
  - 50,000



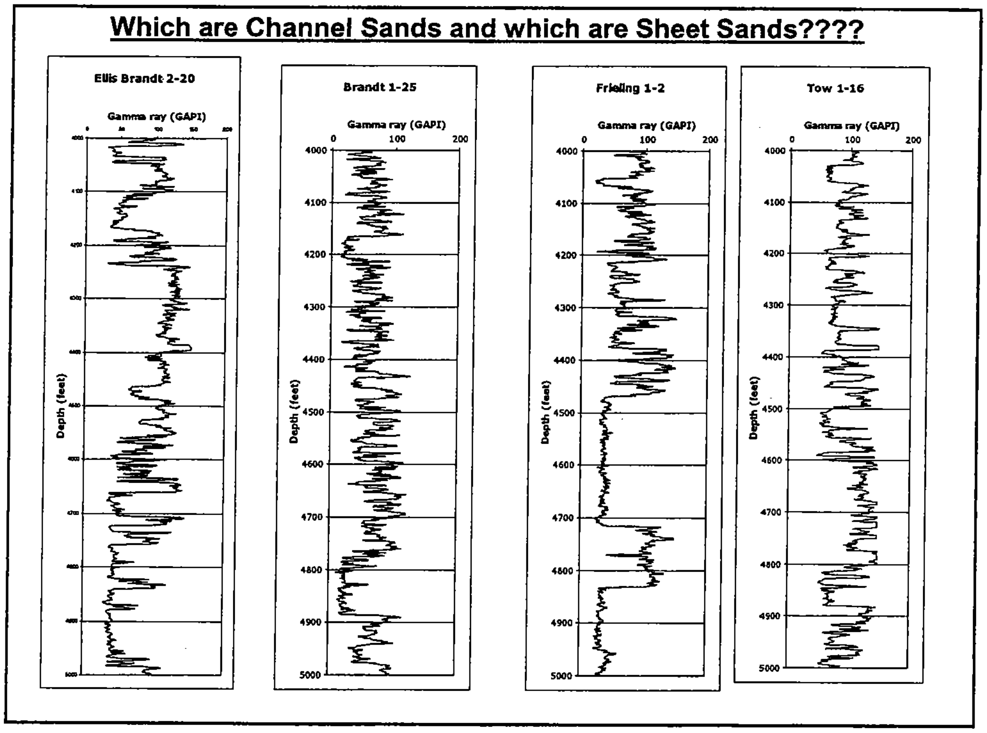
JACKFORK GROUP HYDROCARBON RESERVOIR/TRAP TYPES

- LARGE-SCALE STRUCTURES
- FRACTURES
- STRATIGRAPHIC PINCHOUTS??
- UNCONFORMITY??
- DIAGENETIC??
- STRATIGRAPHICALLY CONTROLLED FRACTURE FREQUENCY??

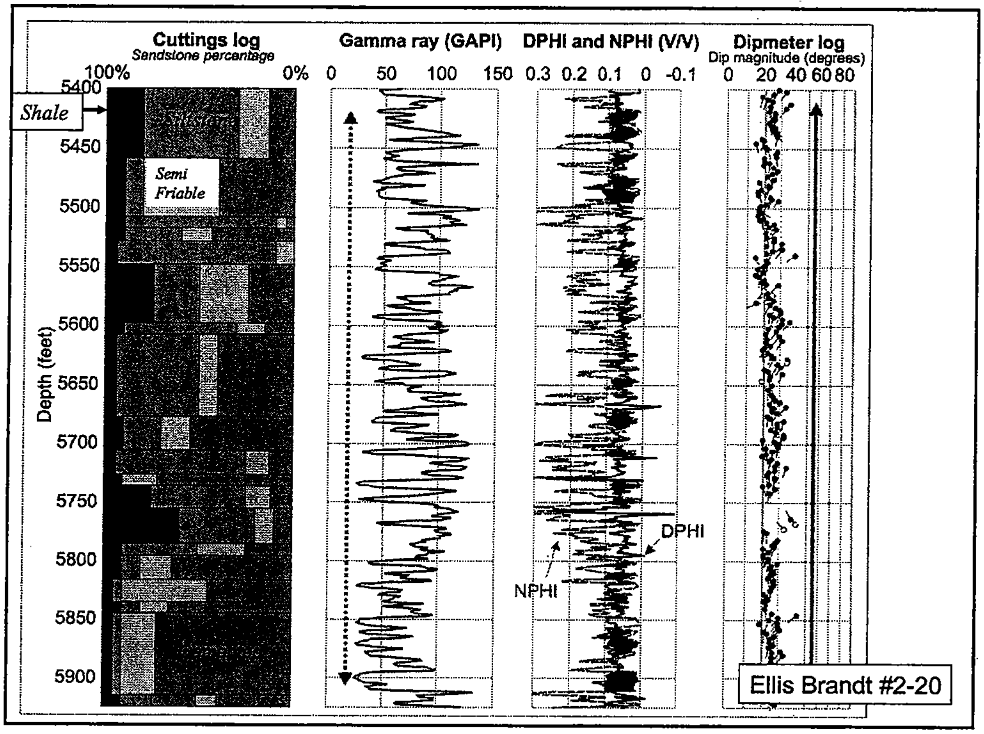


Porous sandstones (matrix porosity)

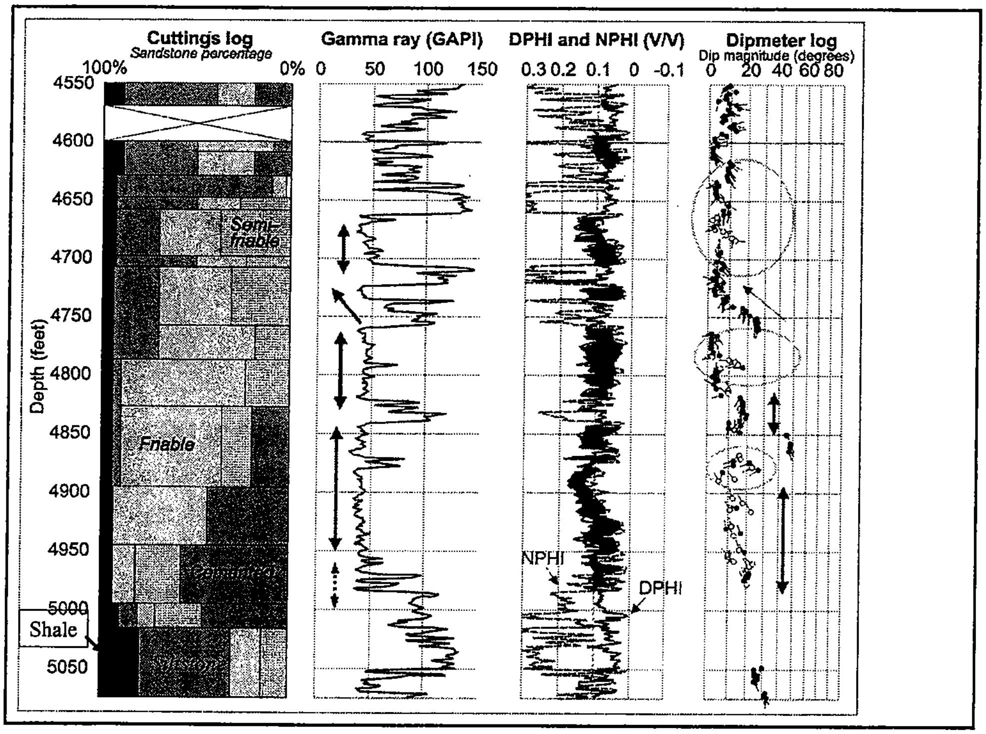
Cemented sandstones (fracture porosity)



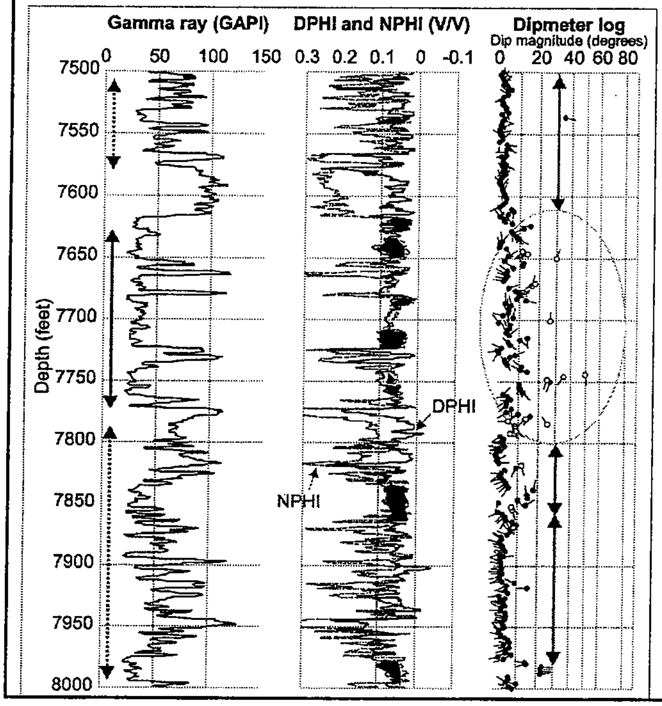
Which are Channel Sands and which are Sheet Sands????



Cuttings log
Sandstone percentage
100%
0%
Gamma ray (GAPI)
0 50 100 150
DPHI and NPHI (V/V)
0.3 0.2 0.1 0 -0.1
Dipmeter log
Dip magnitude (degrees)
0 20 40 60 80
Depth (feet)
5400
5450
5500
5550
5600
5650
5700
5750
5800
5850
5900
Shale
Semi Friable
NPHI
DPHI
Ellis Brandt #2-20



Cuttings log
Sandstone percentage
100%
0%
Gamma ray (GAPI)
0 50 100 150
DPHI and NPHI (V/V)
0.3 0.2 0.1 0 -0.1
Dipmeter log
Dip magnitude (degrees)
0 20 40 60 80
Depth (feet)
4550
4600
4650
4700
4750
4800
4850
4900
4950
5000
5050
Semi-friable
Friable
Cemented
Shale
NPHI
DPHI

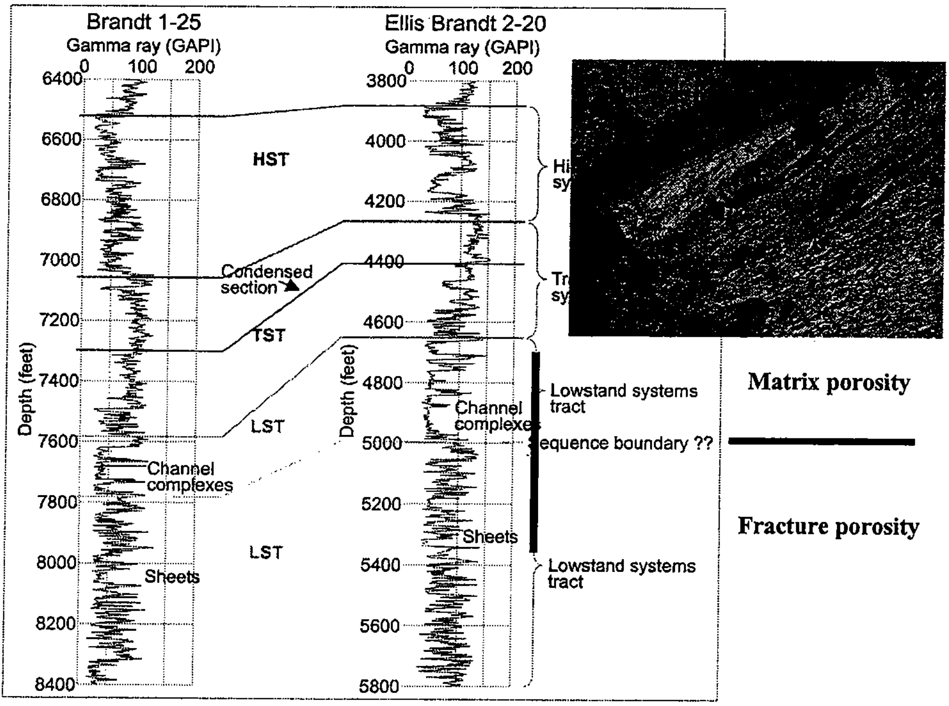


Cemented, Sheet Sandstone??

Friable, Channel Sandstone??

Cemented, Sheet Sandstone??

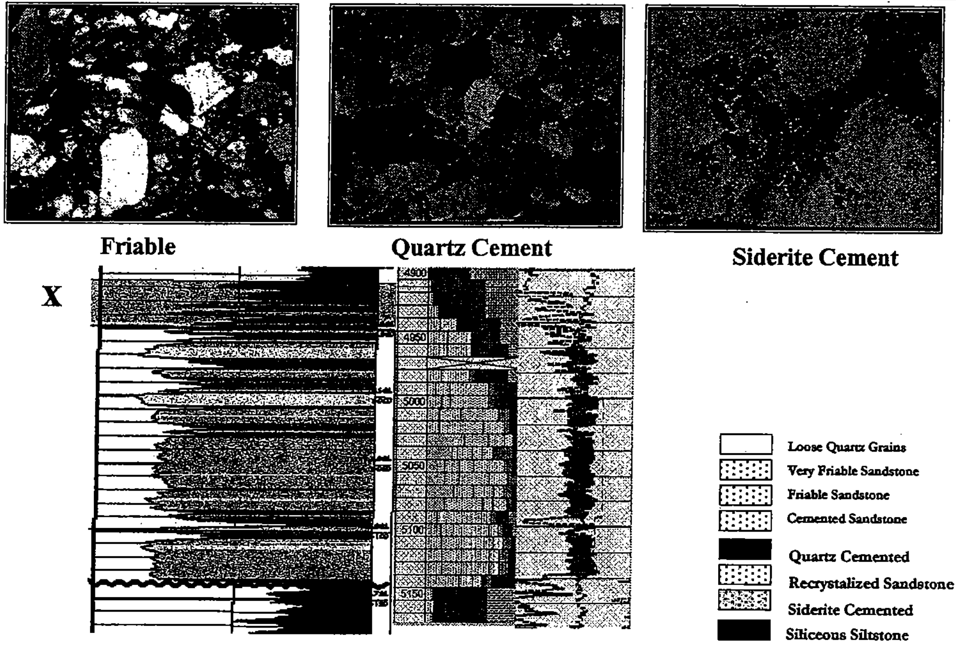
Friable, Channel Sandstone??



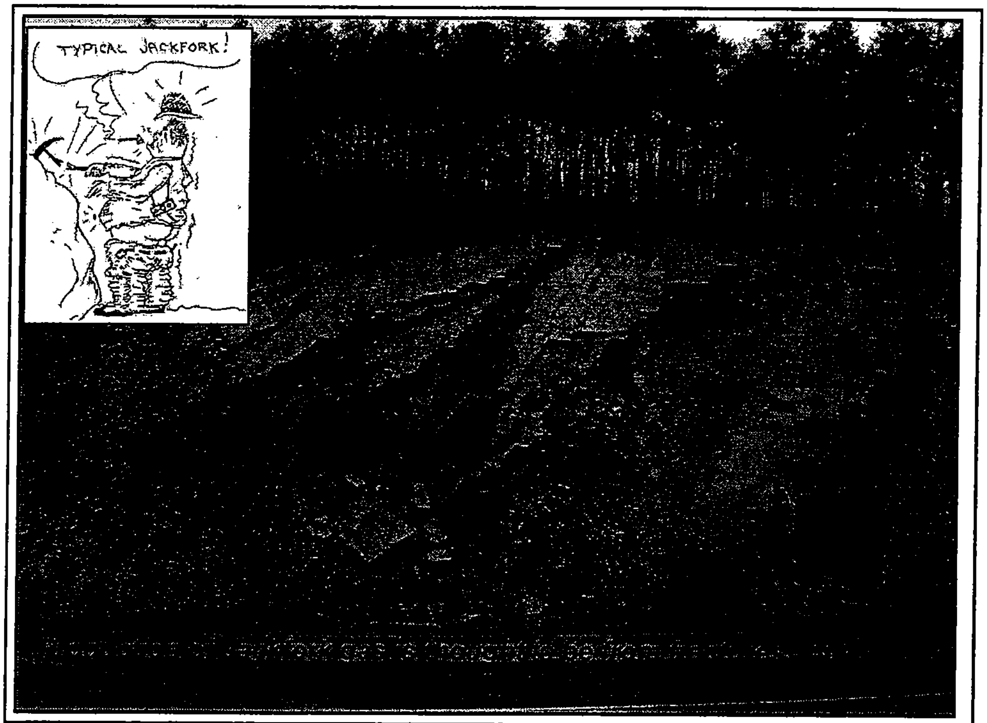
Matrix porosity

Fracture porosity

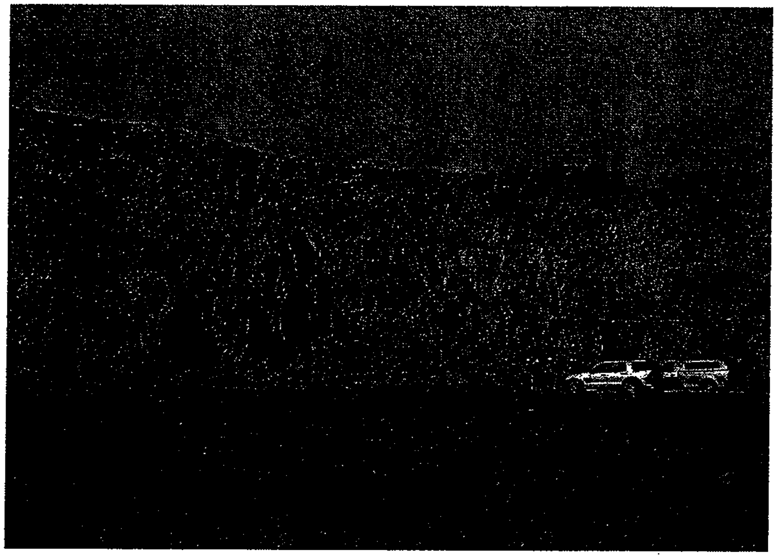
Cement types

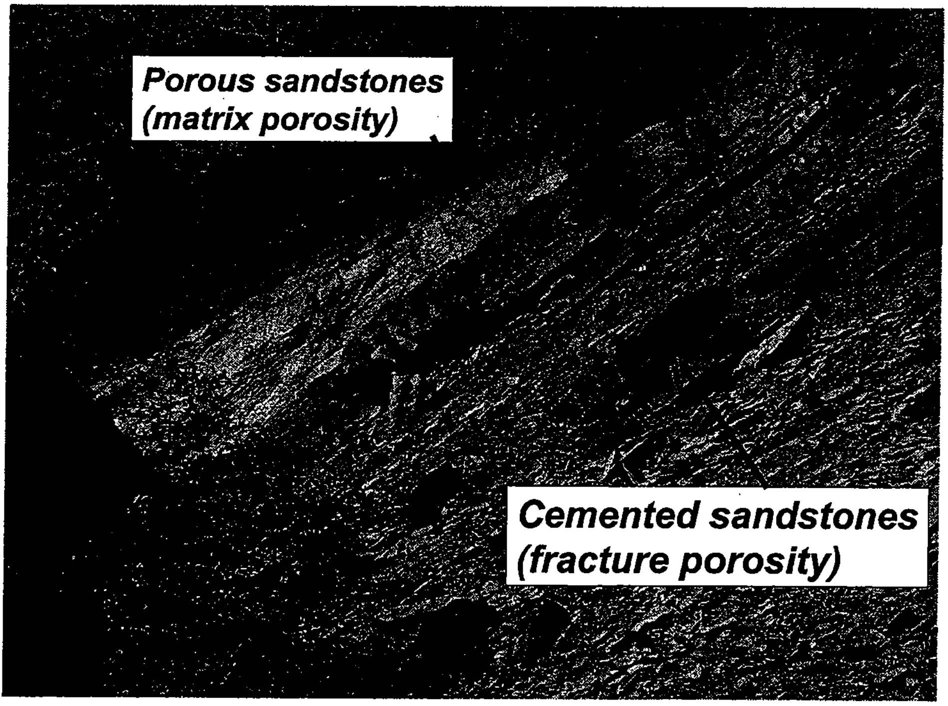


☐	Loose Quartz Grains
▨	Very Friable Sandstone
▨	Friable Sandstone
▨	Cemented Sandstone
■	Quartz Cemented
▨	Recrystalized Sandstone
▨	Siderite Cemented
■	Siliceous Siltstone
■	Dark Mudstone
▤	Light Gray Mudstone



[illegible]

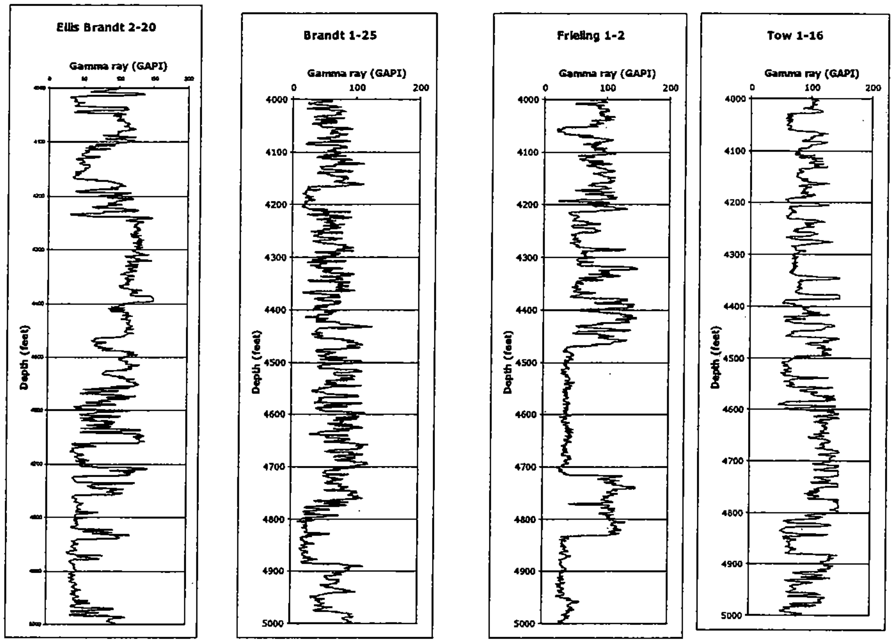


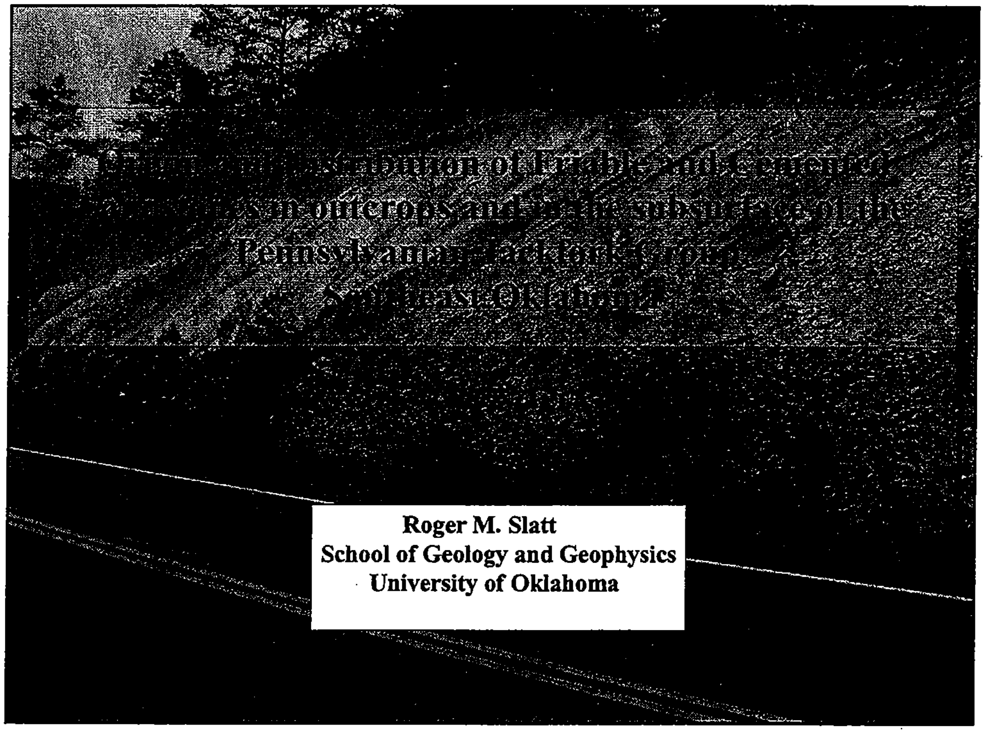


Porous sandstones (matrix porosity)

Cemented sandstones (fracture porosity)

Which are Channel Sands and which are Sheet Sands????





[illegible] Distribution of Friable and Cemented [illegible] in outcrops and in the subsurface of the Pennsylvanian Jackfork Group, Southeast Oklahoma

Roger M. Slatt
School of Geology and Geophysics
University of Oklahoma

Omatsola, T., 2002, Origin and distribution of friable and cemented sandstones in outcrops of the Pennsylvanian Jackfork Group, Arkansas, M.S. thesis, OU

Busetti, S., 2003, Fracture characterization and analysis of the Pennsylvanian Jackfork Group, southeastern Oklahoma, M.S. thesis, OU

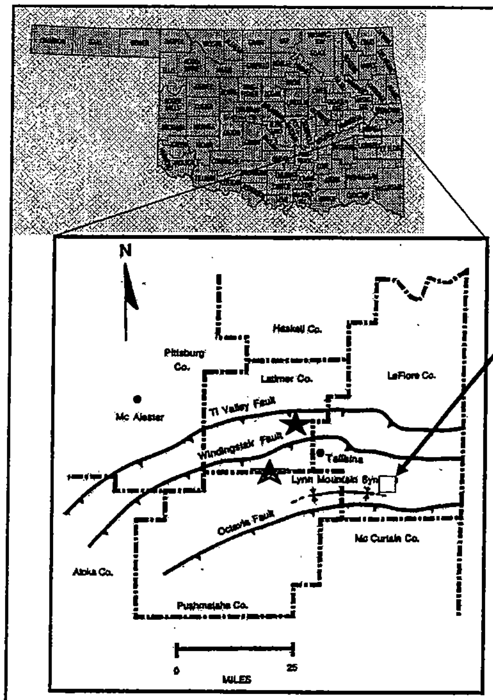
Garich, A., 2004, Porosity types and relation to deepwater sedimentary facies of subsurface Jackfork Group Sandstones, Latimer and Le Flore Counties, Oklahoma, M.S. thesis, OU

Romero, G., in press, Porosity types and relation to deepwater sedimentary facies of subsurface Jackfork Group Sandstones, Pushmahata Countiy, Oklahoma, M.S. thesis, OU

Slatt, on-going work

Funds provided by American Chemical Society, Petroleum Research Fund Grant ACS-PRF#37022-AC2

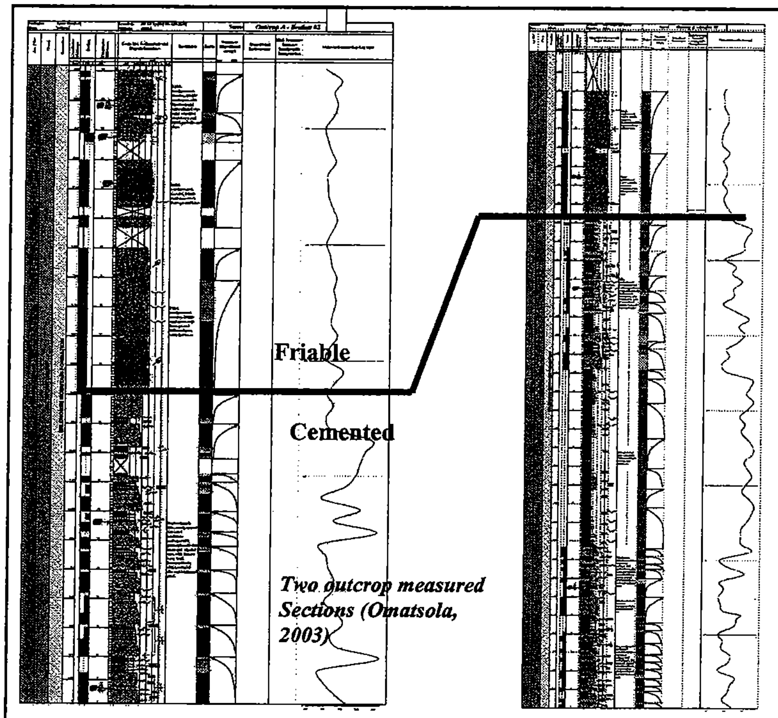
Data provided by GHK, Ward Petroleum, Schlumberger, and Ardmore Geol. Soc.



Omatsola, 2003

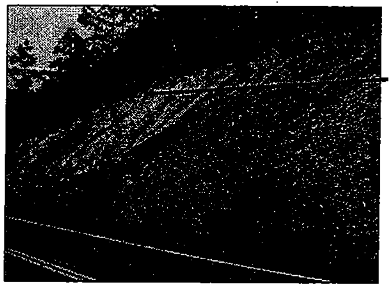
□ *Outcrop*

★ *Subsurface*
★

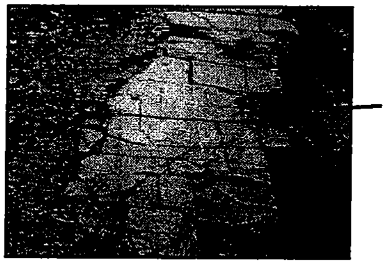


Two outcrop measured Sections (Omatsola, 2003)

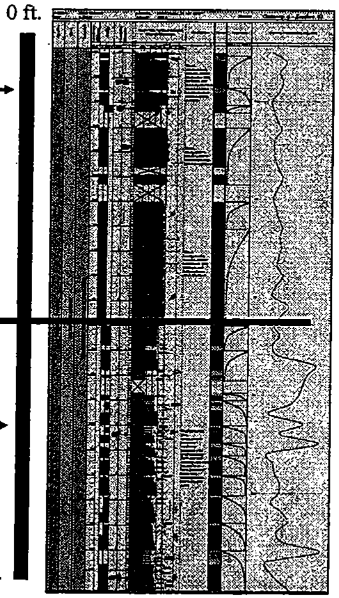
Measured stratigraphic section- U.S. 259



Friable Sandstones; Matrix porosity; Massively bedded

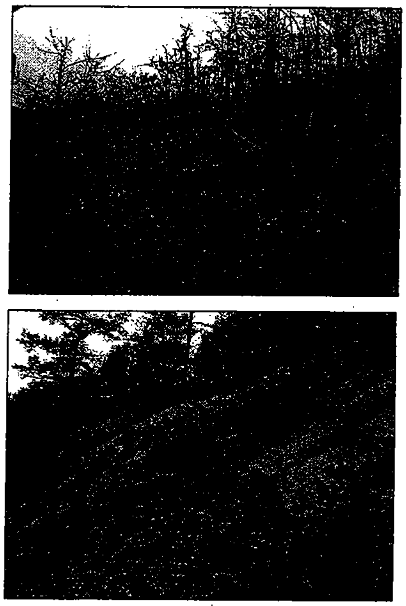


Quartz Cemented Sandstones; Fracture porosity; More thinly bedded



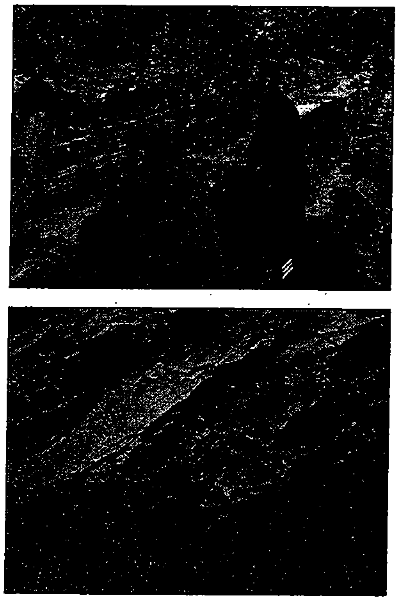
Lithostratigraphy

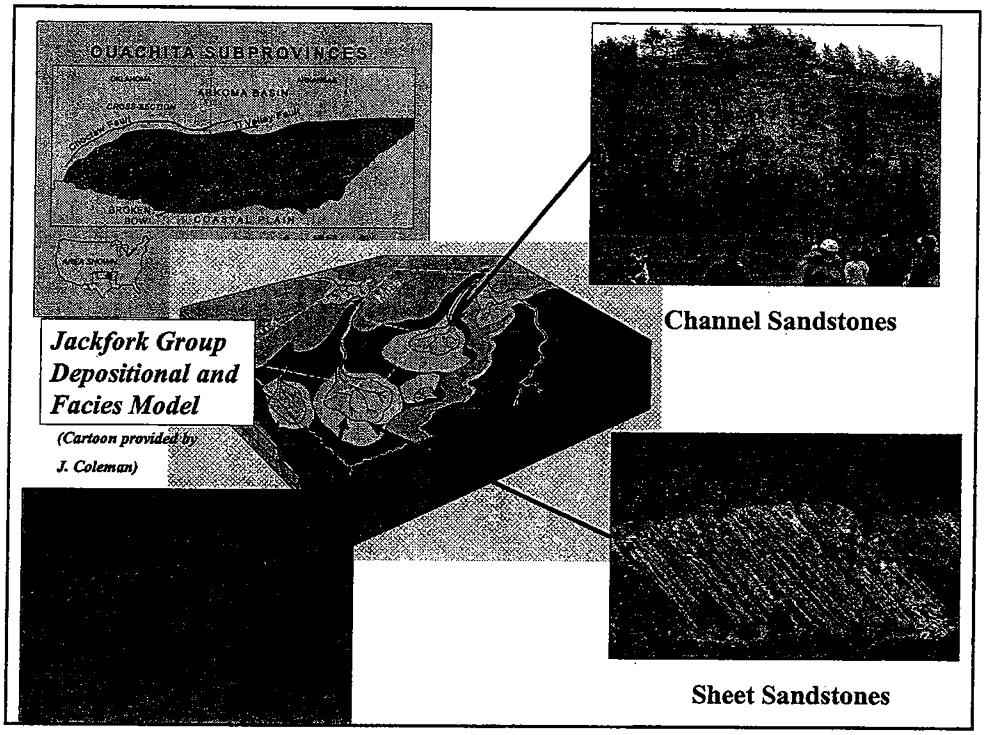
- Friable sandstones
  - Gray – whitish (fresh) and yellow – orange (when weathered)
  - Fine to medium-grained; poorly - moderately sorted
  - Bulbous contacts/bedding; planar bedded (occasionally)
  - Thick & thin bedded (0.5 – 7ft), (0.8m-2.1m); massive, amalgamated or layered (occasionally)
  - Various sedimentary structures
  - Highly porous (and also fractured)



Lithostratigraphy

- Quartz cemented sandstones
  - Gray – tan (fresh) and light gray – medium brown (when weathered)
  - Very fine to fine-grained; moderately - well sorted
  - Planar-tabular bedded; bulbous contacts, scoured bedding (occasionally)
  - Thick & thin bedded (0.5 – 5ft), (0.8m-1.5m); massive, amalgamated or layered; Bouma Ta-Tc beds
  - Various sedimentary structures and deepwater ichnofacies
  - Highly fractured



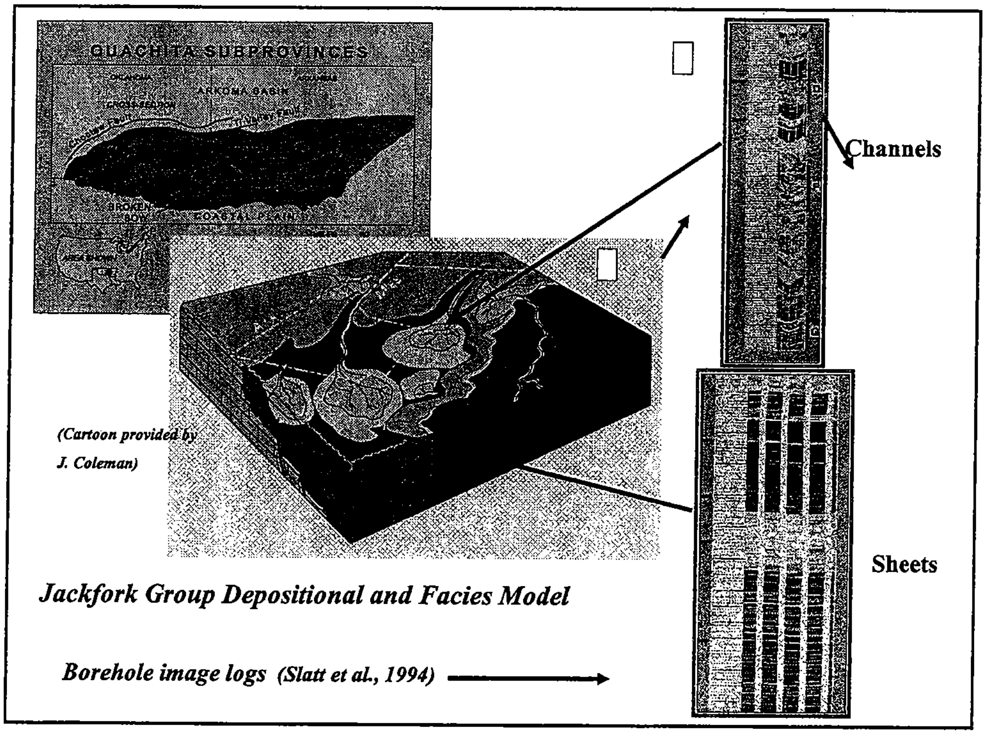


Channel Sandstones

Jackfork Group Depositional and Facies Model

(Cartoon provided by J. Coleman)

Sheet Sandstones



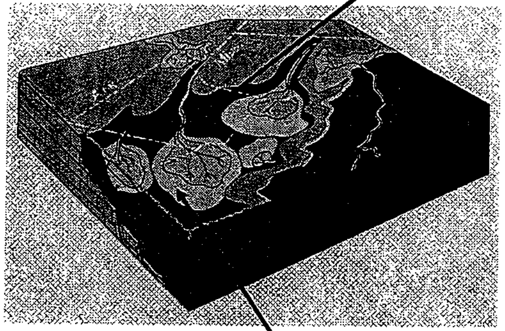
Channels

(Cartoon provided by J. Coleman)

Sheets

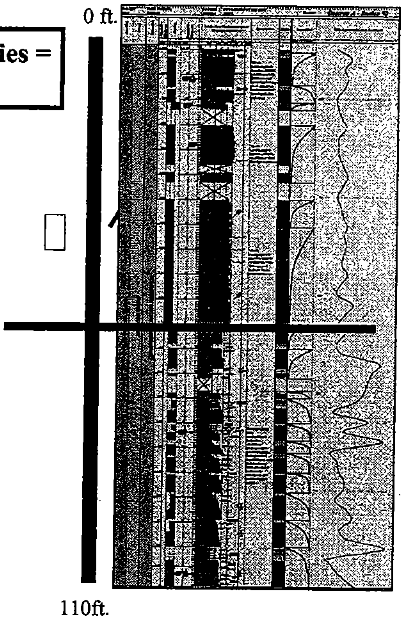
Jackfork Group Depositional and Facies Model

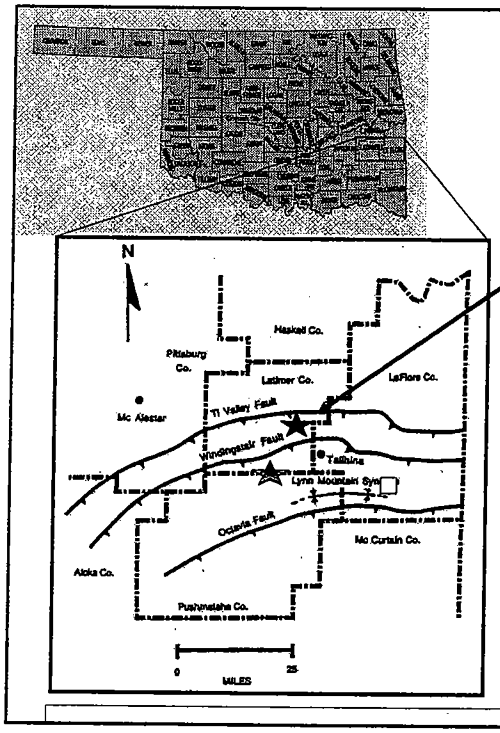
***Borehole image logs** (Slatt et al., 1994)* →



Friable sandstone facies = Channel sandstones

Cemented sandstone facies = Sheet sandstones

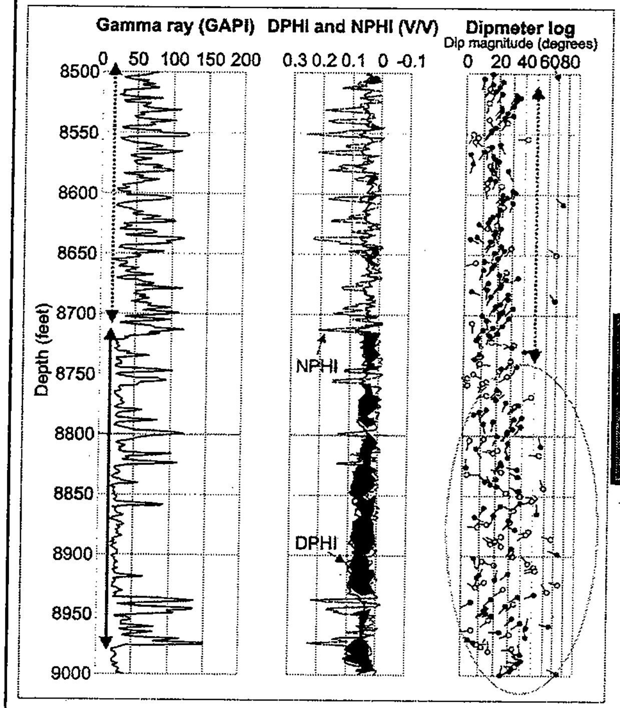




Garich, 2004

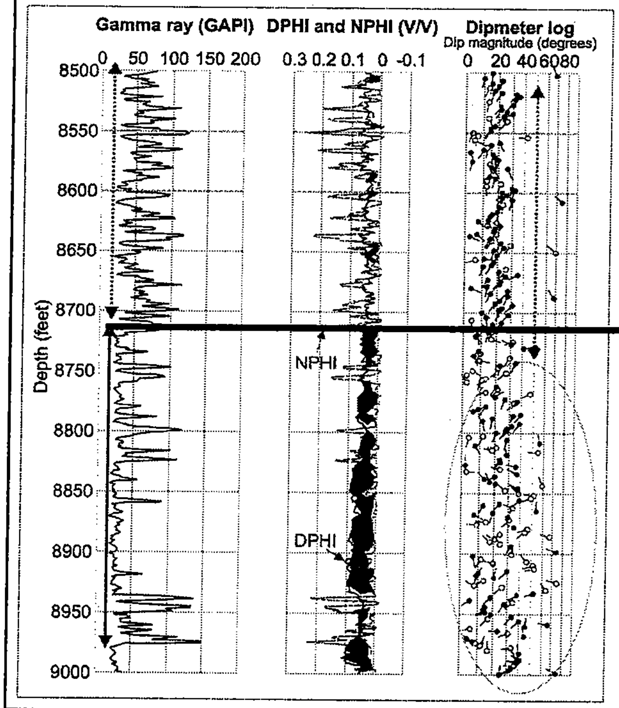
☐ *Outcrop*

★ *Subsurface*



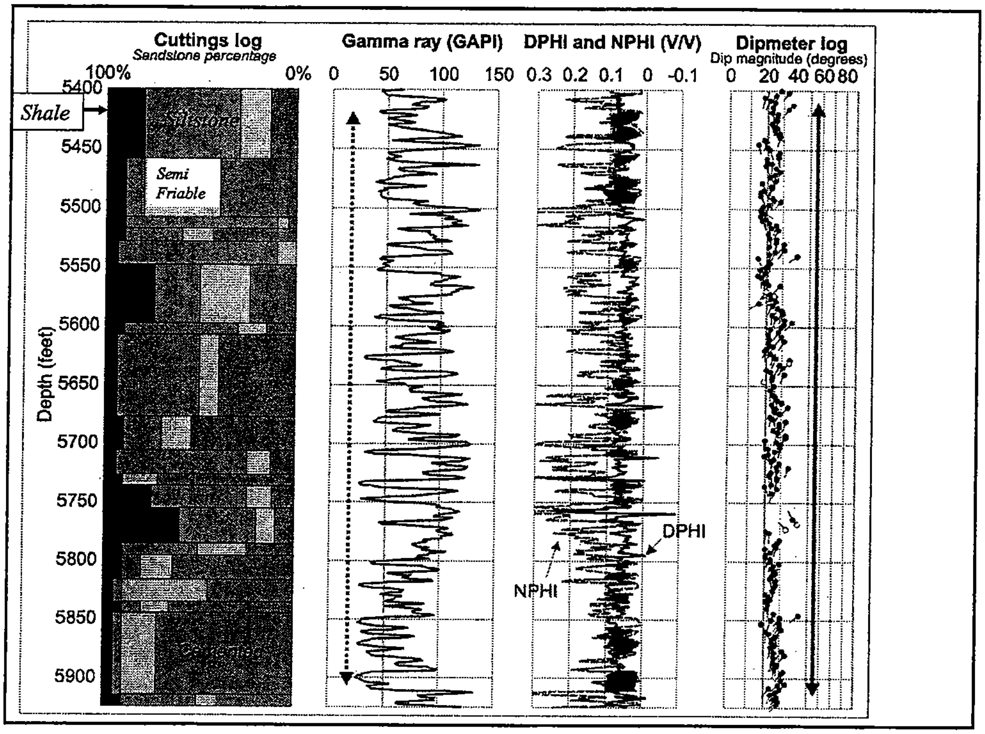
Dipmeter Log

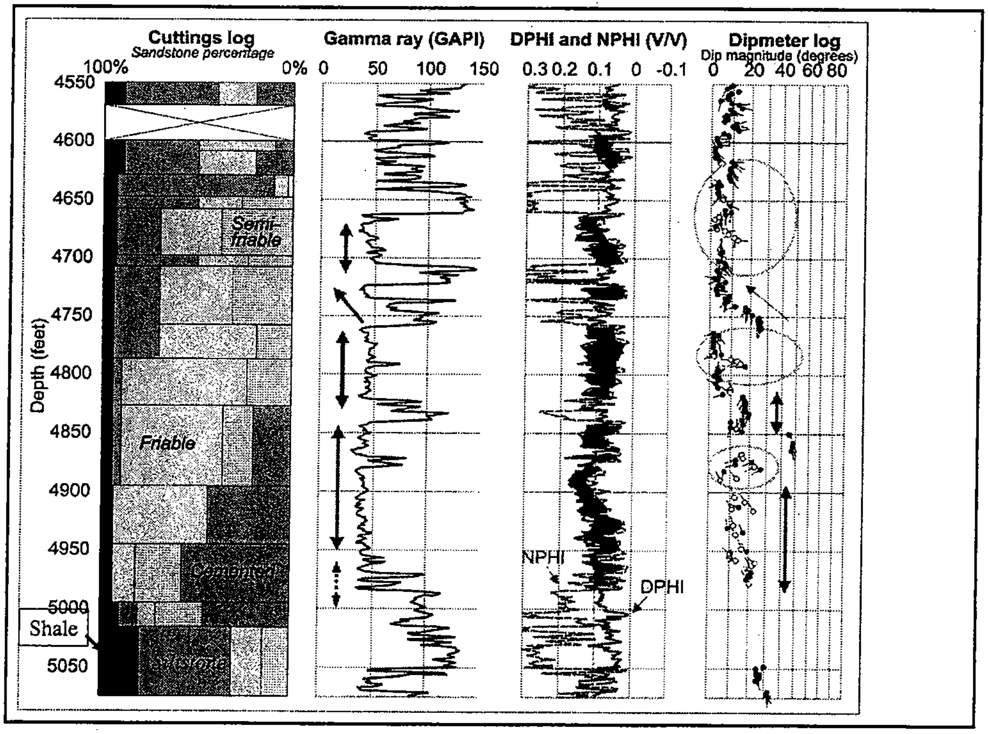
Cuttings

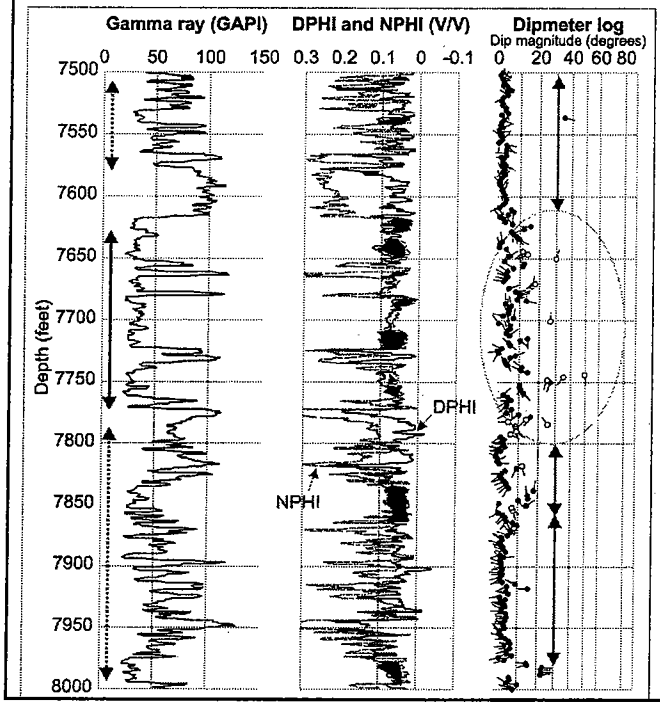


-Sandstone/Shale interbeds
-Relatively good and uniform dips
= Sheet Sandstones; interbedded with shale

-Thick sandstones
-Few shale interbeds
-Relatively poor and variable dips
= Channel Sandstones; thicker bedded with less shale


Cuttings log
Sandstone percentage
100%
0%
Gamma ray (GAPI)
0
50
100
150
DPHI and NPHI (V/V)
0.3
0.2
0.1
0
-0.1
Dipmeter log
Dip magnitude (degrees)
0
20
40
60
80
Depth (feet)
5400
5450
5500
5550
5600
5650
5700
5750
5800
5850
5900
Shale
Siltstone
Semi Friable
Cemented
NPHI
DPHI


Cuttings log
Sandstone percentage
100%
0%
Gamma ray (GAPI)
0
50
100
150
DPHI and NPHI (V/V)
0.3
0.2
0.1
0
-0.1
Dipmeter log
Dip magnitude (degrees)
0
20
40
60
80
Depth (feet)
4550
4600
4650
4700
4750
4800
4850
4900
4950
5000
5050
Semi-friable
Friable
Cemented
Shale
Siltstone
NPHI
DPHI

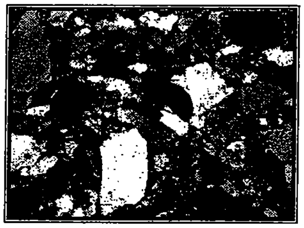


Cemented, Sheet Sandstone

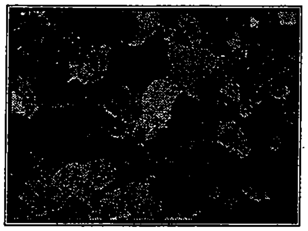
Friable, Channel Sandstone

Cemented, Sheet Sandstone

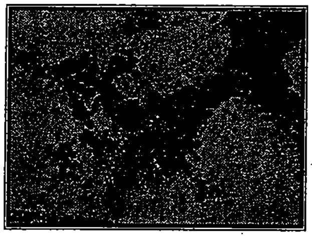
Friable, Channel Sandstone



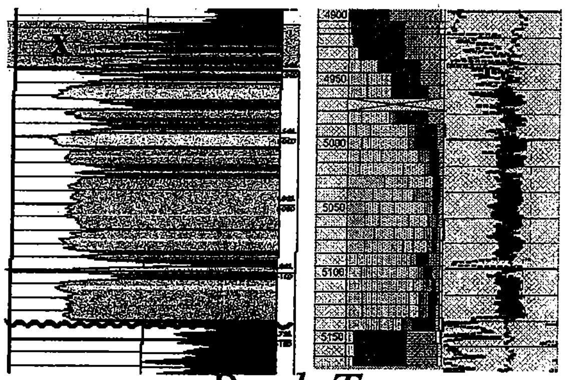
Friable



Quartz Cement

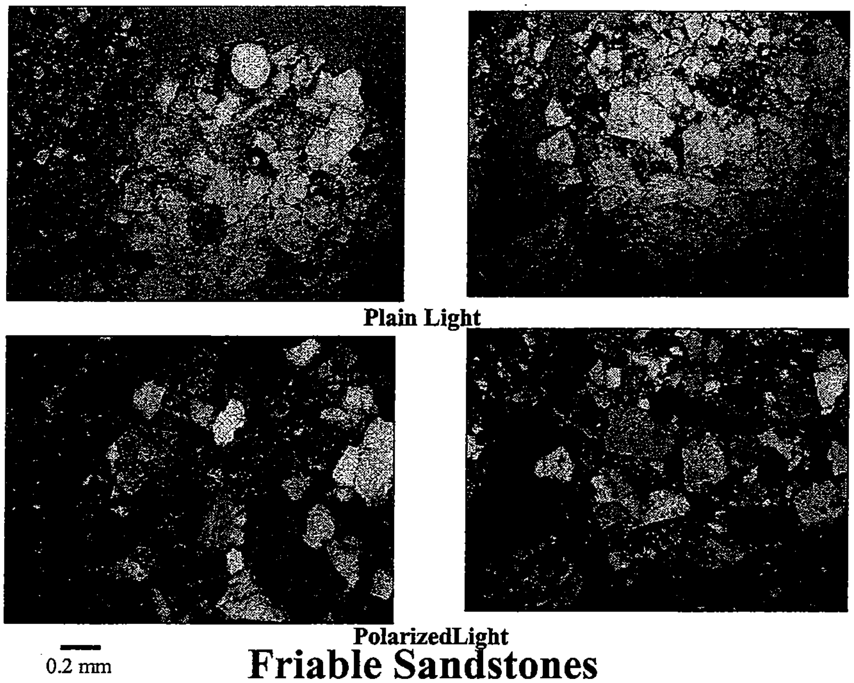


Siderite Cement

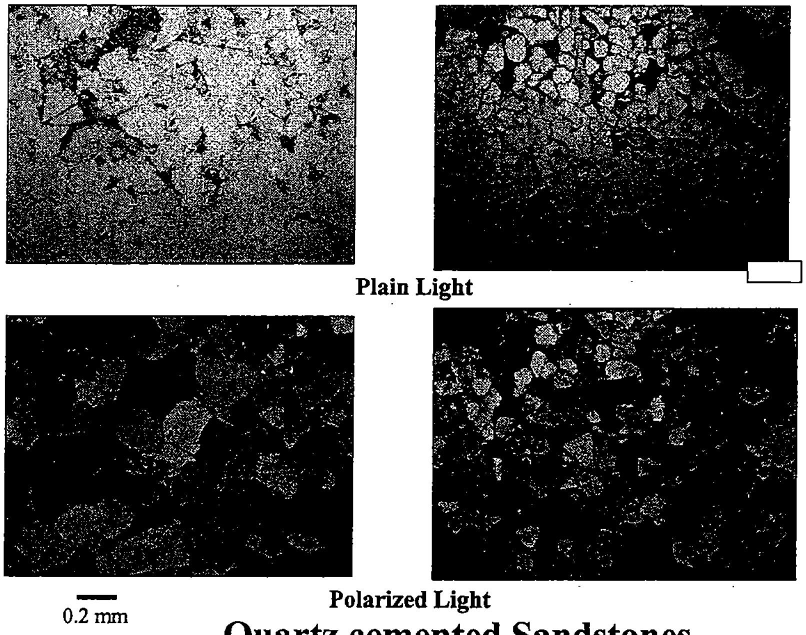


Rock Types

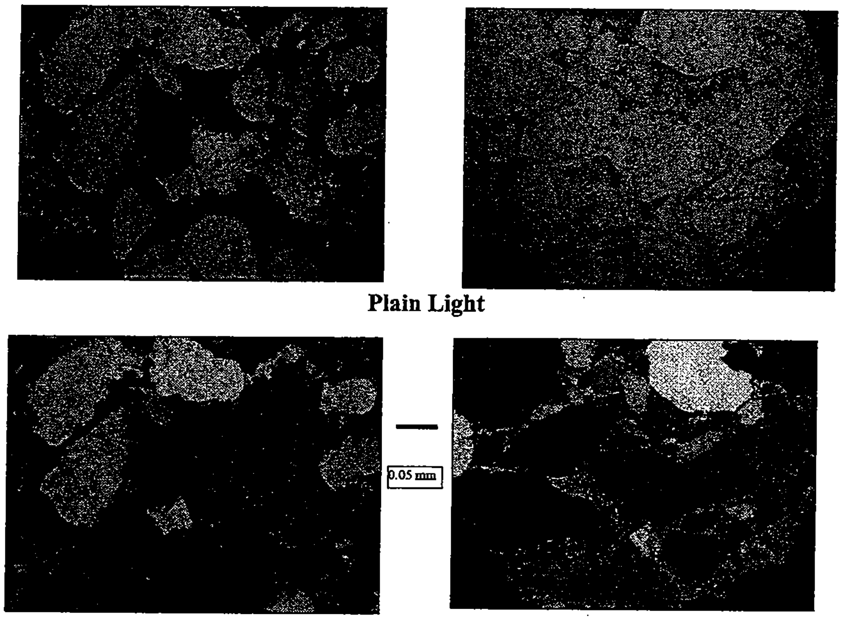
- ☐ Loose Quartz Grains
- ▨ Very Friable Sandstone
- ▨ Friable Sandstone
- ▨ Cemented Sandstone
- ■ Quartz Cemented
- ▨ Recrystalized Sandstone
- ▨ Siderite Cemented
- ■ Siliceous Siltstone
- ■ Dark Mudstone
- ▨ Light Gray Mudstone



Friable Sandstones



Quartz cemented Sandstones



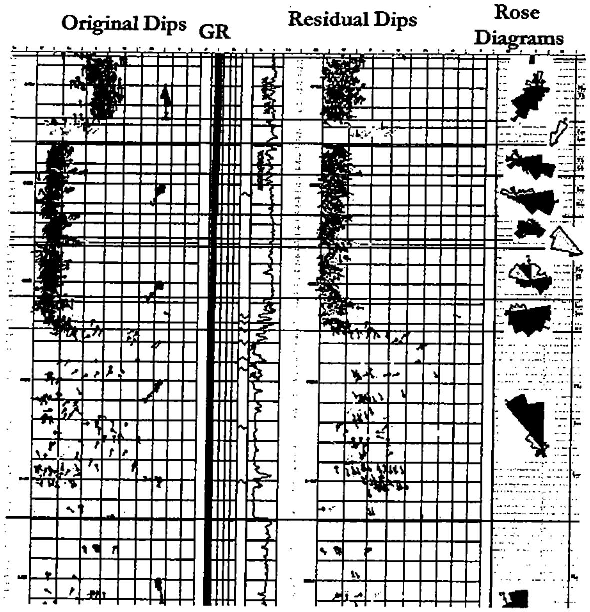
Plain Light

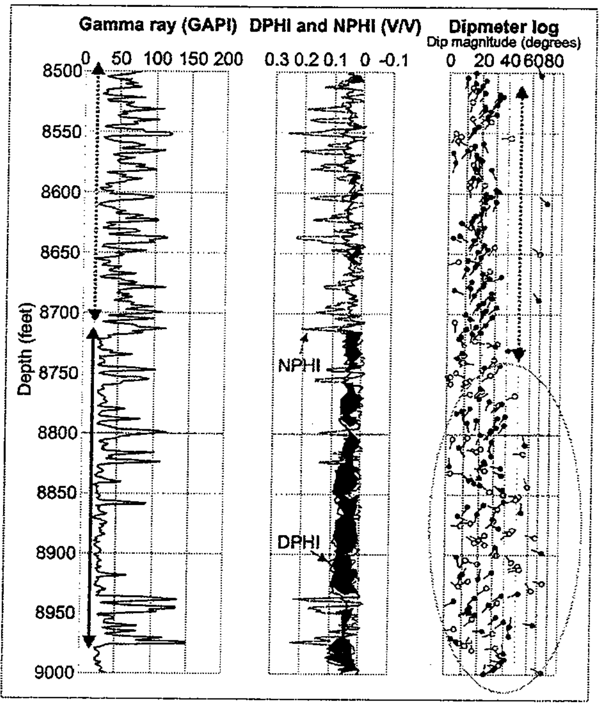
Siderite cemented sandstone

Polarized Light

Calcite cemented sandstone

Correct dip for structure to identify subtle stratigraphic intervals

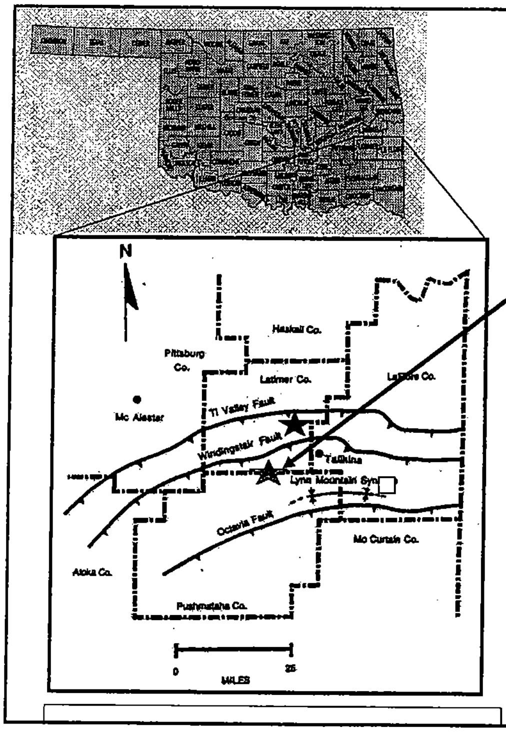




Frieling 1-2

Cemented, Sheet Sandstone??

Friable, Channel Sandstone??

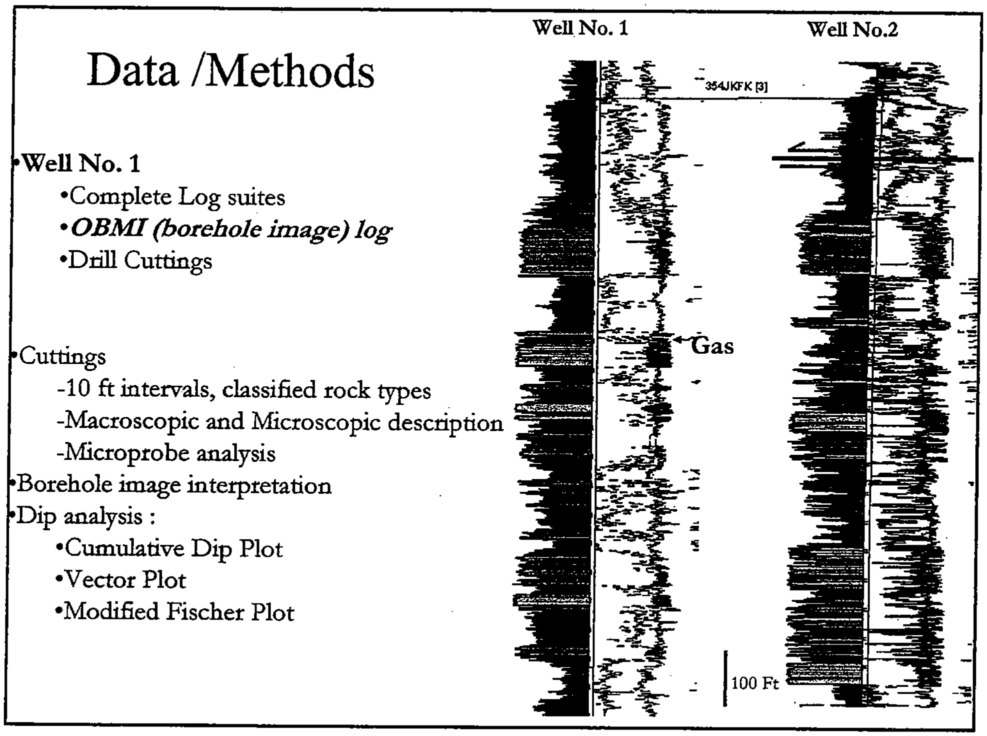


Romero, 2004

□ *Outcrop*

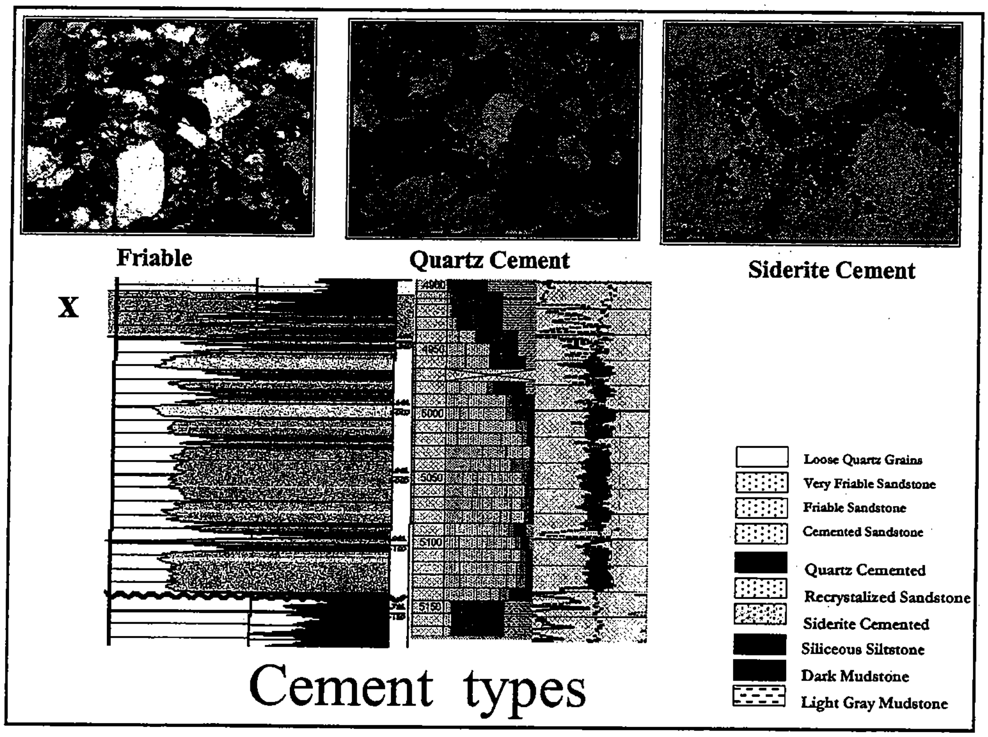
★ *Subsurface*

★



Data /Methods

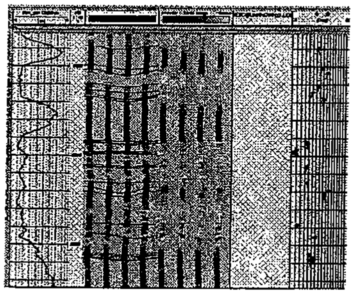
- Well No. 1
  - Complete Log suites
  - ***OBMI (borehole image) log***
  - Drill Cuttings
- Cuttings
  - -10 ft intervals, classified rock types
  - -Macroscopic and Microscopic description
  - -Microprobe analysis
- Borehole image interpretation
- Dip analysis :
  - Cumulative Dip Plot
  - Vector Plot
  - Modified Fischer Plot



Cement types

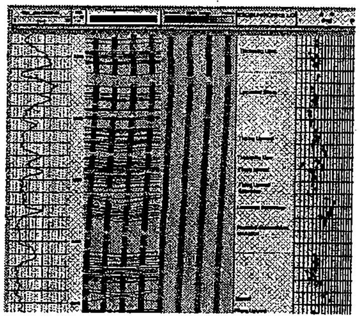
Borehole image and dipmeter logs

Channel facies



Scoured surfaces **Variable dip**

Sheet facies



Depositional surfaces **More uniform dip**

Friable vs. Cemented Sandstones , why?

Working hypotheses:

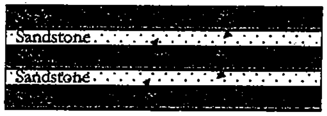
- Composition and cementation differences are related to depositional facies:
  - Channels:Proximal, textural and compositional immaturity. → Friable Sandstones
  - Sheets: Distal, textural and compositional maturity. → Cemented Sandstones.

Channels
(Proximal)

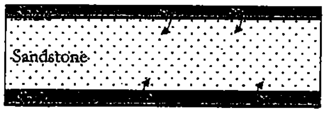
Sheets
(Distal)

Increasing
Textural and compositional maturity

- Cementation differences are related to diagenesis:
  - Transformation of Smectite to Illite within adjacent shale intervals liberates silica that migrates into sandstones and forms quartz overgrowths to give cemented sandstones.

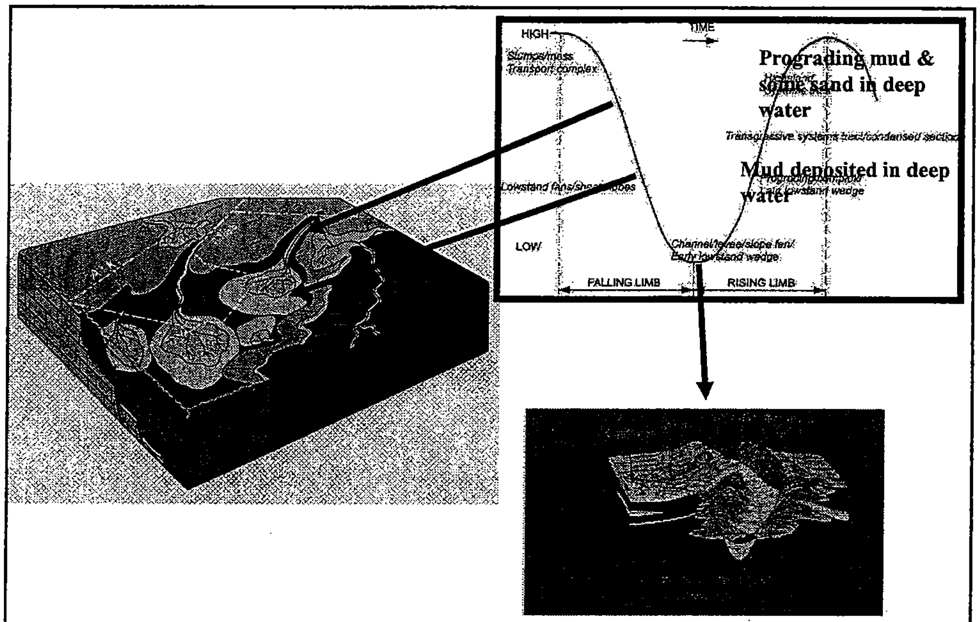


Thin bedded **Sheet sandstones**



Thick bedded **Channel sandstones**

- Different provenances for sheet and channel sandstones.

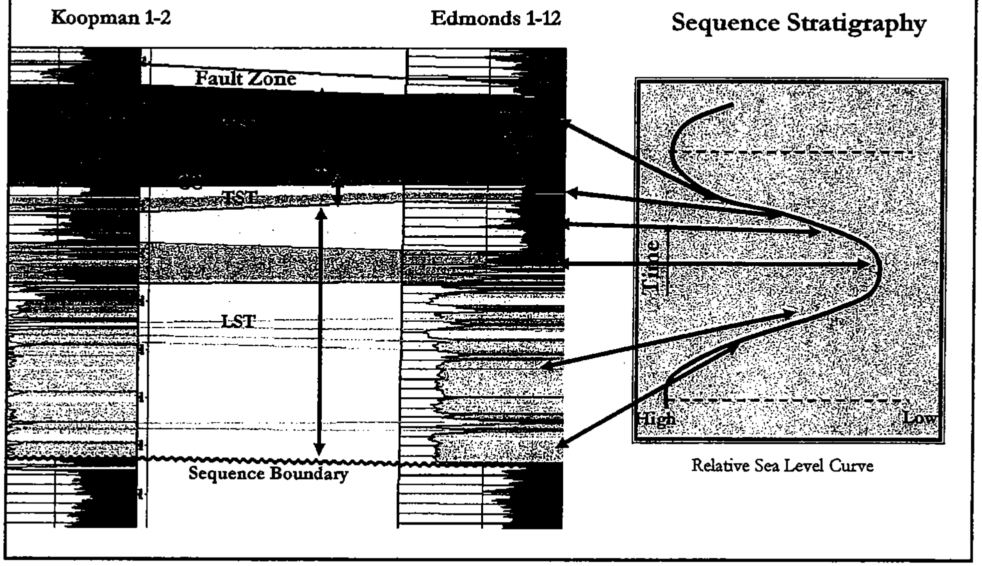


Prograding mud & some sand in deep water

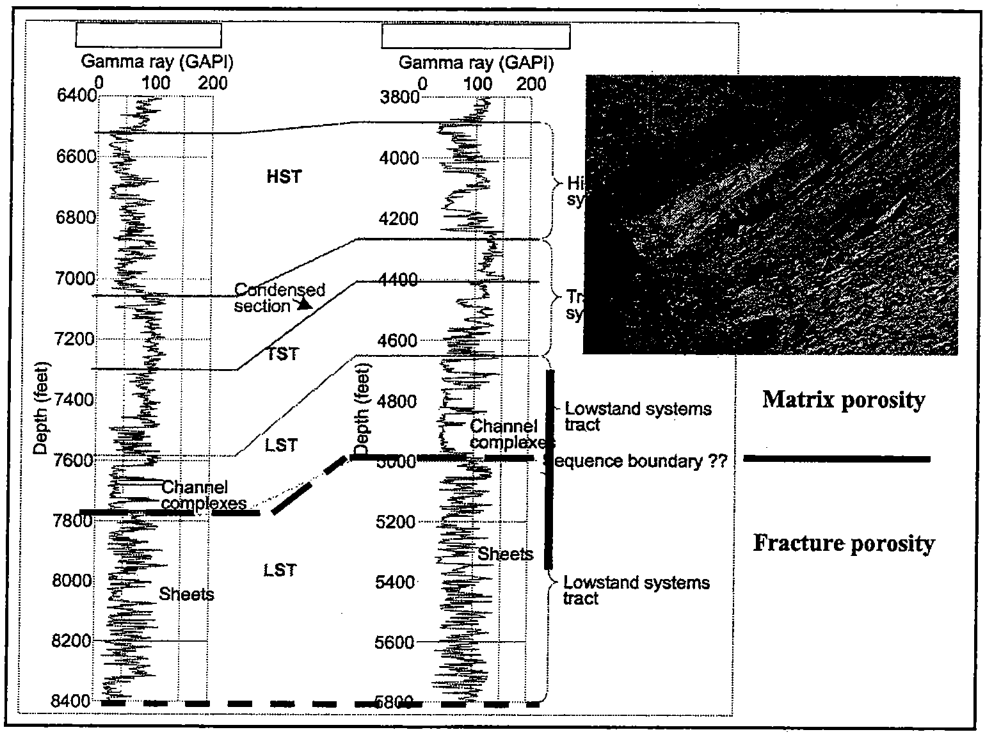
Mud deposited in deep water

Sequence stratigraphy of deepwater deposits

Turbidite Elements and Sequence stratigraphy



Relative Sea Level Curve



JACKFORK GROUP HYDROCARBON RESERVOIR/TRAP TYPES

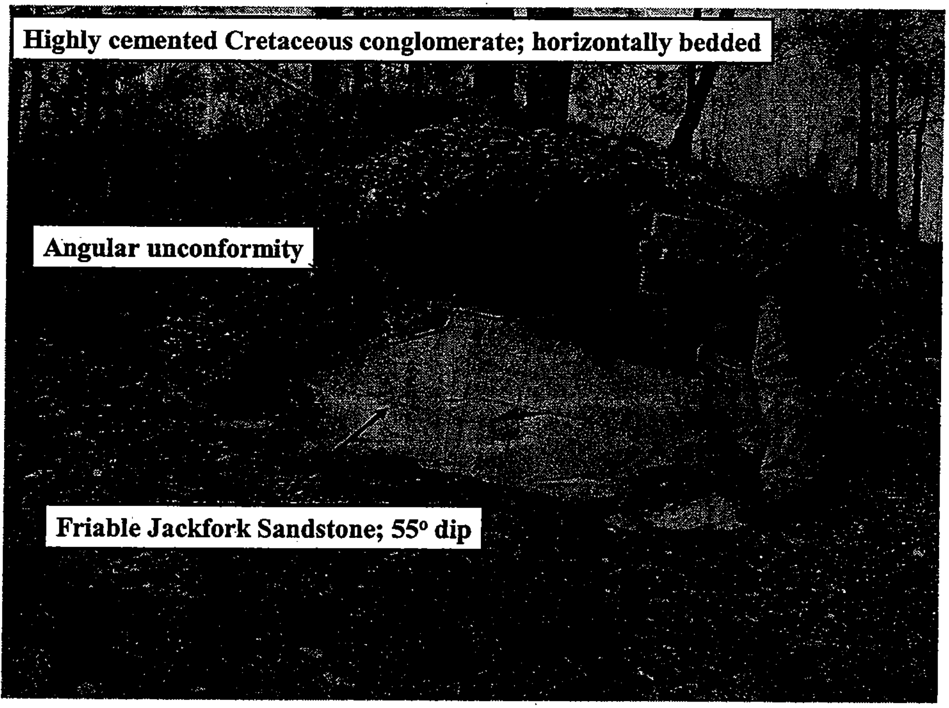
-DIAGENETIC ??

-STRATIGRAPHICALLY CONTROLLED FRACTURE FREQUENCY ??

- **Matrix porosity in channel sandstones**
  - **variable, poor dips**
  - **thick sandstones**
- **Fracture porosity in sheet sandstones**
  - **uniform, good dips**
  - **thinner sandstones with interbedded shales**
- **Sequence stratigraphy good for correlation and identifying sandstone types**

JACKFORK GROUP HYDROCARBON RESERVOIR/TRAP TYPES

- LARGE-SCALE STRUCTURES
- FRACTURES
- STRATIGRAPHIC PINCHOUTS??
- UNCONFORMITY??
- DIAGENETIC??
- STRATIGRAPHICALLY CONTROLLED FRACTURE FREQUENCY??



Correlation of Atoka and Adjacent Strata Within a Sequence Stratigraphic Framework, Arkoma Basin, Oklahoma

Presented by

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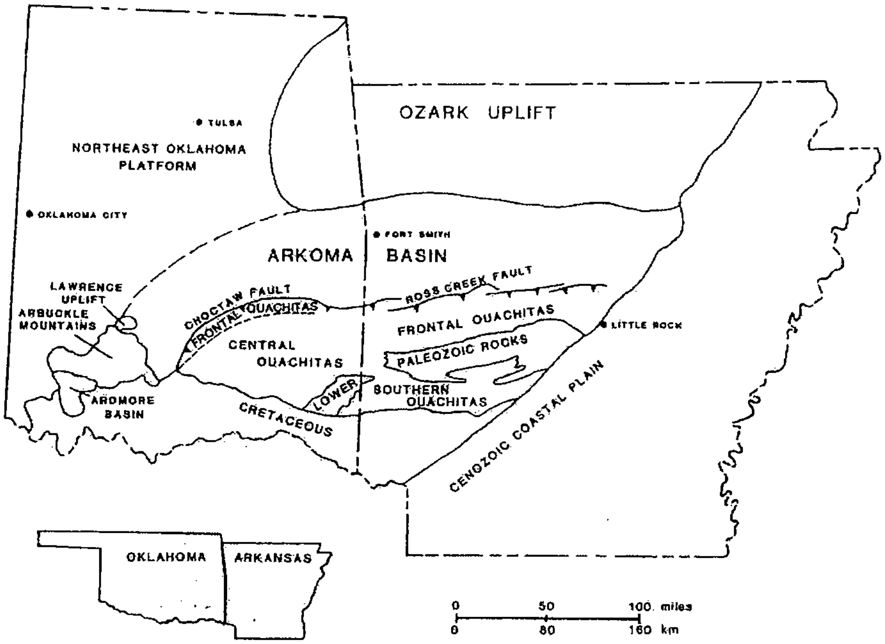
University of Oklahoma

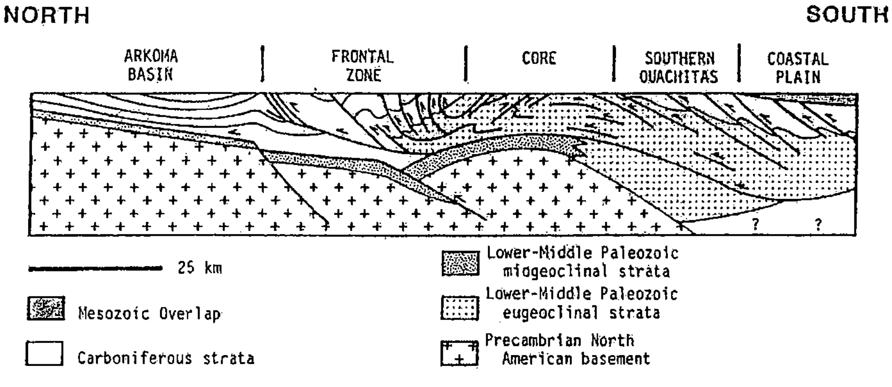
Azzeldeen A. Saleh
School of Geology and Geophysics
University of Oklahoma

Correlation of Atoka and Adjacent Strata Within a Sequence Stratigraphic Framework, Arkoma Basin, Oklahoma

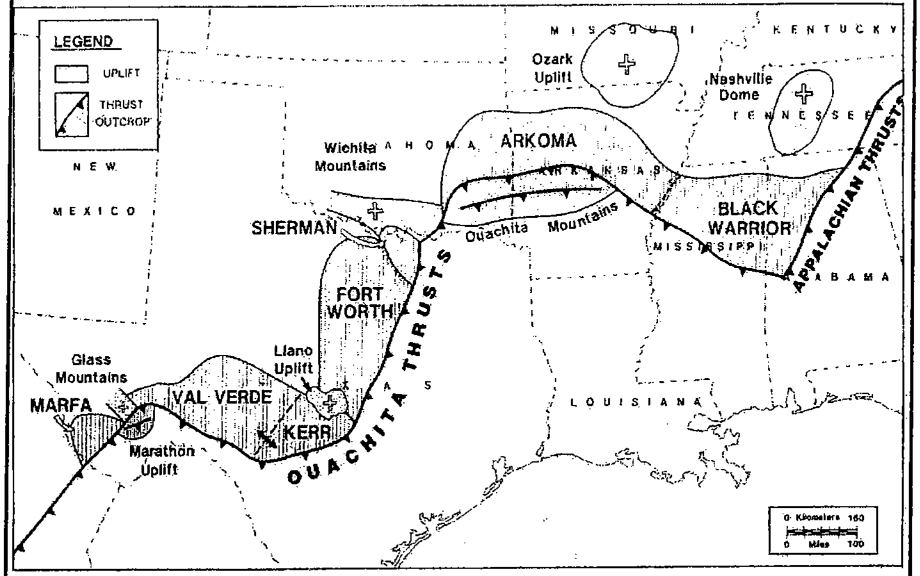
Regional Setting



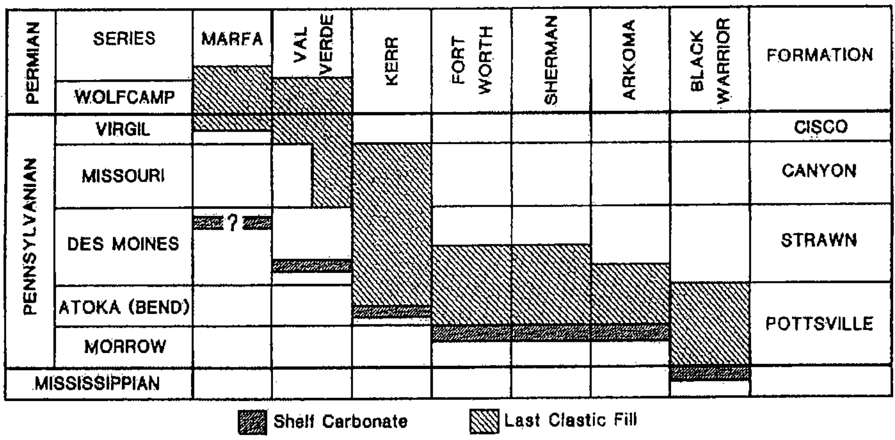
Map showing the location of Arkoma basin in Oklahoma and Arkansas, and the surrounding geologic provinces (after Johnson et al., 1989).



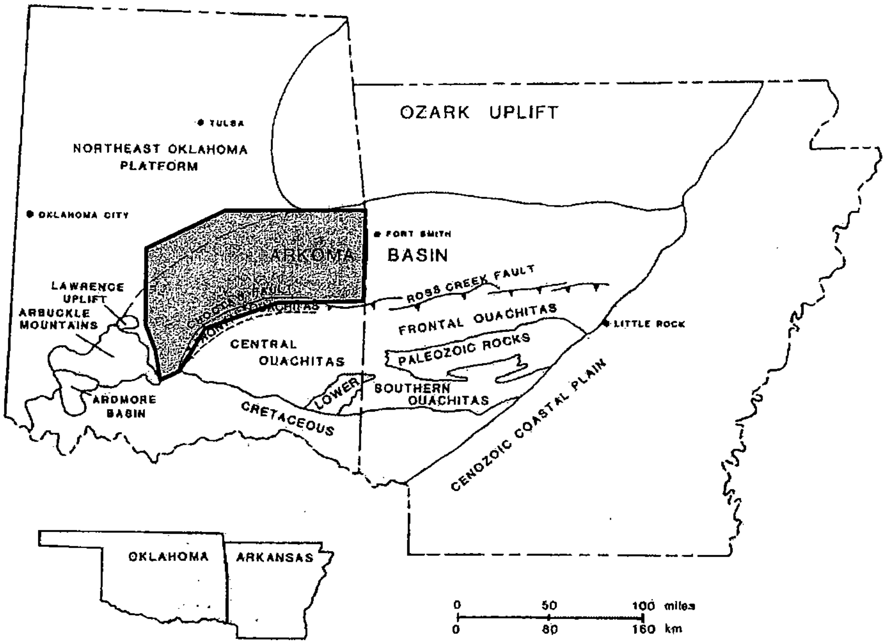
Generalized structural cross section showing the structural relationship between the Arkoma basin and Ouachita orogenic belt (after Lillie et al., 1983).



Map showing the Arkoma basin as one of a series of seven basins that 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).



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).



Regional map showing the location of the study area covering the Arkoma basin in Oklahoma.

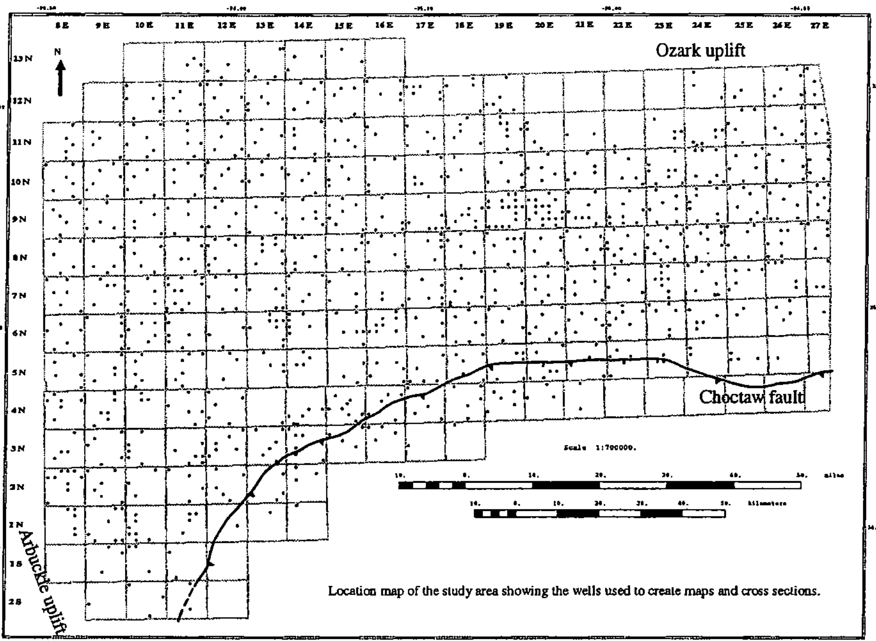
Over 30,000 wells drilled in Arkoma Basin in Oklahoma, yet, the understanding of the Atoka stratigraphy is based on models developed for:

1) the Arkansas part of the basin
2) outcrop studies conducted on the Ouachitas and Ozark uplift
3) prospect style studies that involve few townships for specific sandstone intervals within the Atokan section

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

1) limited Atokan outcrops within the Oklahoma part of the basin
2) dominance of shale and discontinuous nature of many sandstone units
3) lack of regional lithostratigraphic or biostratigraphic markers
4) the complex interaction of active tectonics and huge sediment supply during the deposition of the Atoka Formation

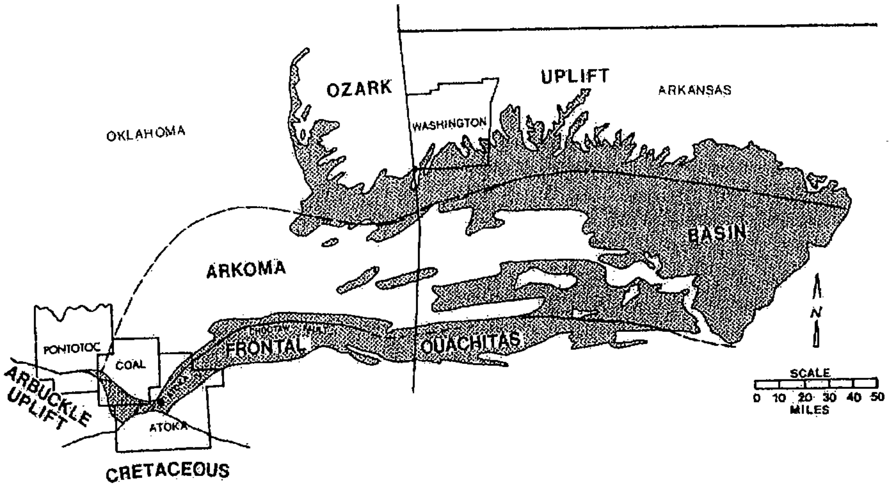
The purpose of this study is to delineate the stratigraphy of the Atoka Formation covering the entire Arkoma basin in Oklahoma, using <u>detailed well log correlations within a sequence stratigraphic framework.</u>



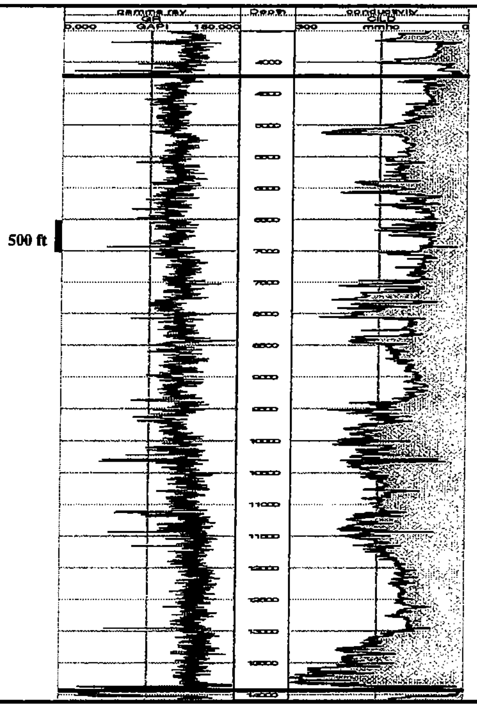
Location map of the study area showing the wells used to create maps and cross sections.

	SERIES	ARKOMA BASIN			OUACHITA MOUNTAINS
PENNSYLVANIAN	Desmoinesian	Krebs Gp.	Boggy Fm.	ℙbg	
			Savanna Fm.	ℙsv	
			McAlester Fm. (Booch)	ℙma	
			Hartshorne Fm. Upper Lower	ℙhs	
	Atokan	Atoka Fm.		ℙa	Atoka Formation
	Morrowan	Wapanucka Ls.		ℙm	Johns Valley Shale
		Union Valley Ls. Cromwell ss.			Jackfork Group
MISSISSIPPIAN	Chesterian	"Caney" Sh.		MD	Stanley Shale
	Meramecian				
	Osagean				
	Kinderhookian				

The upper part of the stratigraphic column for the Arkoma basin and Ouachita mountains (modified after Johnson, 1988).



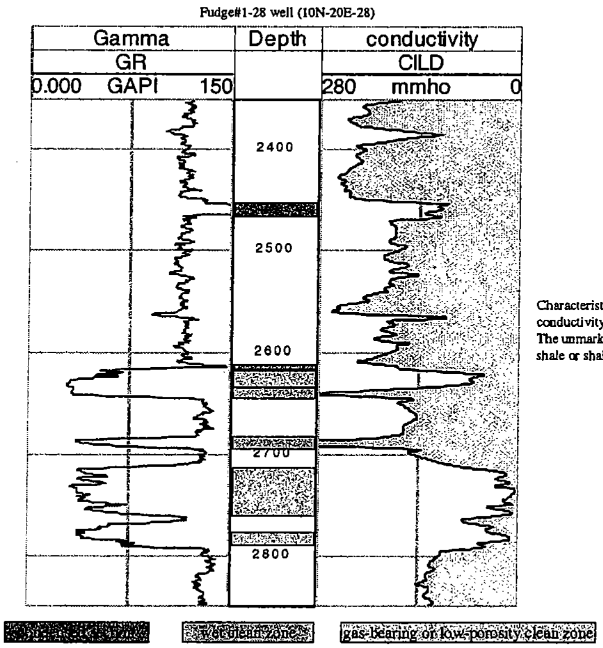
Distribution of Atoka Formation outcrop belts in Arkoma basin and its surroundings (stippled area). Very limited Atokan rocks crop out in the Oklahoma part of Arkoma basin. Most Atokan outcrops are in the Arkansas part of Arkoma basin, Frontal Ouachitas, and Ozark uplift (after Zachry and Sutherland,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



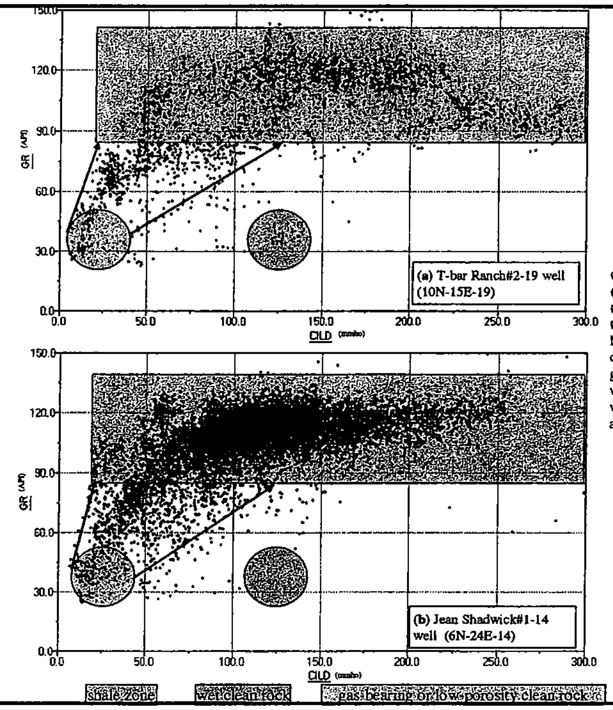
An example for the dominance of shale in the Atoka interval as shown in the Swart#1-20 well (6N-20E-20).

- ➢Logs- conductivity vs gamma ray and sonic
- ➢Sequence stratigraphic concepts

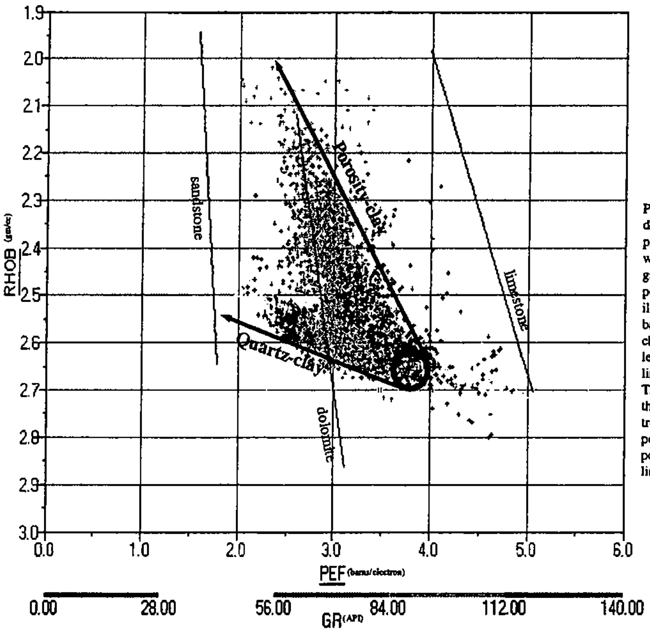
The key:
Establishing boundaries based on tracking shale packages with specific conductivity patterns


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

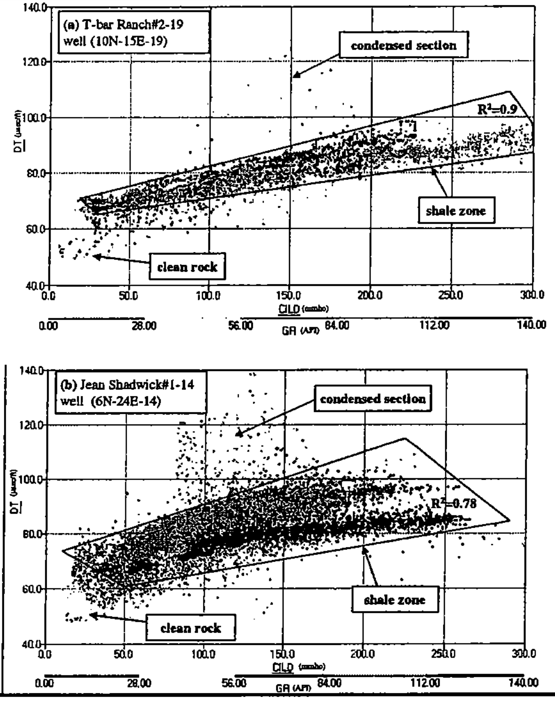
Characteristic signature for rocks on conductivity and gamma ray logs. The unmarked section consists of shale or shaly intervals.



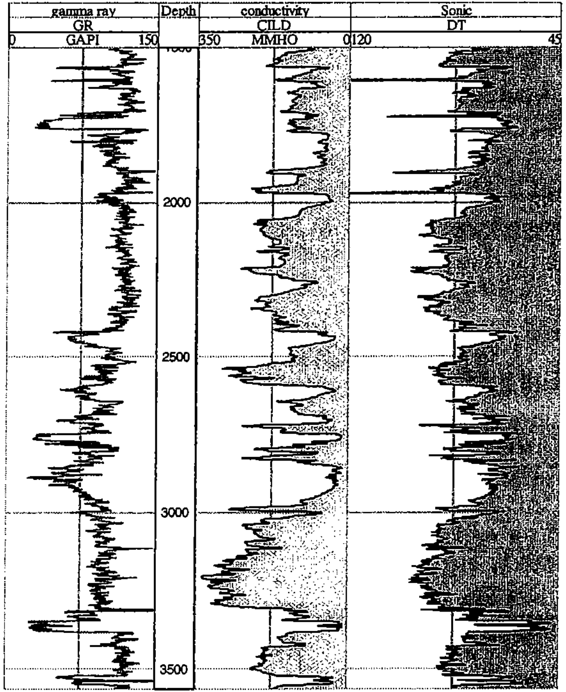
Conductivity (CILD)-gamma ray (GR) cross plot for two wells: (a) on the shelf of Arkoma basin, and (b) in the deep part of the basin. In the lower segment of the plots, the conductivity values increase at higher gamma ray values. In the shale zone, wide variation in the conductivity values occurs indicating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



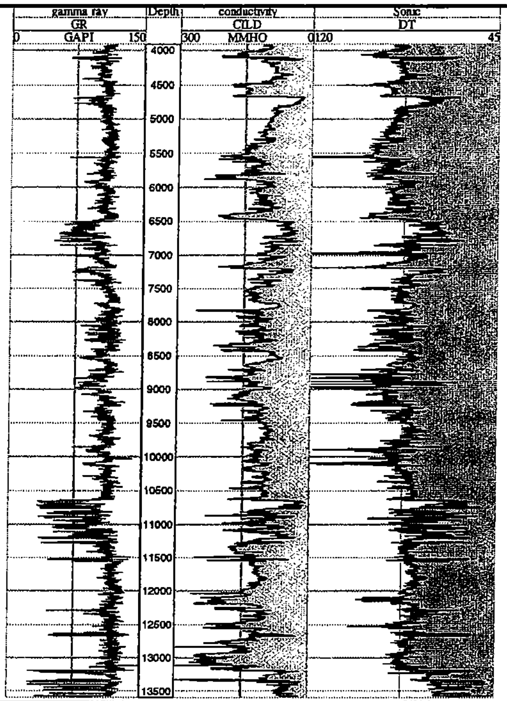
Photoelectric factor (PEF)-density (Rhob)-gamma ray (GR) plot for the T-bar Ranch#2-19 well. Shale is indicated by high gamma ray values. The clay point (black circle) indicates illite mineralogy (3.5-3.8 barns/electron). The points are clustered in a triangle area leaning toward the sandstone line away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



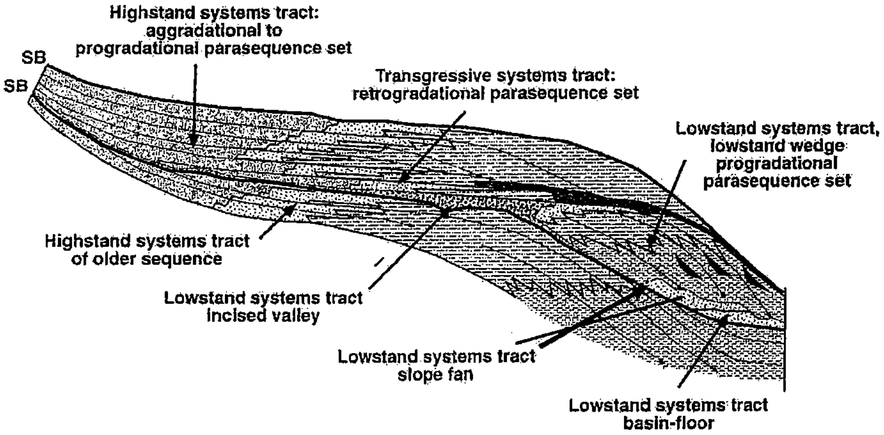
Conductivity (CILD)-sonic (DT)- Gamma (GR) plot for two wells: (a) on the shelf of Arkoma basin, and (b) in the deep part of the basin. The plots show good correlation between the conductivity and sonic measurements for the shaly zones (R^2 =0.78-0.9) indicating the conductivity log sensitivity to textural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



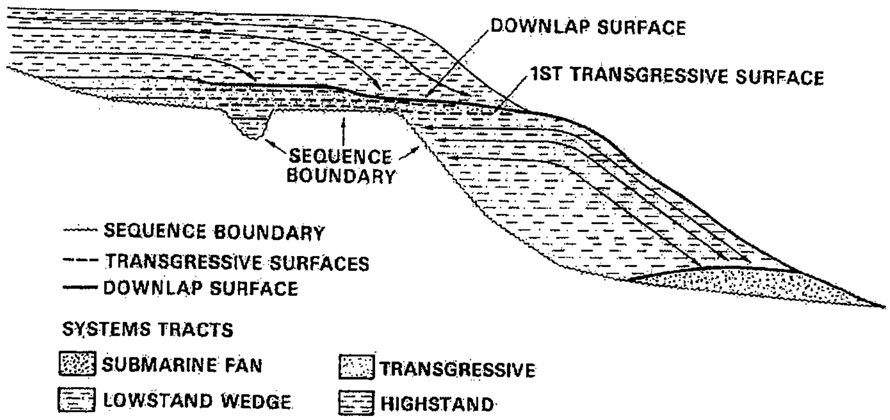
Log curves for T-bar Ranch#2-19 well (10N-15E-11). The conductivity and sonic logs show very similar patterns throughout the studied stratigraphic section on the shelf of Arkoma basin.



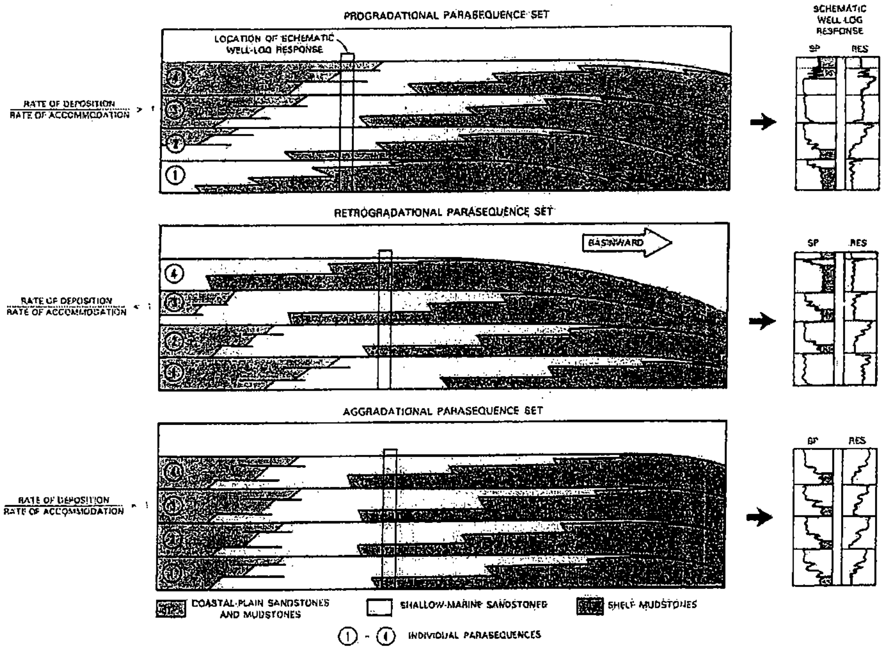
Log curves for Jean Shadwick#1-14 well (6N-24E-14). The conductivity and sonic logs show very similar patterns throughout the studied stratigraphic section in the deep part of Arkoma basin.



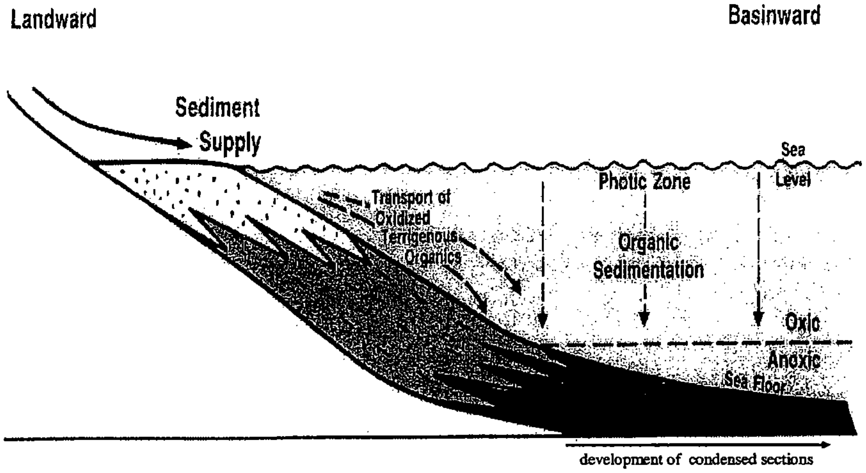
The sequence stratigraphic model showing the three main components of type 1 sequence in a basin with shelf break: lowstand systems tract, transgressive systems tract, and highstand systems tract (modified after Kerans and Tinker, 1997).



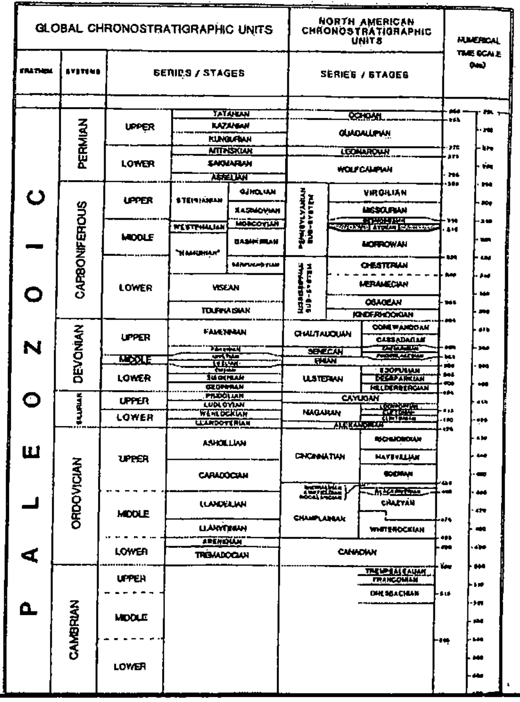
Schematic diagram showing the stratigraphic relations of the key correlation surfaces within a sequence: sequence boundary (unconformity), first transgressive surface, and downlap surface (maximum flooding surface) (after Loutit et al., 1988).



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).

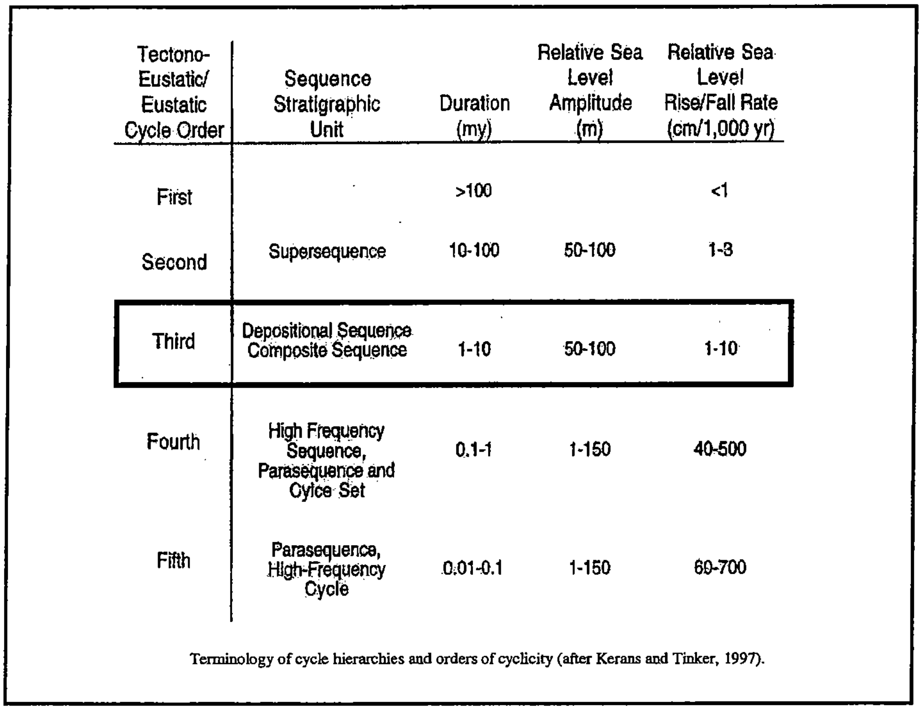


Condensed section incorporates slowly accumulating sediments laid down in the distal parts of both the transgressive and highstand deposits. This thin section is characterized by its wide extension across the basin, and abundance of organic matter and authigenic minerals showing on a gamma ray log as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



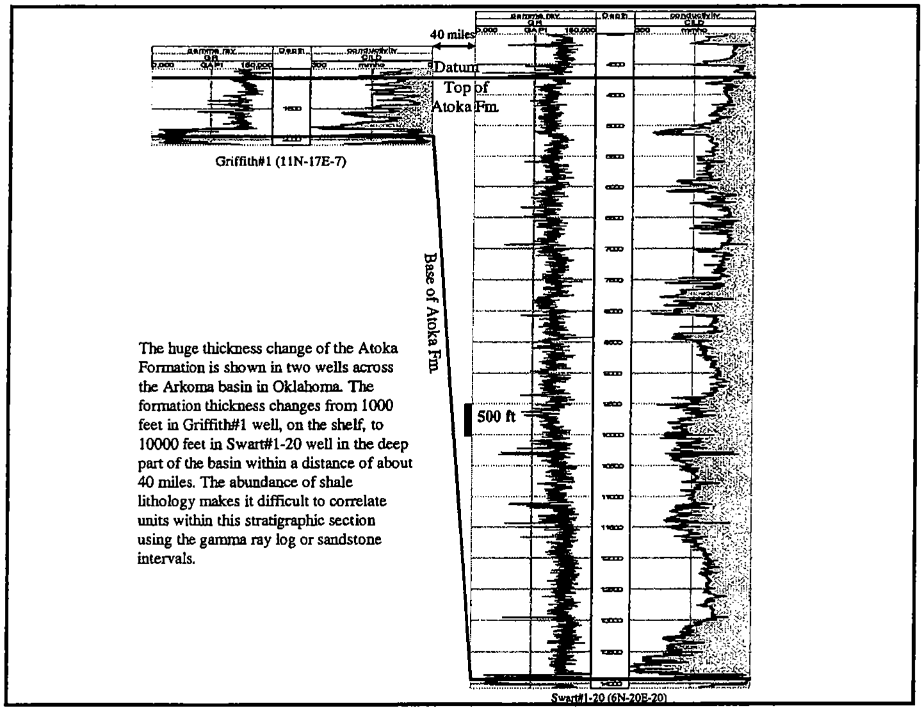
GLOBAL CHRONOSTRATIGRAPHIC UNITS					NORTH AMERICAN CHRONOSTRATIGRAPHIC UNITS		NUMERICAL TIME SCALE (Ma)
ERATHEM	SYSTEMS	SERIES / STAGES			SERIES / STAGES		
PALEOZOIC	PERMIAN	UPPER	TATARIAN		OCHOAN		
			KAZANIAN		GUADALUPIAN		
			KUNGURIAN				
		LOWER	ARTINSKIAN		LEONARDIAN		
			SAKMARIAN		WOLFCAMPIAN		
			ASSELIAN				
	CARBONIFEROUS	UPPER	STEPHANIAN	GZHELIAN	PENNSYLVANIAN SUB-SYSTEM	VIRGILIAN	
				KASIMOVIAN		MISSOURIAN	
			WESTPHALIAN	MOSCOVIAN		DESMOINESIAN ATOKAN	
		MIDDLE	"NAMURIAN"	BASHKIRIAN		MORROWAN	
				SERPUKHOVIAN	MISSISSIPPIAN SUB-SYSTEM	CHESTERIAN	
		LOWER	VISEAN			MERAMECIAN	
			TOURNAISIAN			OSAGEAN	
						KINDERHOOKIAN	
	DEVONIAN	UPPER	FAMENNIAN		CHAUTAUQUAN	CONEWANGOAN	
						CASSADAGAN	
			FRASNIAN		SENECAN	CHEMUNGIAN	
		MIDDLE	GIVETIAN			FINGERLAKESIAN	
			EIFELIAN		ERIAN		
		LOWER	EMSIAN		ULSTERIAN	ESOPUSIAN	
			SIEGENIAN			DEERPARKIAN	
			GEDINNIAN			HELDERBERGIAN	
	SILURIAN	UPPER	PRIDOLIAN		CAYUGAN		
			LUDLOVIAN		NIAGARAN	LOCKPORTIAN	
		LOWER	WENLOCKIAN			CLIFTONIAN	
						CLINTONIAN	
			LLANDOVERIAN		ALEXANDRIAN		
	ORDOVICIAN	UPPER	ASHGILLIAN		CINCINNATIAN	RICHMONDIAN	
						MAYSVILLIAN	
			CARADOCIAN			EDENIAN	
					[illegible]	[illegible]	
		MIDDLE	LLANDEILIAN		CHAMPLAINIAN	CHAZYAN	
			LLANVIRNIAN			WHITEROCKIAN	
		LOWER	ARENIGIAN		CANADIAN		
			TREMADOCIAN				
	CAMBRIAN	UPPER				TREMPEALEAUAN	
						FRANCONIAN	
						DRESBACHIAN	
		MIDDLE					
		LOWER					

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

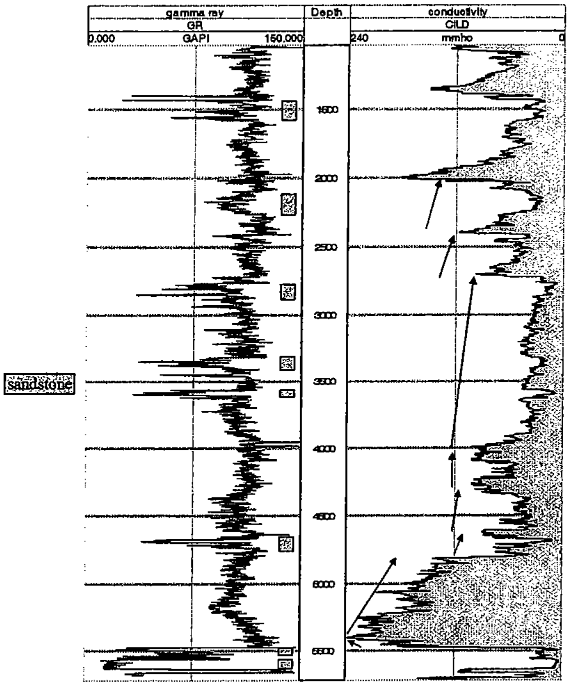


Tectono-Eustatic/ Eustatic Cycle Order	Sequence Stratigraphic Unit	Duration (my)	Relative Sea Level Amplitude (m)	Relative Sea Level Rise/Fall Rate (cm/1,000 yr)
First		>100		<1
Second	Supersequence	10-100	50-100	1-3
Third	Depositional Sequence Composite Sequence	1-10	50-100	1-10
Fourth	High Frequency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

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



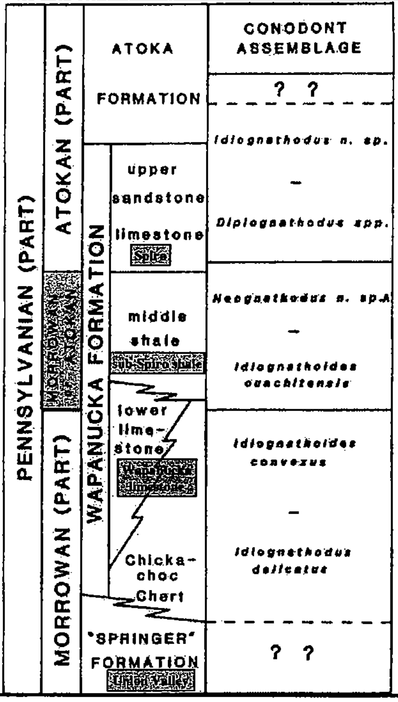
The huge thickness change of the Atoka Formation is shown in two wells across the Arkoma basin in Oklahoma. The formation thickness changes from 1000 feet in Griffith#1 well, on the shelf, to 10000 feet in Swart#1-20 well in the deep part of the basin within a distance of about 40 miles. The abundance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



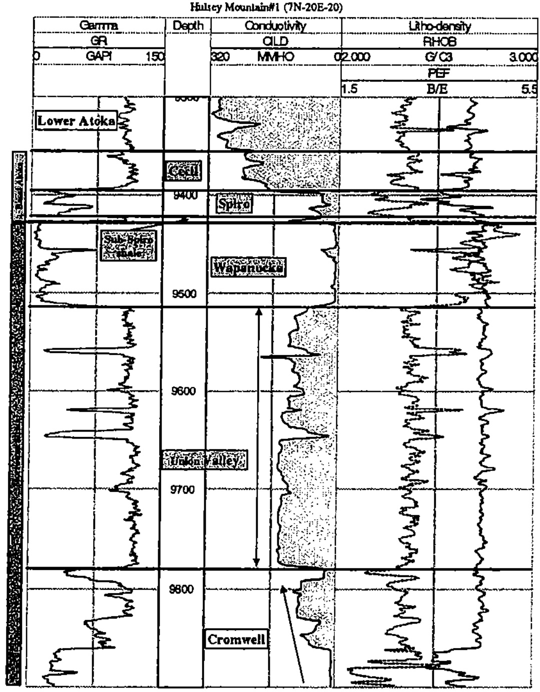
Conductivity log shows good definition of the stacking pattern for the shale packages in MaCafferty Unit#2 well (8N-22E-26). Such packages are much more continuous than the sandstone intervals that occur within them.

Union Valley-basal Atoka

A stratigraphic model for the Union Valley-basal Atoka stratigraphic section consists of: 1) Both the Wapanucka limestone and the Union Valley intervals represent a Morrowan carbonate shelf grading from northeast to southwest. 2) Morrowan/Atokan unconformity, and represents a third-order sequence boundary. 3) The basal Atoka LST consists of the sub-Spiro shale and its time equivalent the Foster sandstone. 4) The basal Atoka TST includes both the Spiro and Cecil sandstones.

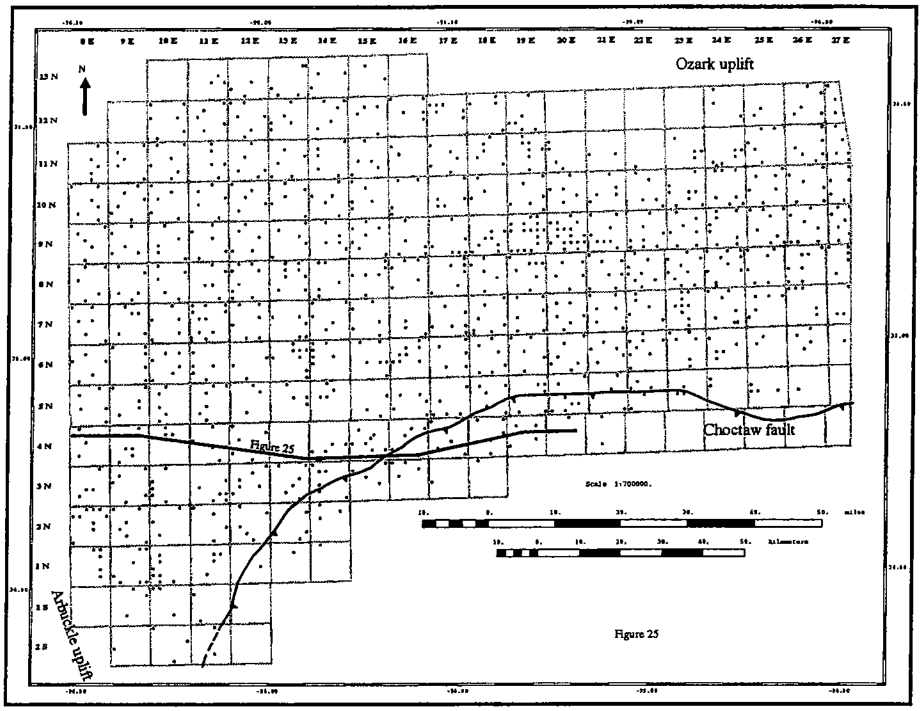


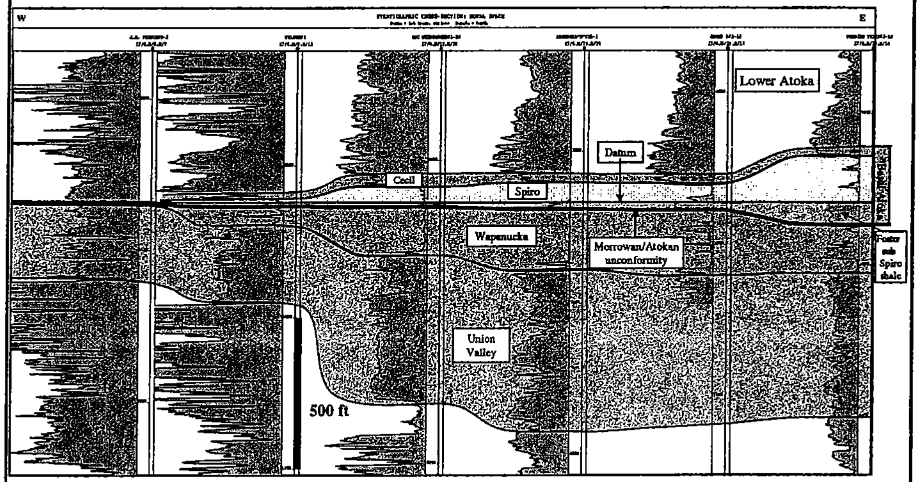
Lithostratigraphic and biostratigraphic subdivisions of the Wapanucka Formation and conodont assemblages, frontal Ouachita mountains (after Groves and Grayson, 1984). The equivalent lithostratigraphic nomenclature of these subdivisions in the Arkoma basin are presented in boxes. Different suggestions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



Morrowan/Atokan unconformity

Characteristic log patterns for the Union Valley-basal Atoka section. The Union Valley shale is characterized by 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 shale shows a relatively lower conductivity than the overlying lower Atoka.





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).

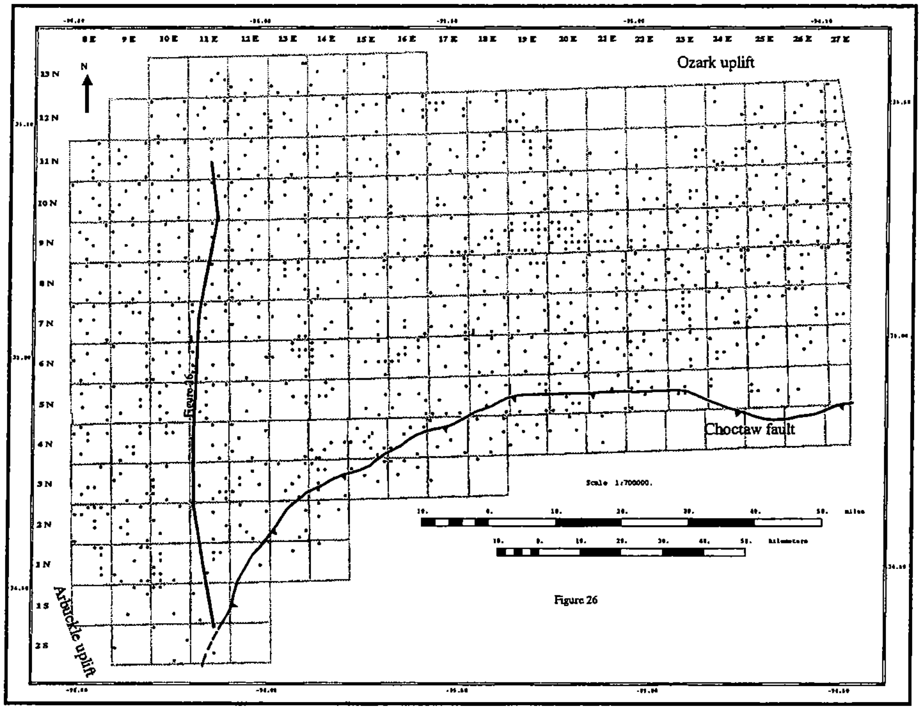
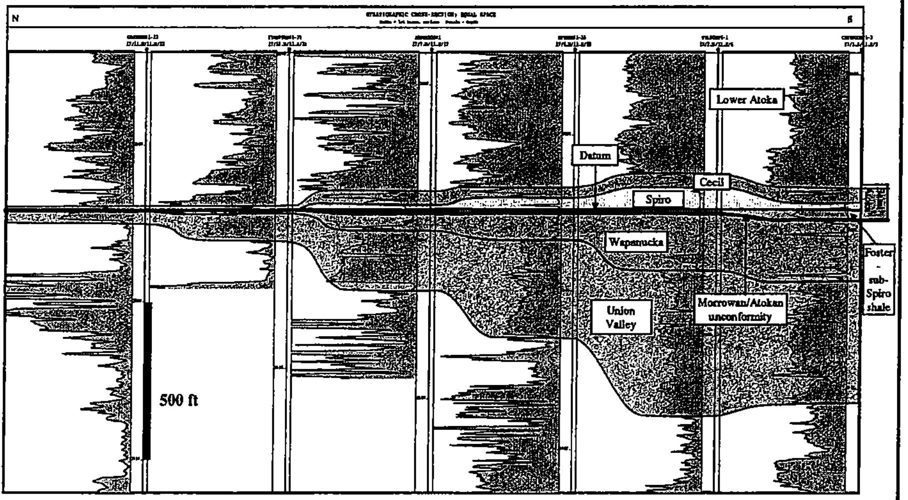


Figure 26



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).

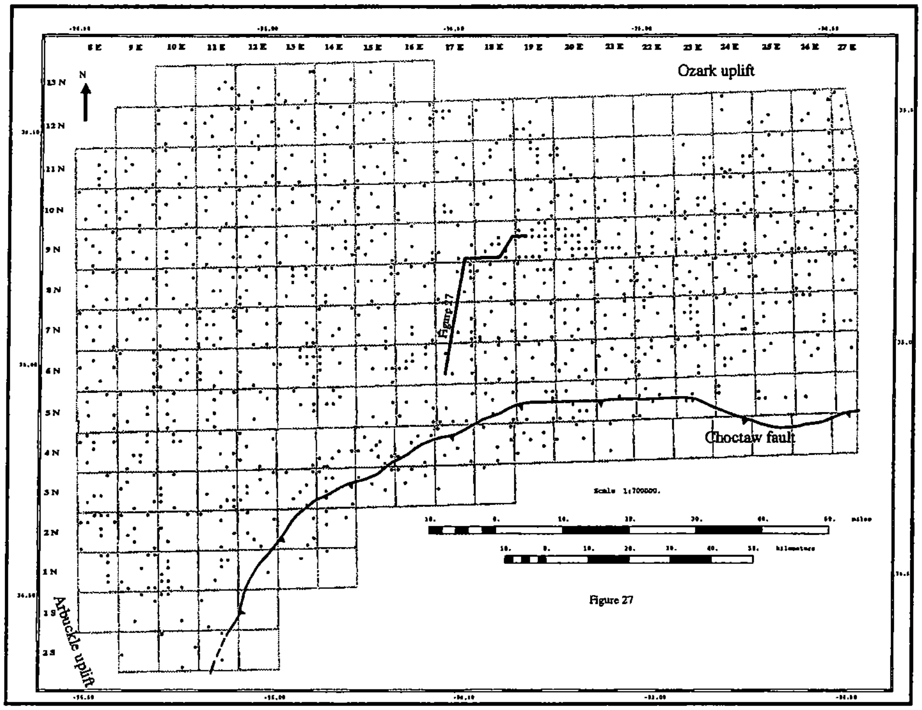
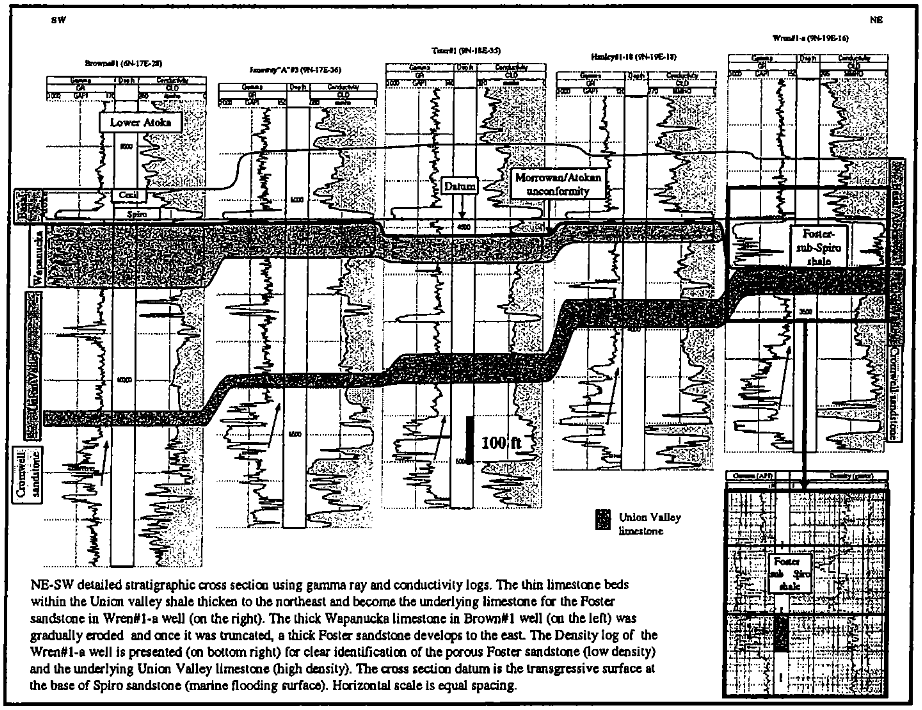
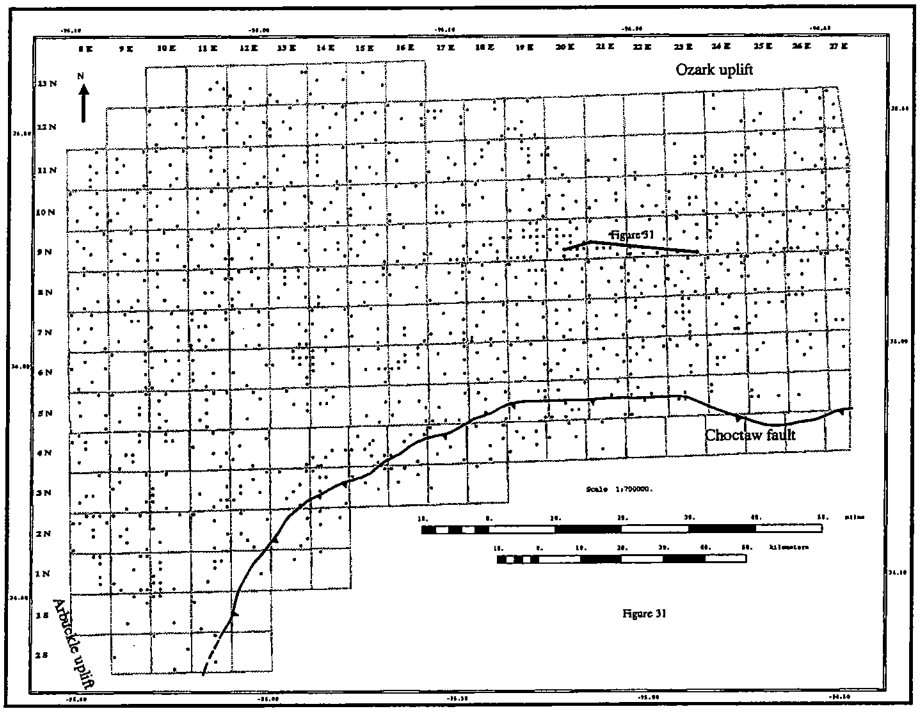
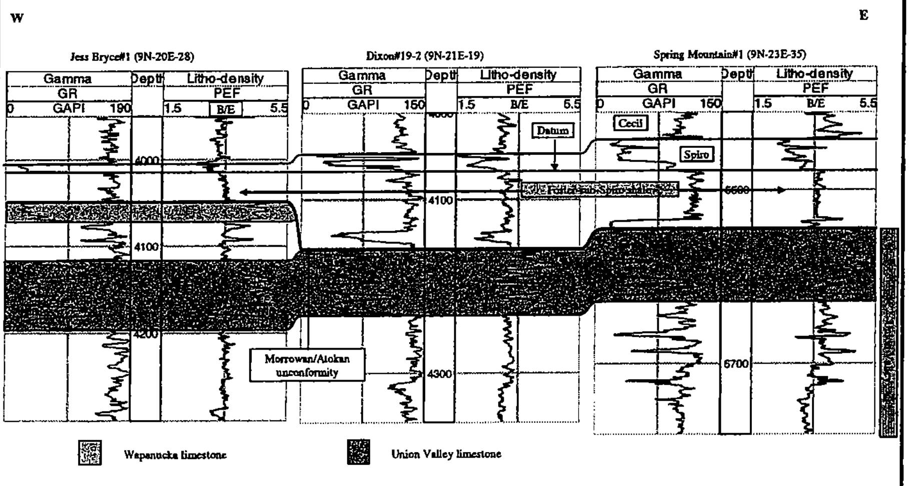


Figure 27



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 gradually 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.





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.

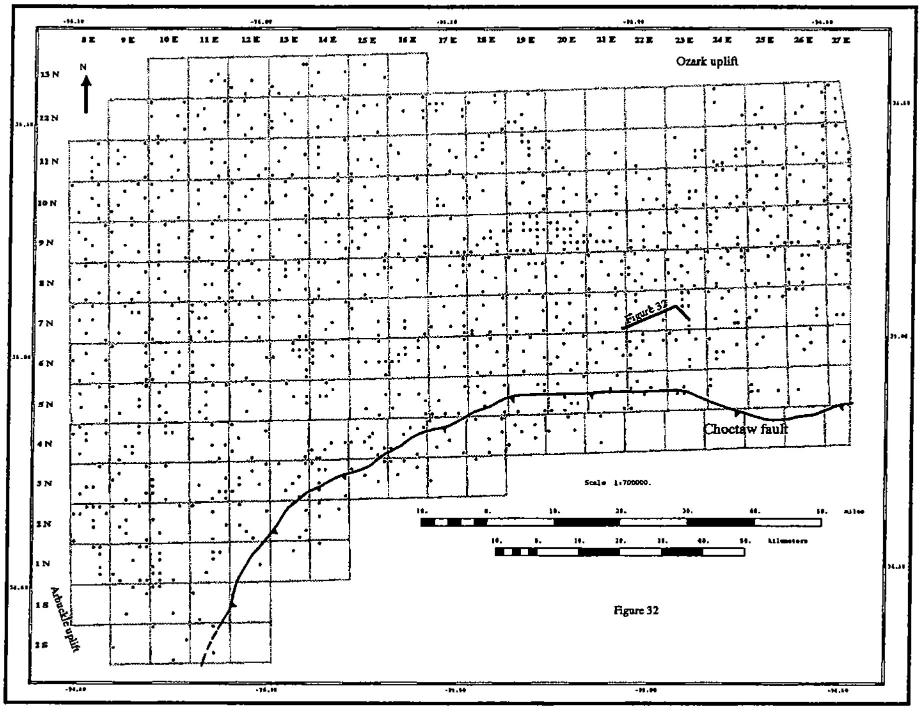
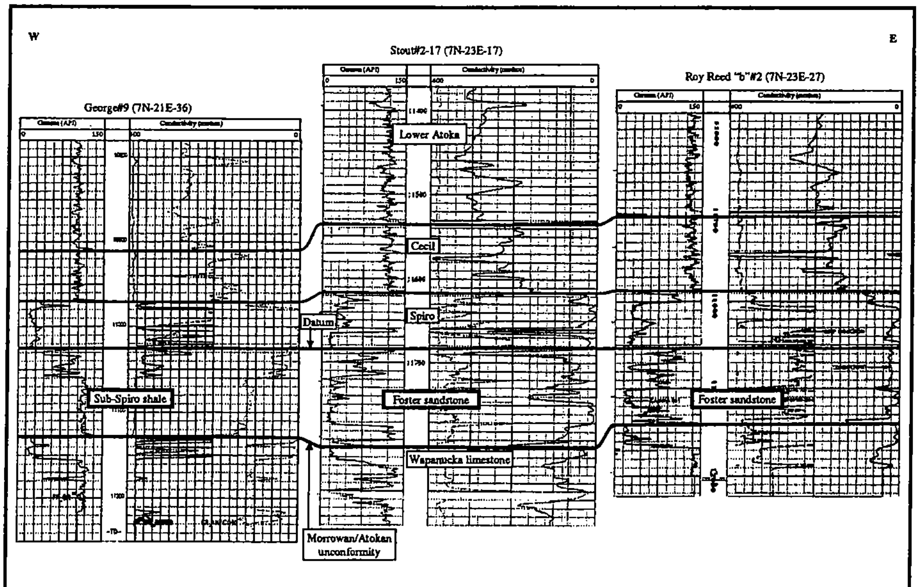
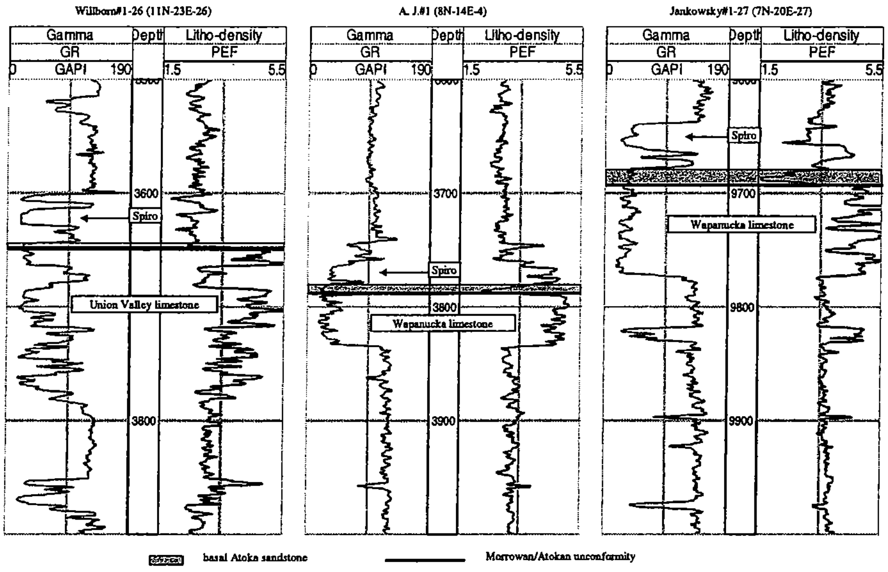


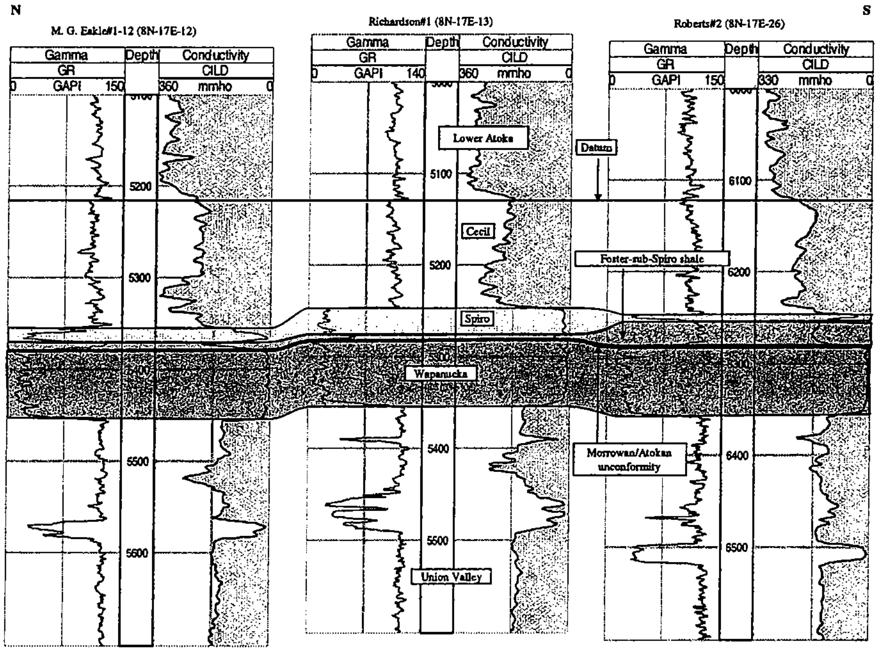
Figure 32



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.



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.



N-S detailed stratigraphic cross section showing that individual Spiro sandstone bar pinches out to the north and south in 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.

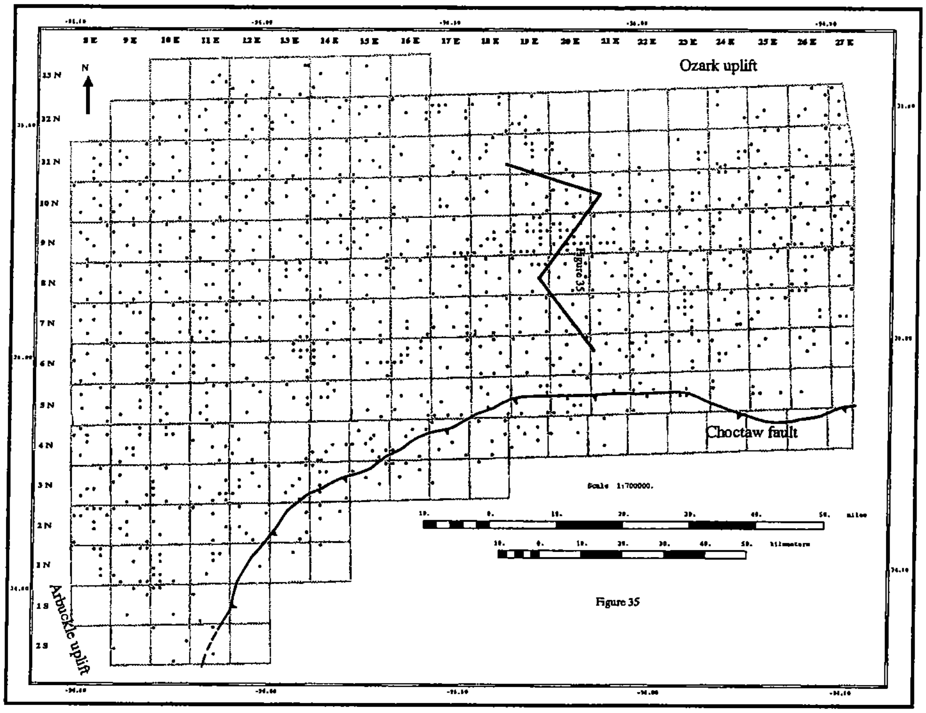
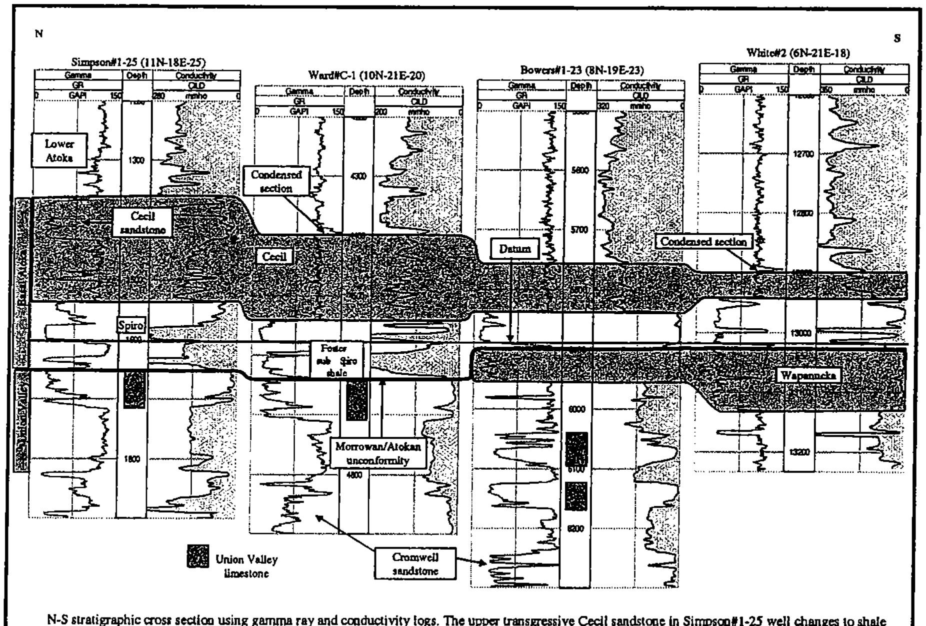
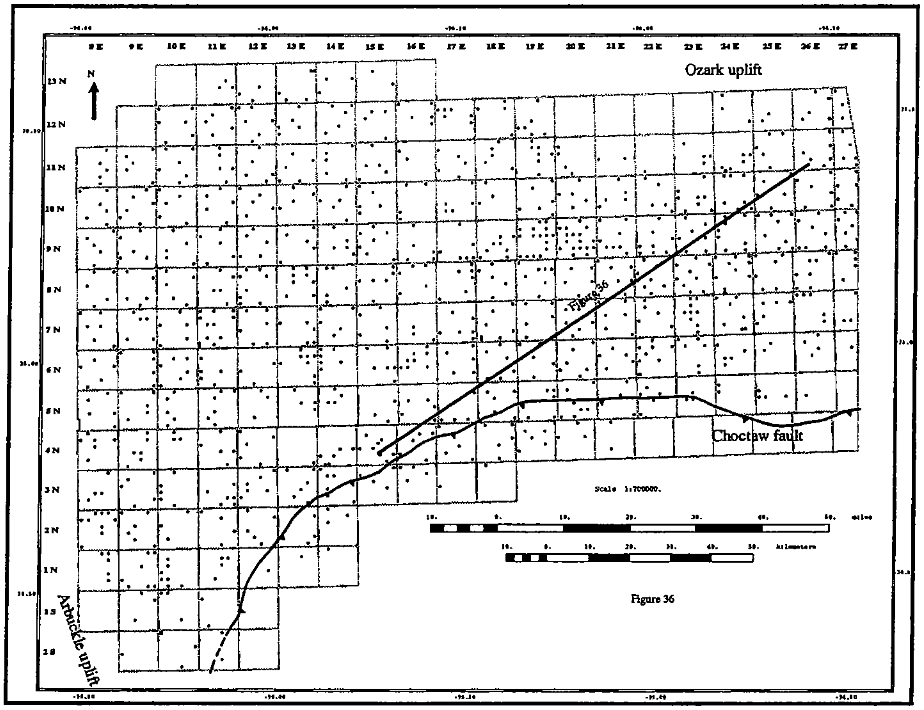
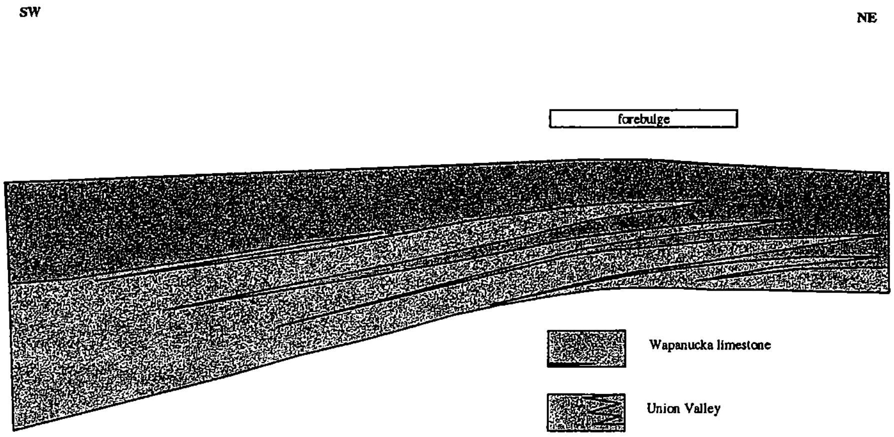


Figure 35



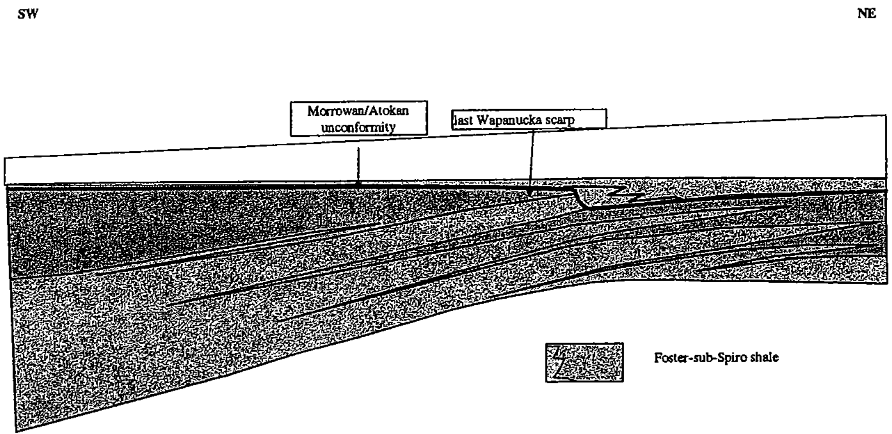
N-S stratigraphic cross section using gamma ray and conductivity logs. The upper transgressive Cecil sandstone in Simpson#1-25 well changes to shale to the south. A log pattern of slightly lower conductivity characterizes this interval when it becomes shaly. A condensed section marks the top of this 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.





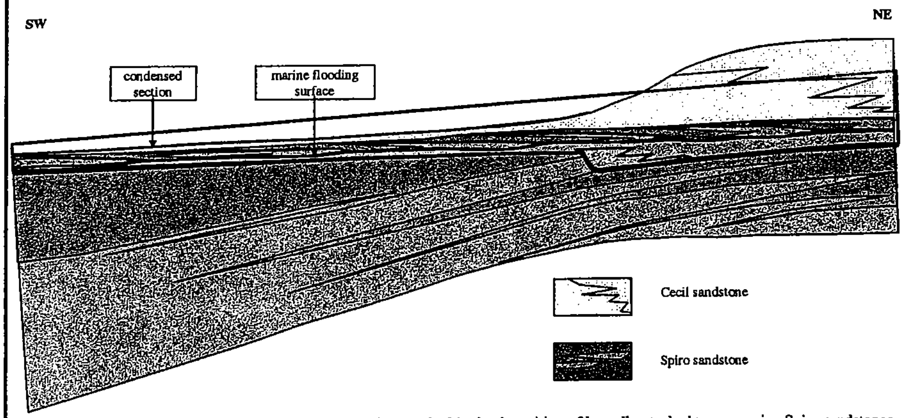
(a) Both of the Wapanucka limestone and Union Valley intervals represent a carbonate shelf prograding from NE to SW. By the end of Morrowan time, a bulge may have formed in the northwestern part of Arkoma basin, with a forebulge to the east.

Stratigraphic model for the evolution of the Union Valley-basal Atoka sedimentary section. Different green shades are shales, yellow is sandstone, blue is limestone.



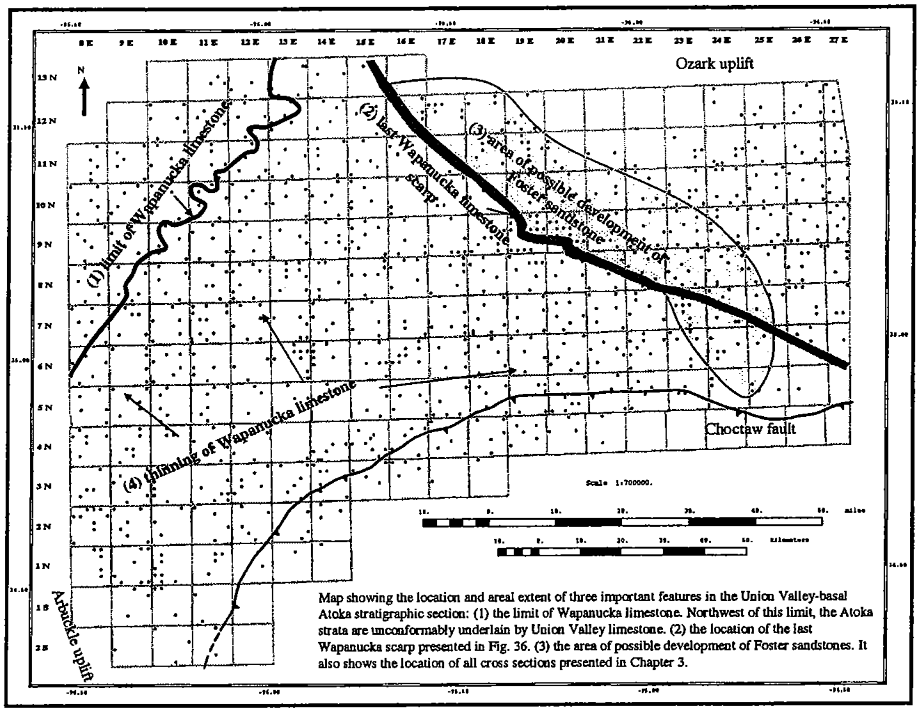
(b) Deposition of the basal Atoka LST: differential erosion along the Morrowan/Atokan unconformity surface resulted in the development of strike valleys in the eastern part of Arkoma basin where beds of the Union Valley shale were exposed at the forebulge area. Foster sandstones were deposited in these 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.

Stratigraphic model for the evolution of the Union Valley-basal Atoka sedimentary section. Different green shades are shales, yellow is sandstone, blue is limestone.

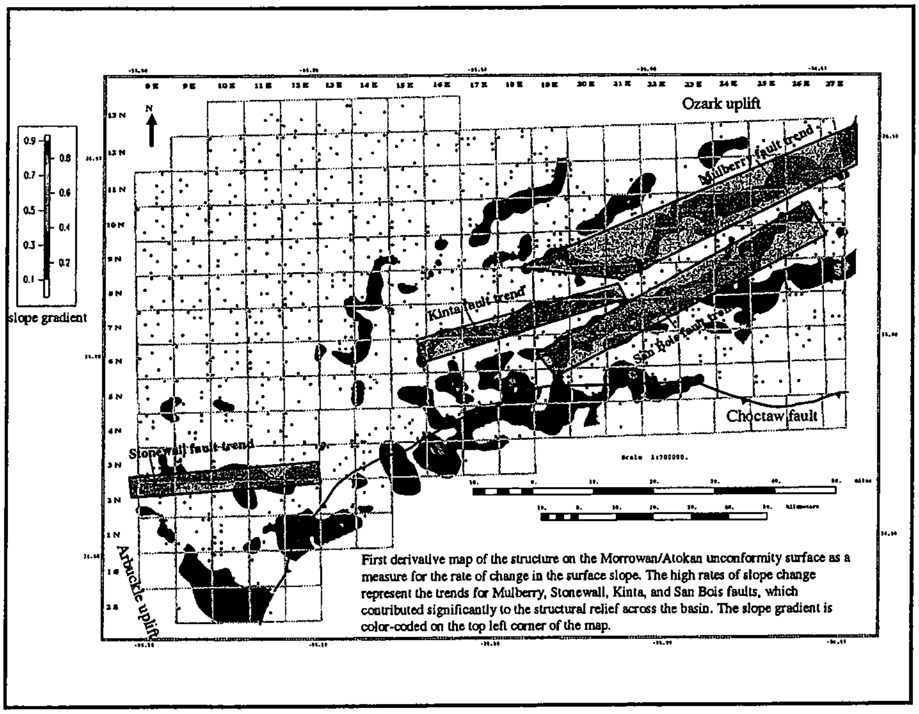


(c) Deposition of the basal Atoka TST: marine flooding resulted in the deposition of laterally-stacked transgressive Spiro sandstones covering the entire Arkoma shelf. As the relative sea level rose, the Cecil sandstone developed farther northeast. To the south condensed section caps this transgressive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

Stratigraphic model for the evolution of the Union Valley-basal Atoka sedimentary section. Different green shades are shales, yellow is sandstone, blue is limestone.



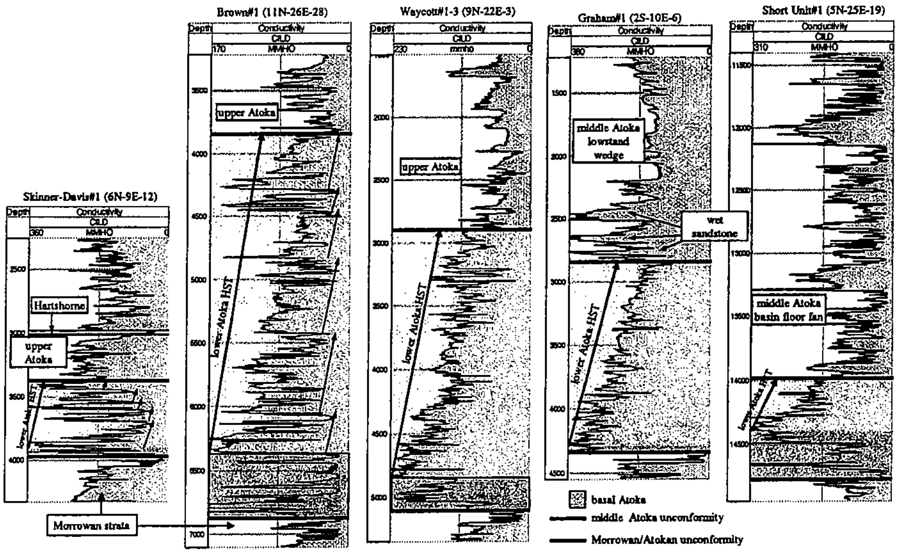
Map showing the location and areal extent of three important features in the Union Valley-basal Atoka stratigraphic section: (1) the limit of Wapanucka limestone. Northwest of this limit, the Atoka strata are unconformably underlain by Union Valley limestone. (2) the location of the last Wapanucka scarp 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.



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.

Lower Atoka

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 in Oklahoma. This section is interpreted as high stand systems tract. The lower Atoka HST is characterized by substantial development of deltas in the shelf areas of the Arkoma Basin. 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. This sequence is bounded by the Morrowan/Atokan unconformity at its base, and by the middle Atoka unconformity at its top.



Examples from wells in different parts of 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.

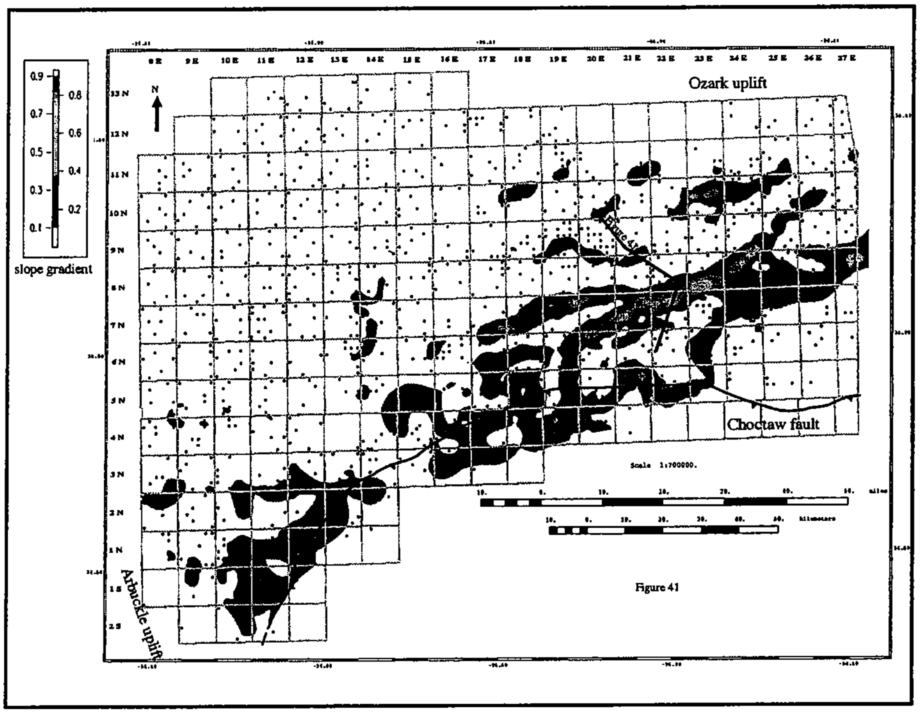
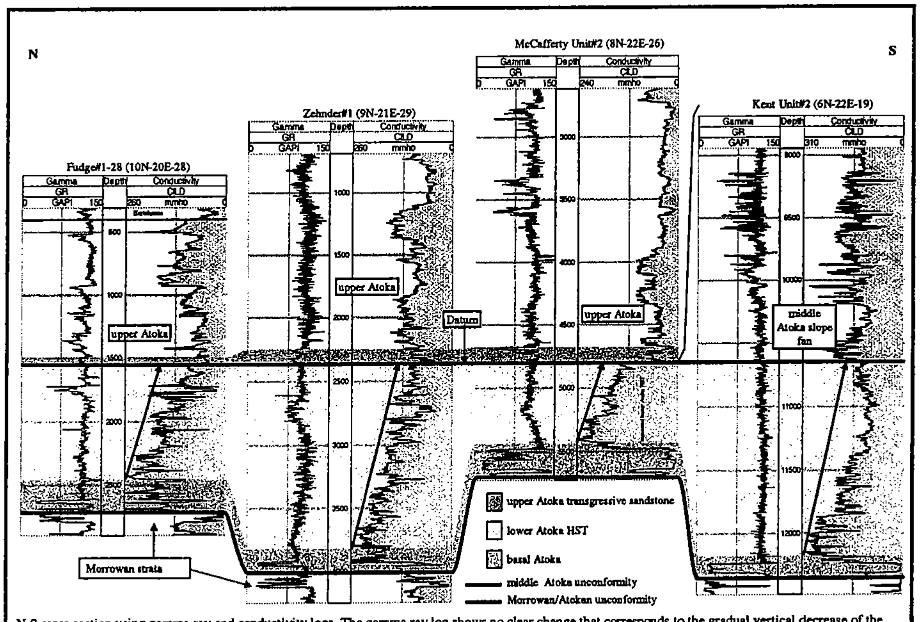
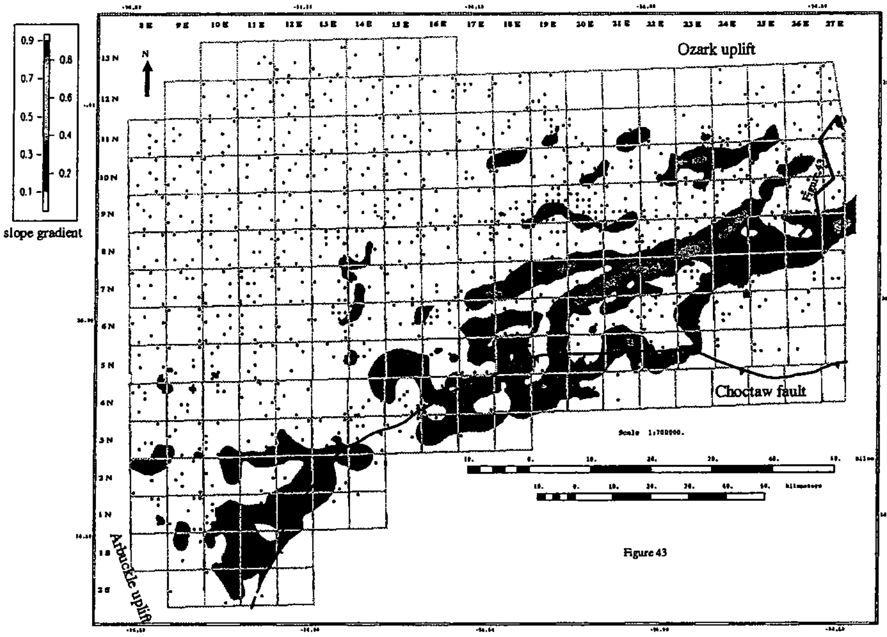
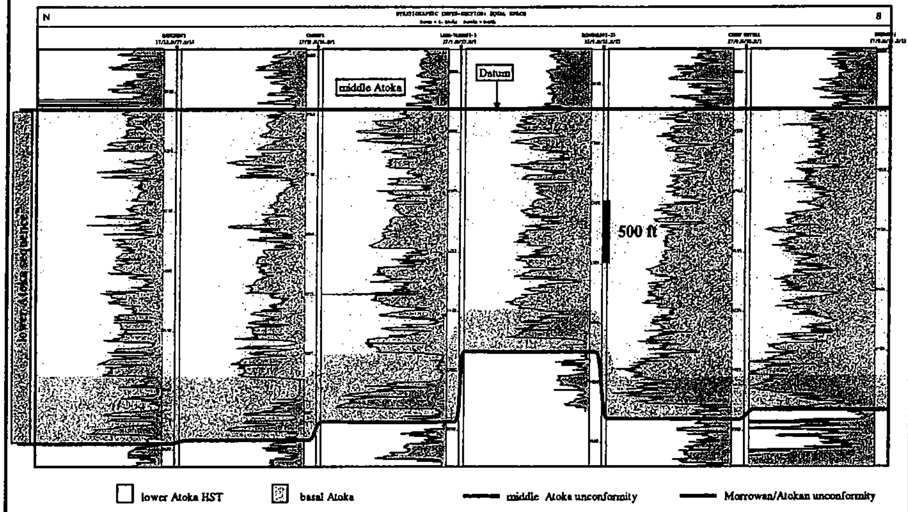


Figure 41

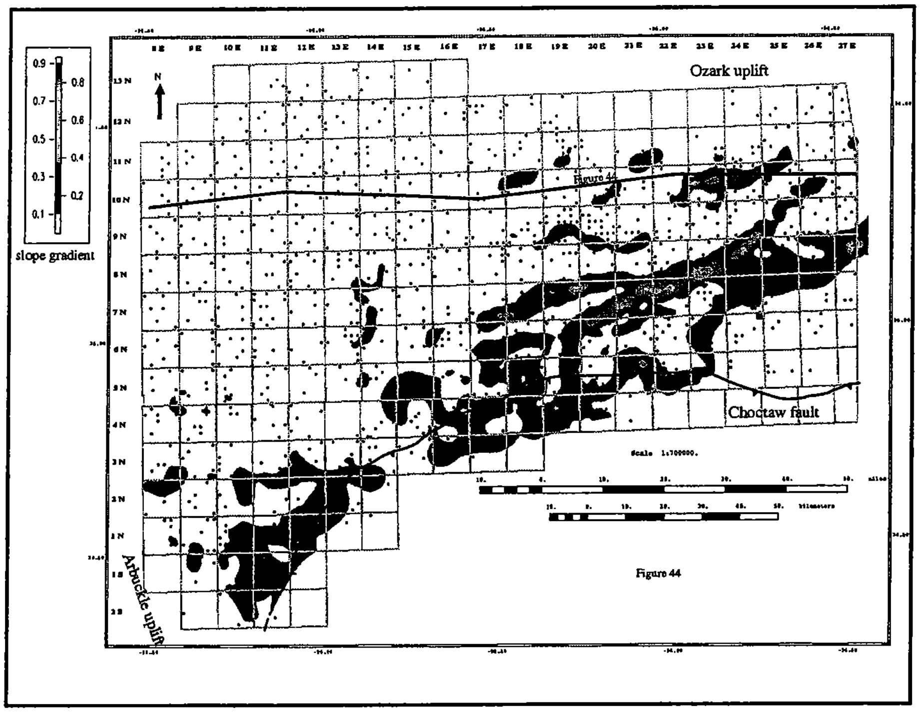


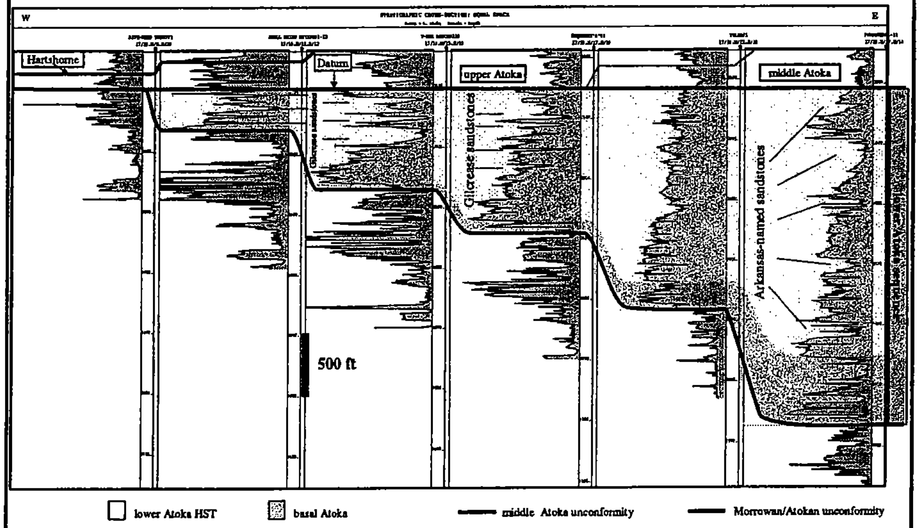
N-S cross section using gamma ray and conductivity logs. The gamma ray log shows no clear change that corresponds to the gradual vertical decrease of the conductivity values in the lower Atoka section, except where sandstone units occur. This can be attributed to the high sensitivity of the conductivity 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 (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.



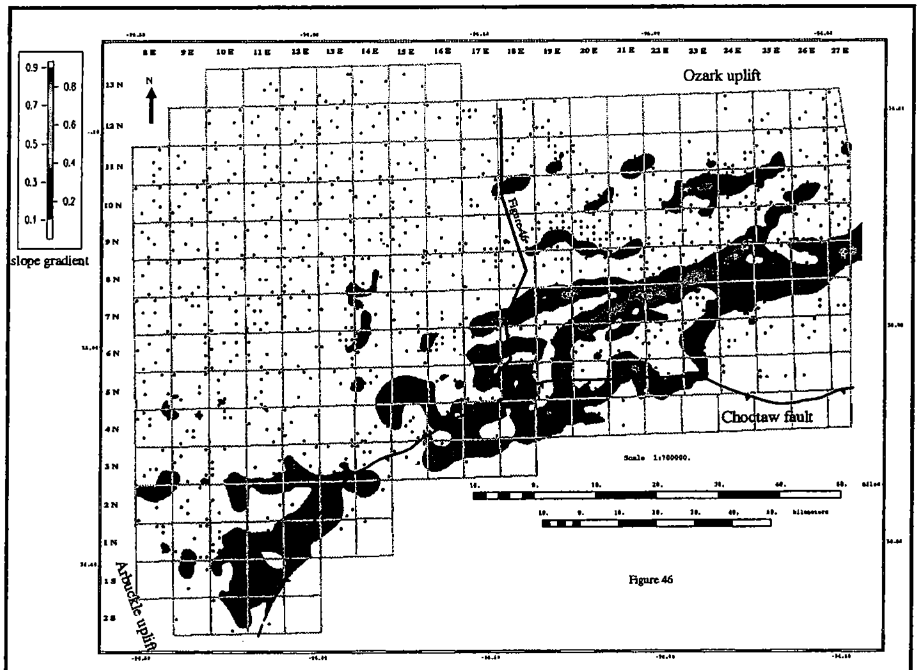


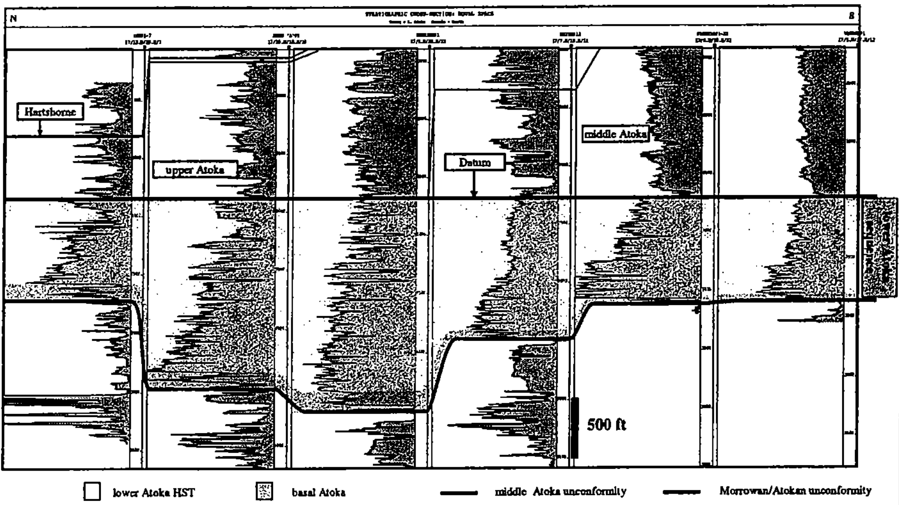
N-S regional stratigraphic cross section in the eastern part of the Arkoma basin using conductivity logs. The thickest delta system in the lower Atoka HST occurs in this part of the basin. In the north, the section is composed of several parasequences stacked in a delta front, which grades to prodelta 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.





E-W regional stratigraphic cross section in the northern part of the Arkoma basin using conductivity logs. Along the shelf of Arkoma 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.





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 overlie 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

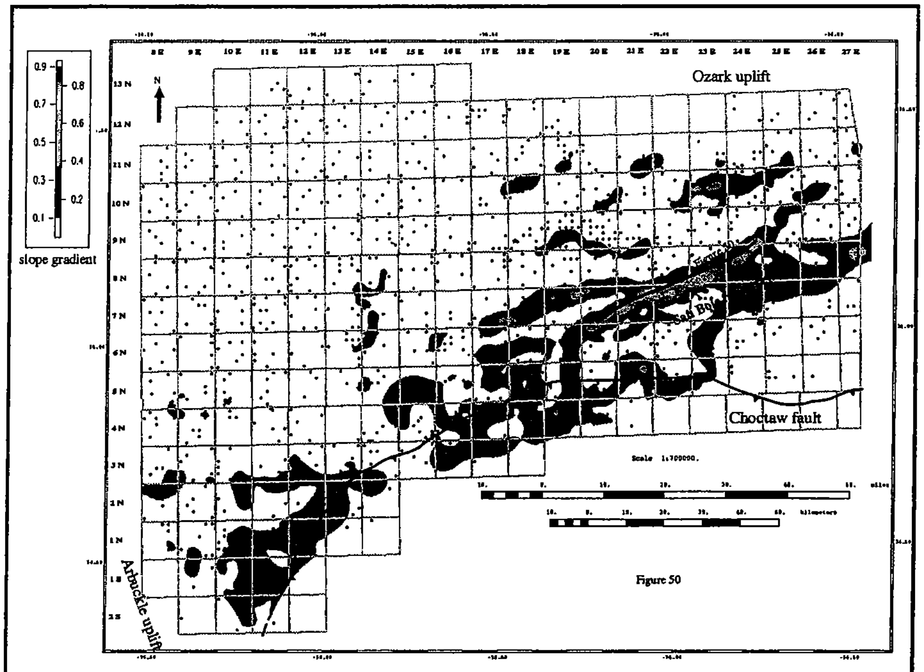
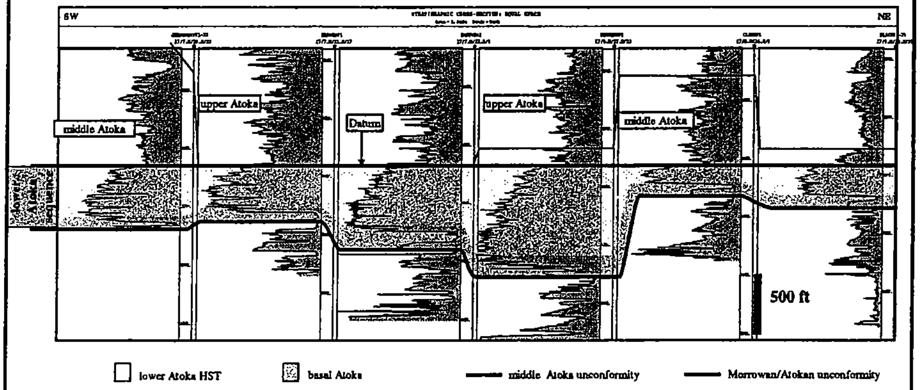
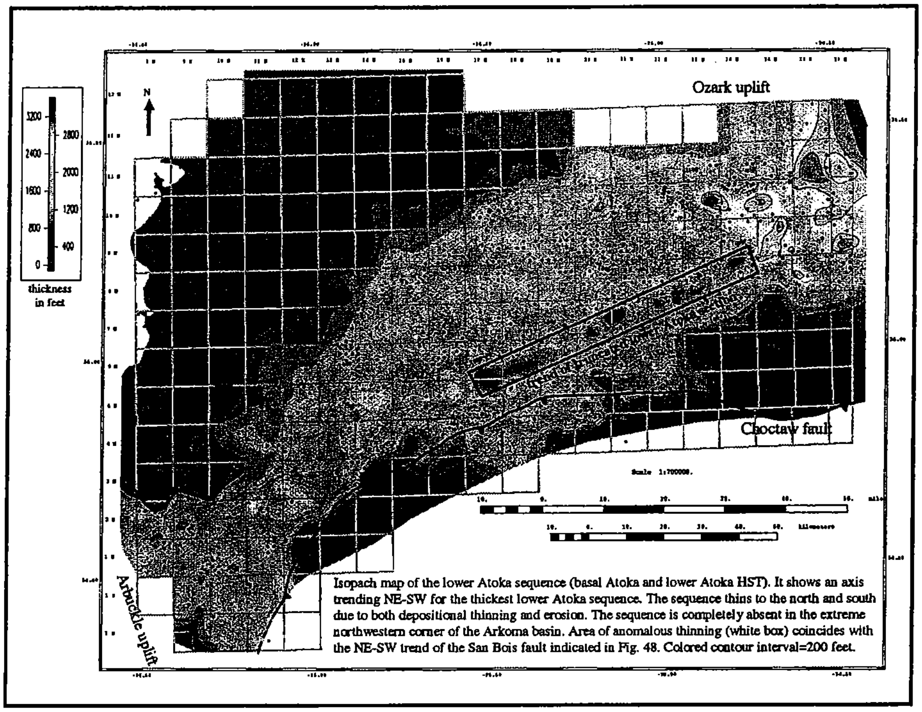


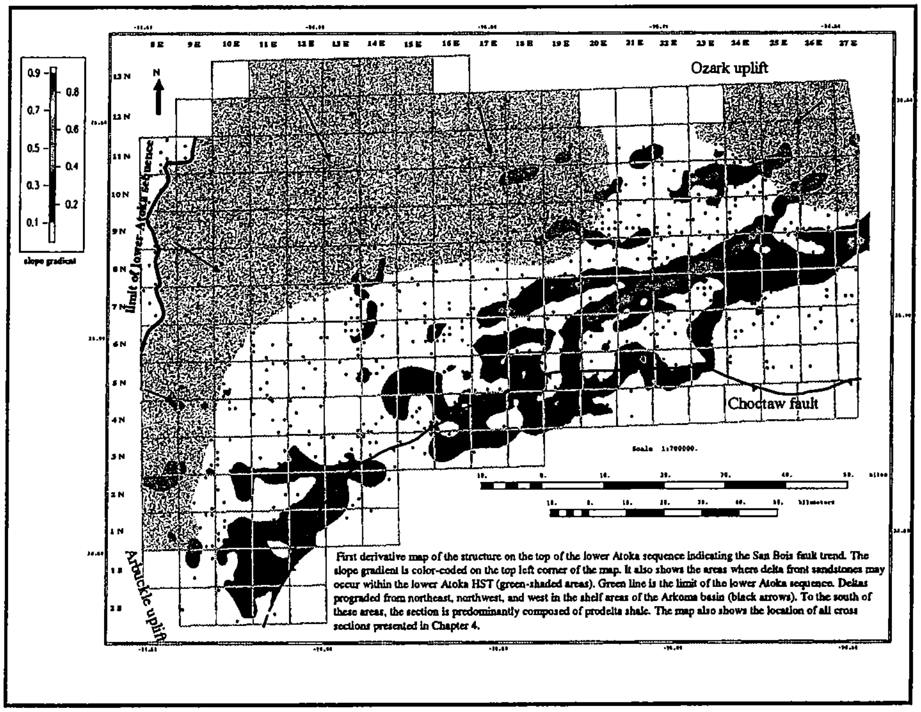
Figure 50



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.



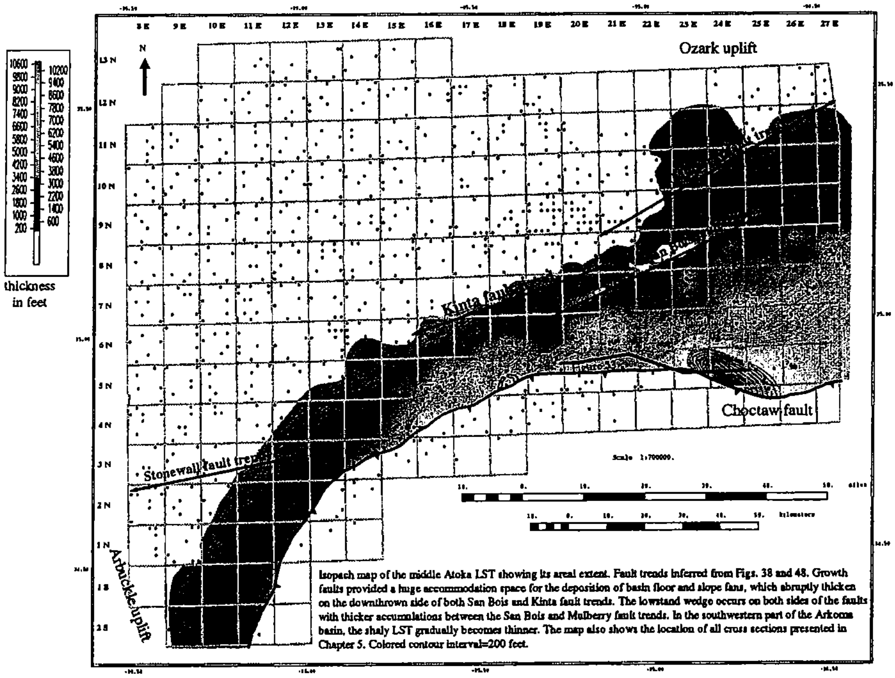
Isopach map of the lower Atoka sequence (basal Atoka and lower Atoka HST). It shows an axis trending NE-SW for the thickest lower Atoka sequence. The sequence thins to the north and south due to both depositional thinning and erosion. The sequence is completely absent in the extreme northwestern corner 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.



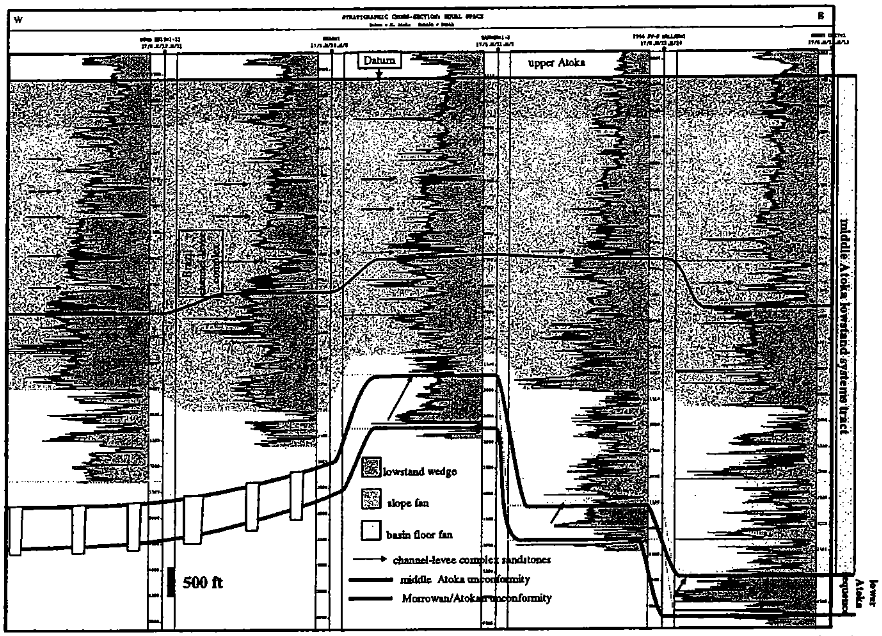
First derivative map of the structure on the top of the lower Atoka sequence indicating the San Bois fault trend. The slope gradient is color-coded on the top left corner of the map. It also shows the areas where delta front sandstones may occur within the lower Atoka HST (green-shaded areas). Green 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.

Middle Atoka

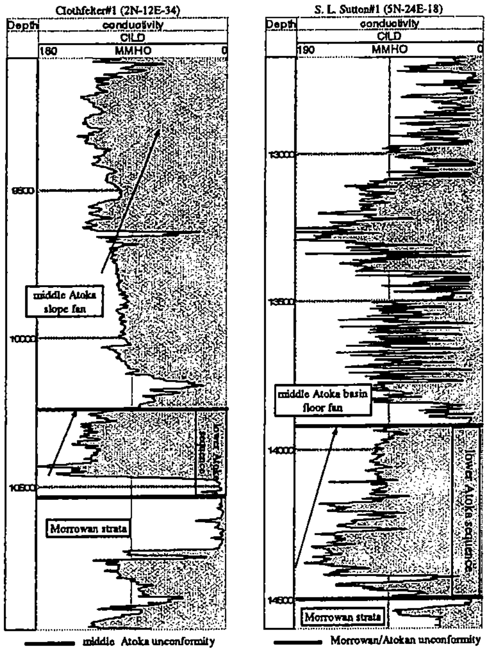
The middle Atoka section is the thickest stratigraphic interval within the Arkoma Basin in Oklahoma, and is mainly confined to the southern and eastern parts of the basin. The thickness changes dramatically from few hundred feet close to the shelf areas to about 10000 feet north of the Choctaw fault in the southeast part of the basin. 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. The upper bounding surface is the transgressive surface between the middle Atoka LST and the upper Atoka transgressive systems tract. Different nomenclatures are used to define the units within a lowstand systems tract. This work uses Van Wagoner et al. (1988) terminology for LST. The middle Atoka LST is composed of basin floor fan, slope fan, and lowstand wedge.



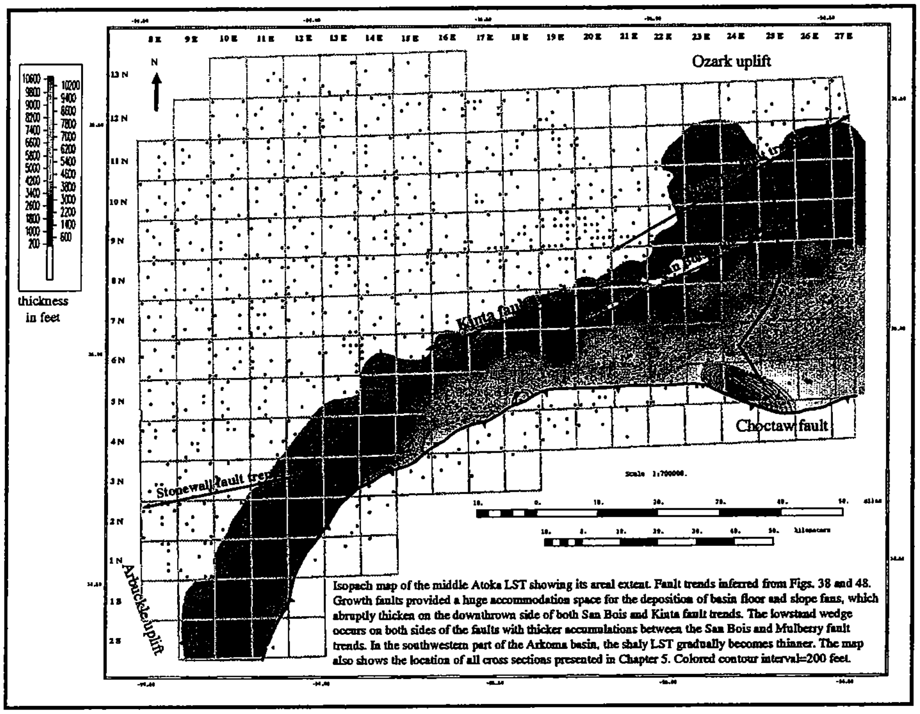
Isopach map of the middle Atoka LST showing its areal extent. Fault trends inferred from Figs. 38 and 48. Growth faults provided a huge accommodation space for the deposition of basin floor and slope fans, which abruptly thicken on the downthrown side of both San Bois and Kinta fault trends. The lowstand 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.



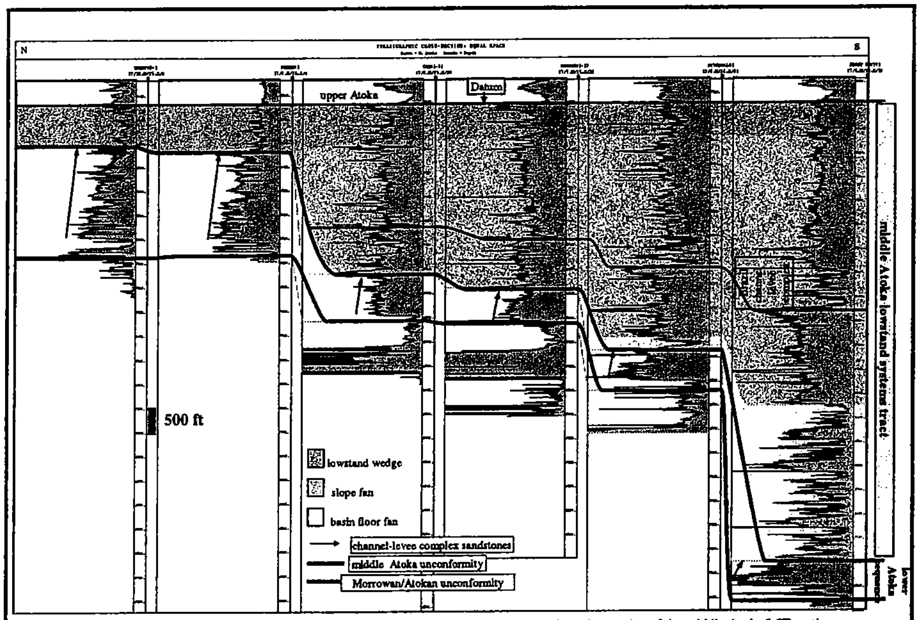
E-W stratigraphic cross section in the southeast margin of the Arkoma basin where the thickest middle Atoka LST section occurs. The section is composed of basin floor fan, slope fan, and lowstand wedge. The sandstones within the basin floor fan are mistakenly called Cecil sandstones which were deposited 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.



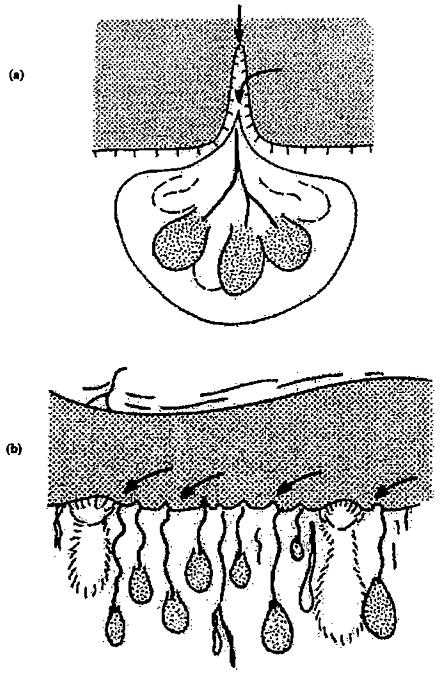
Two wells in the east and west within the southern depocenter of the Arkoma Basin showing the remaining section of the lower Atoka sequence. It is likely that the thin lower Atoka section was completely eroded in areas in the frontal Ouachita resulting in the merging of the two unconformities bounding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



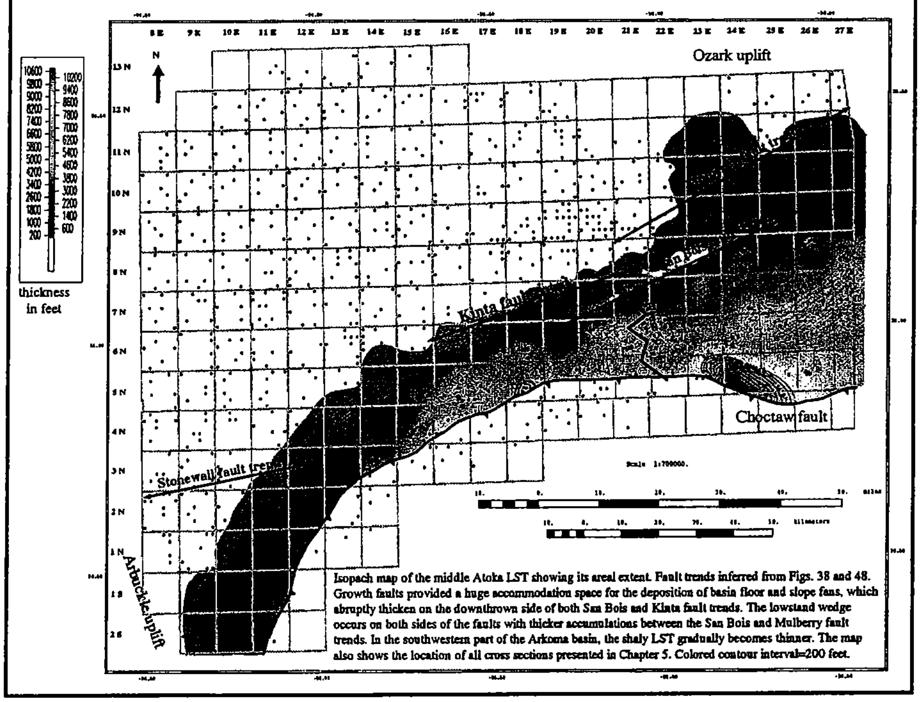
Isopach map of the middle Atoka LST showing its areal extent. Fault trends inferred from Figs. 38 and 48. Growth faults provided a huge accommodation space for the deposition of basin floor and slope fans, which abruptly thicken on the downthrown side of both San Bois and Kinta fault trends. The lowstand 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.



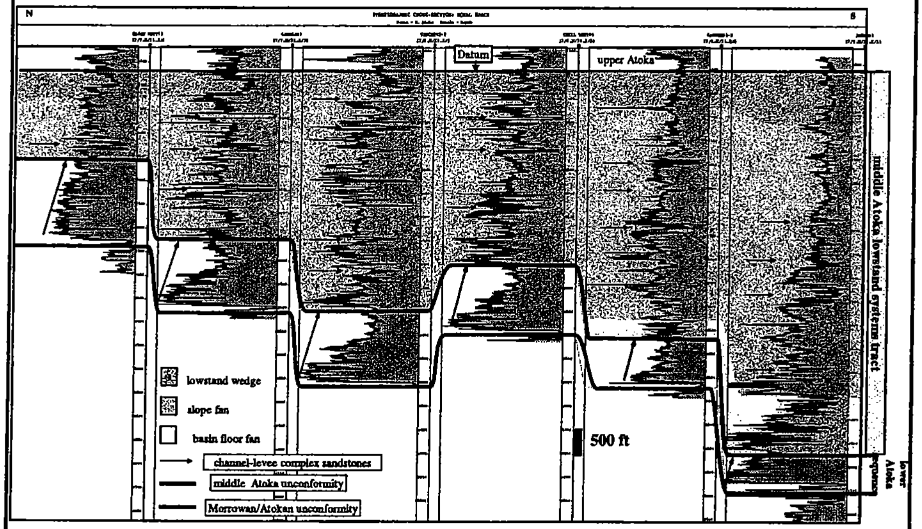
N-S stratigraphic cross section across the eastern part of the Arkoma basin where the farthest northward extension of the middle Atoka LST section occurs. The section thickness changes from a few hundred feet to about 10000 feet within a distance of less than 30 miles. Growth faults in the south provided 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 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.



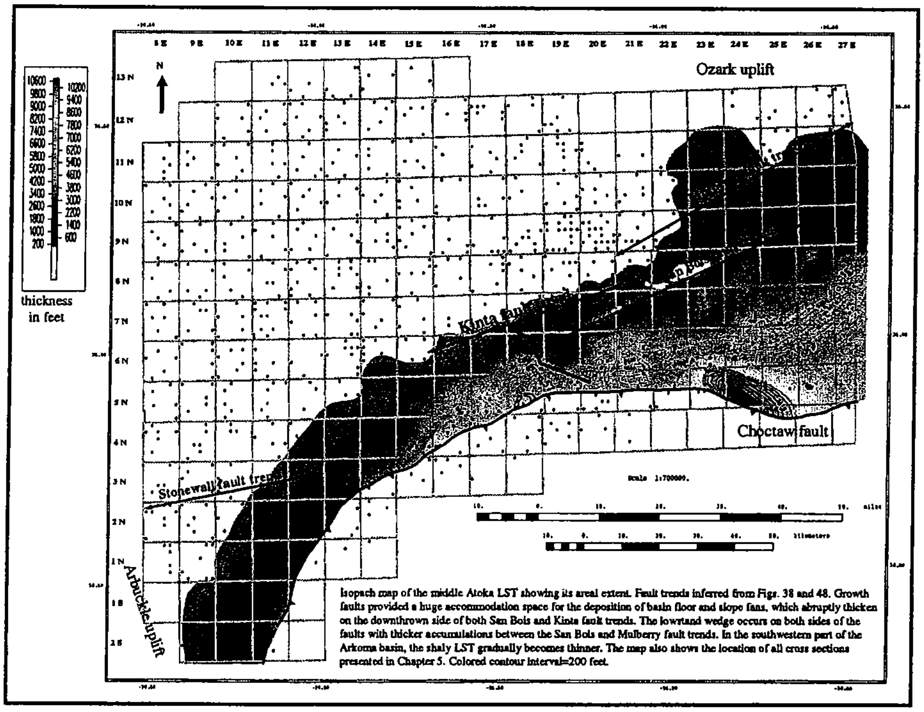
Two patterns among several others suggested by Galloway (1998) for the sediments sourcing of slope turbidite systems. (a) point source through submarine canyon, basin-floor channel, or tectonic trough. (b) sediments are locally funneled through notches or small erosional channels that shift frequently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



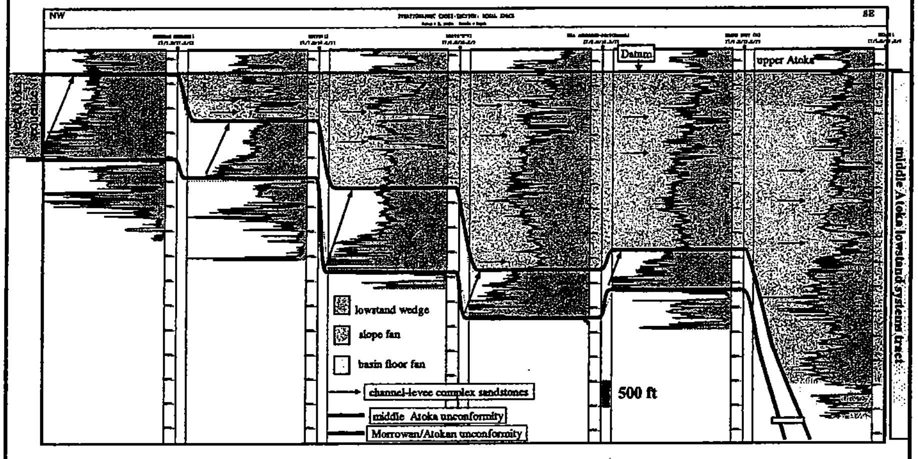
Isopach map of the middle Atoka LST showing its areal extent. Fault trends inferred from Figs. 38 and 48. Growth faults provided a huge accommodation space for the deposition of basin floor and slope fans, which abruptly thicken on the downthrown side of both San Bois and Kinta fault trends. The lowstand 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.



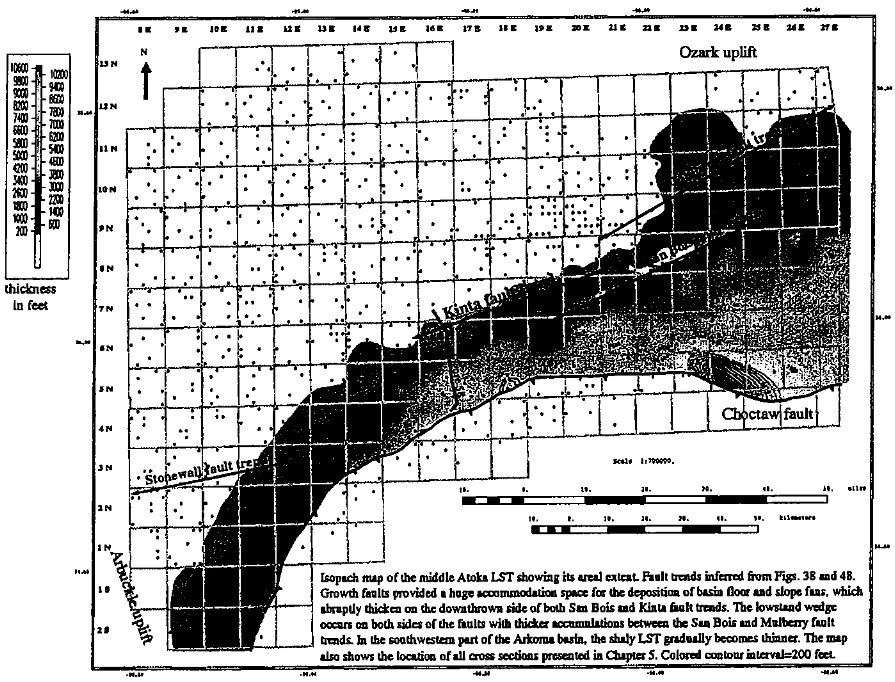
N-S stratigraphic cross section across the San Bois fault trend shown in Fig. 51. Several sandstones of the channel-levee complexes, composing the slope fan, occur south of the San Bois fault trend. Many of these sandstones occur without a clear indication of a point source such as a canyon or long thick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



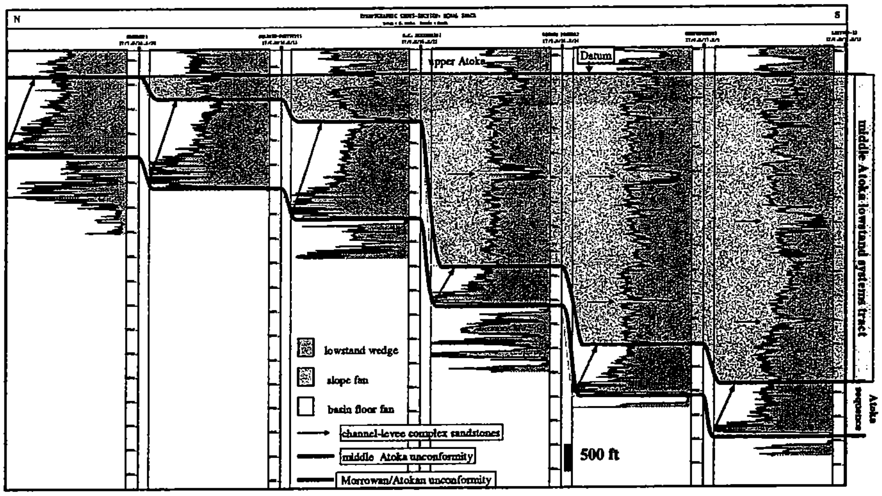
Isopach map of the middle Atoka LST showing its areal extent. Fault trends inferred from Figs. 38 and 48. Growth faults provided a huge accommodation space for the deposition of basin floor and slope fans, which abruptly thicken on the downthrown side of both San Bois and Kinta fault trends. The lowstand 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.



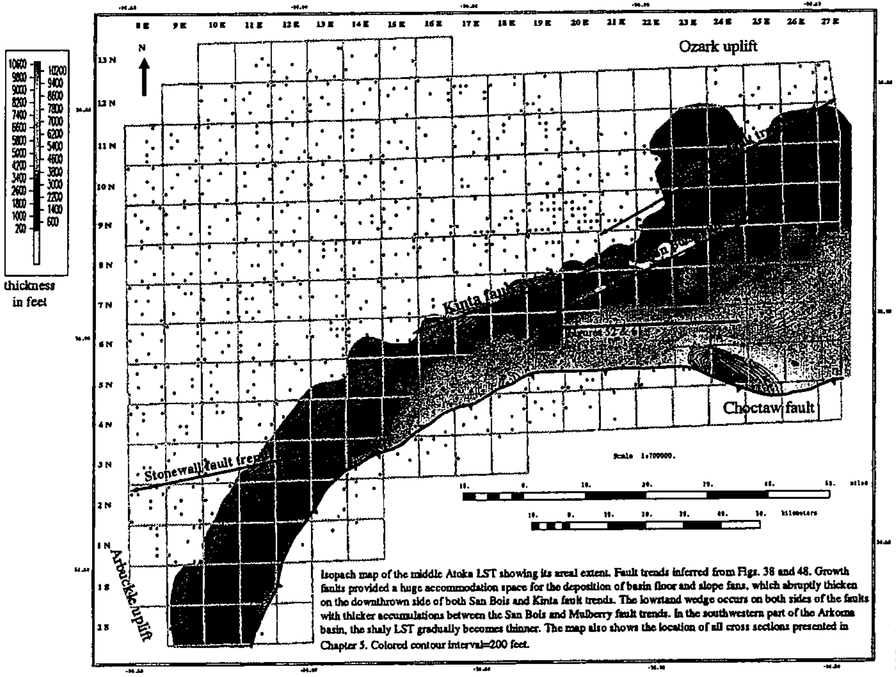
NW-SE stratigraphic cross section just west of the San Bois fault trend and across the Kinta fault trend shown in Fig. 51. Thick sandstones occur within the slope fan close to the shelf area of the Arkoma basin indicating deposition within a canyon or long channel. Adapting the Galloway (1998) classification,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



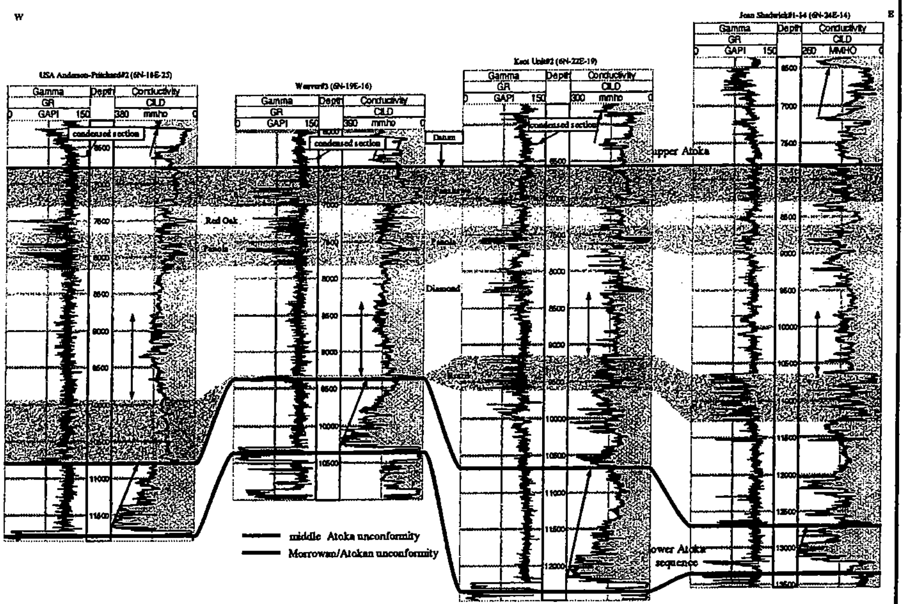
Isopach map of the middle Atoka LST showing its areal extent. Fault trends inferred from Figs. 38 and 48. Growth faults provided a huge accommodation space for the deposition of basin floor and slope fans, which abruptly thicken on the downthrown side of both San Bois and Kinta fault trends. The lowstand 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.



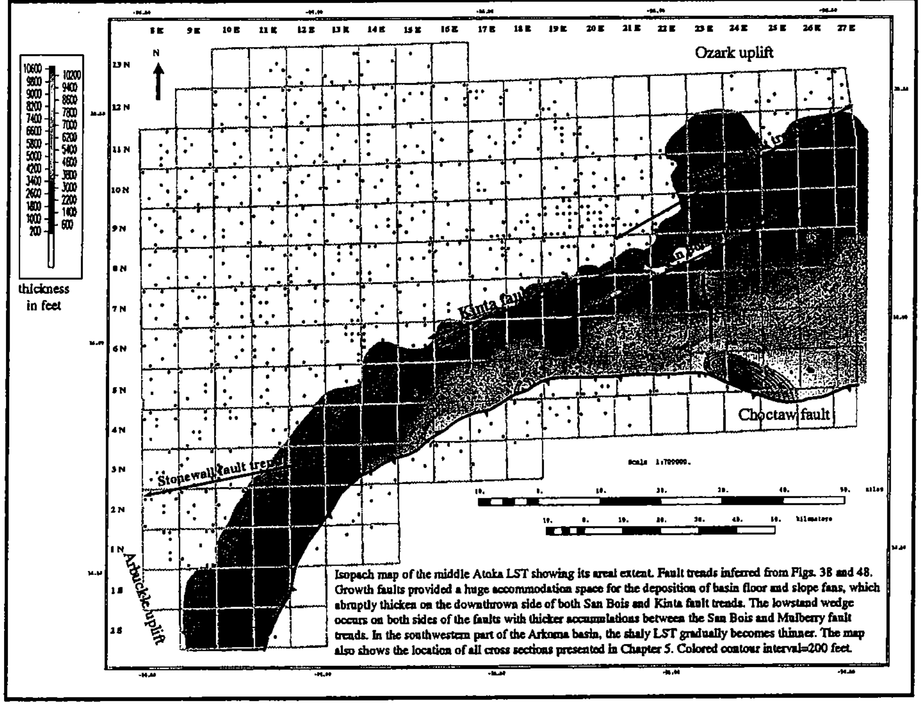
N-S stratigraphic cross section across the Kinta fault trend shown in Fig. 51 . A thick sandstone channel occurs within the slope fan of the middle Atoka LST clearly indicating a point-source for sediment supply at this area of the Arkoma basin. Note the general N-S dipping trend of this channel. The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



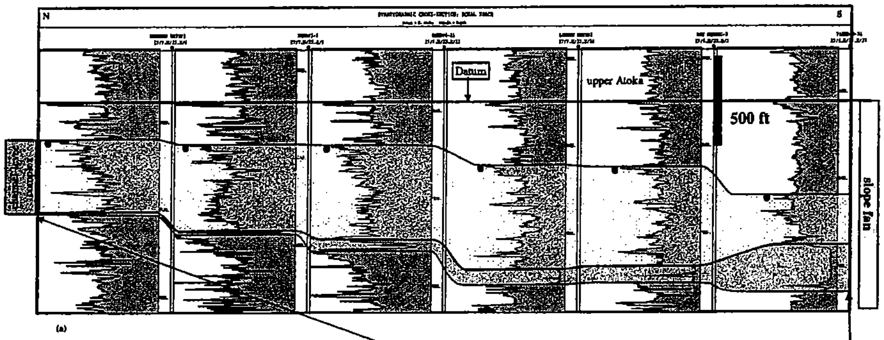
Isopach map of the middle Atoka LST showing its areal extent. Fault trends inferred from Figs. 38 and 48. Growth faults provided a huge accommodation space for the deposition of basin floor and slope fans, which abruptly thicken on the downthrown side of both San Bois and Kinta fault trends. The lowstand 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.

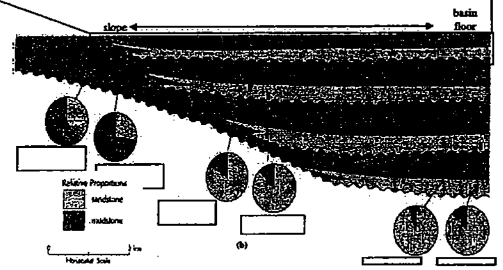


E-W stratigraphic cross section south of the San Bois fault trend. It shows the importance of recognizing a proper datum for correlating the sandstones within the channel-levee complexes. This is due to the lateral discontinuous nature of these sandstones and their vertical multiple occurrences within 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.

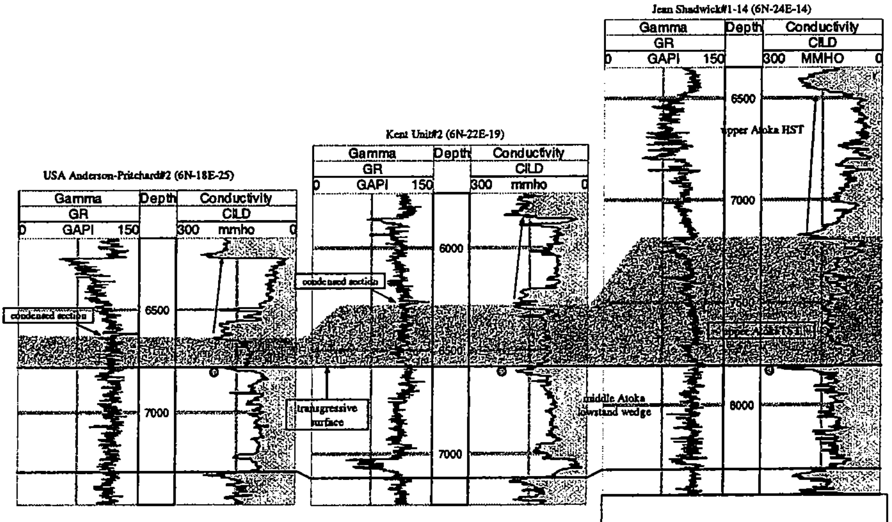


Isopach map of the middle Atoka LST showing its areal extent. Fault trends inferred from Figs. 38 and 48. Growth faults provided a huge accommodation space for the deposition of basin floor and slope fans, which abruptly thicken on the downthrown side of both San Bois and Kinta fault trends. The lowstand 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.





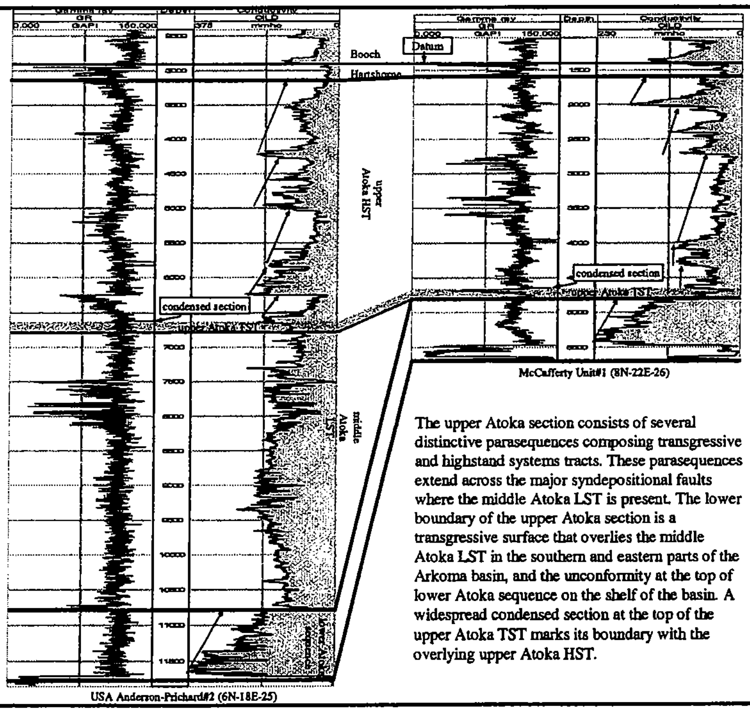
(a) N-S detailed stratigraphic cross section showing one channel-levee complex at the top part of the middle Atoka slope fan. A ten-mile long sandstone interval at the base of the complex (light brown) dips from north to south in contrast to the E-W direction suggested by other workers for turbidite 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.



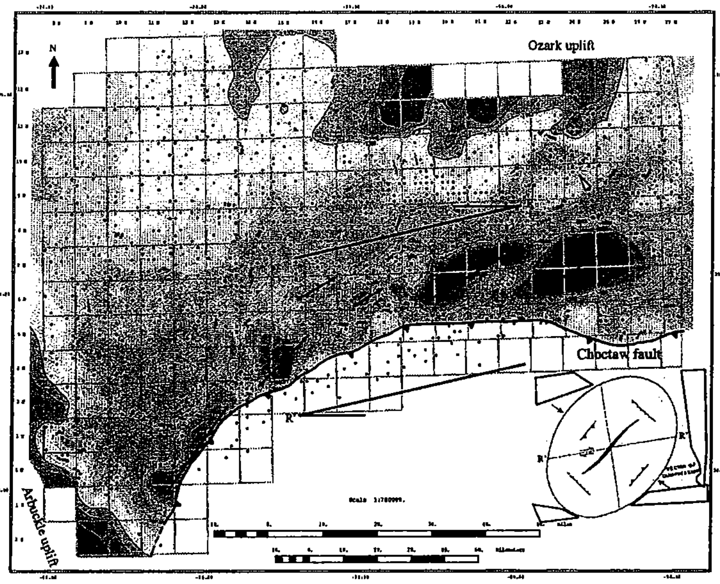
E-W detailed cross section using gamma ray and conductivity logs. A relatively high conductivity signature (green circle) marks the transgressive surface between the the middle Atoka LST and upper Atoka TST. In areas where the upper Atoka TST becomes shaly, a condensed section occurs at its top, and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

Upper Atoka

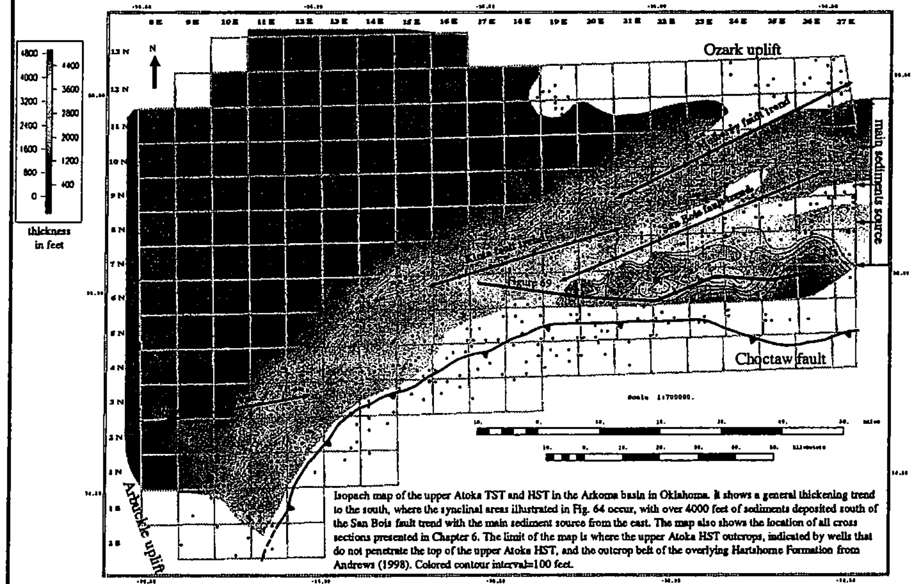
The upper Atoka section consists of several distinctive parasequences composing transgressive and highstand systems tracts. These parasequences extend across the major syndepositional faults present in the southeast part of the Arkoma Basin. The lower boundary of the upper Atoka section is a transgressive 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. Several interpretations have been proposed for the nature of the upper boundary of the upper Atoka section. The Atokan/Desmoinesian contact is defined in this work as unconformity. In terms of sequence stratigraphy, both the middle Atoka LST and the upper Atoka section (TST and HST) form 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.



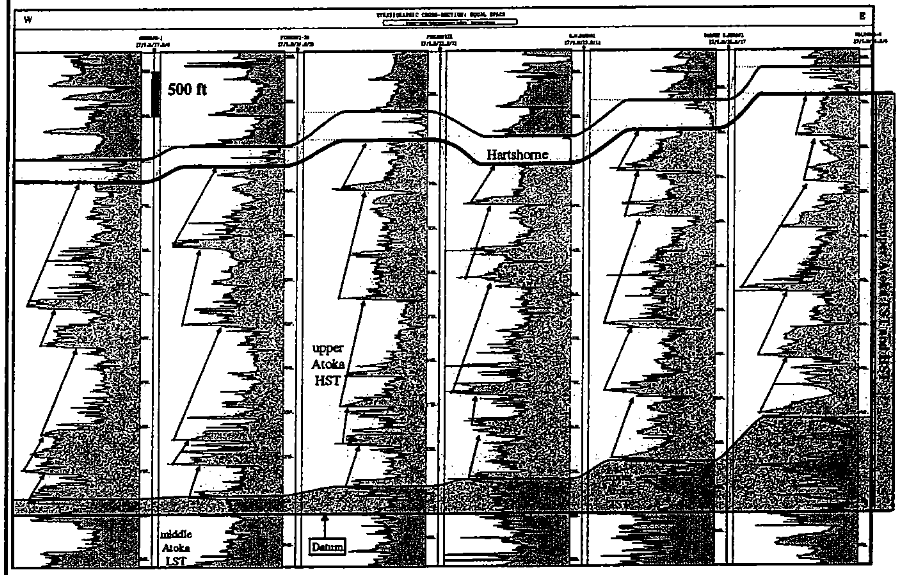
The upper Atoka section consists of several distinctive parasequences composing transgressive and highstand systems tracts. These parasequences extend across the major syndepositional faults where the middle Atoka LST is present. The lower boundary of the upper Atoka section is a transgressive surface 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.



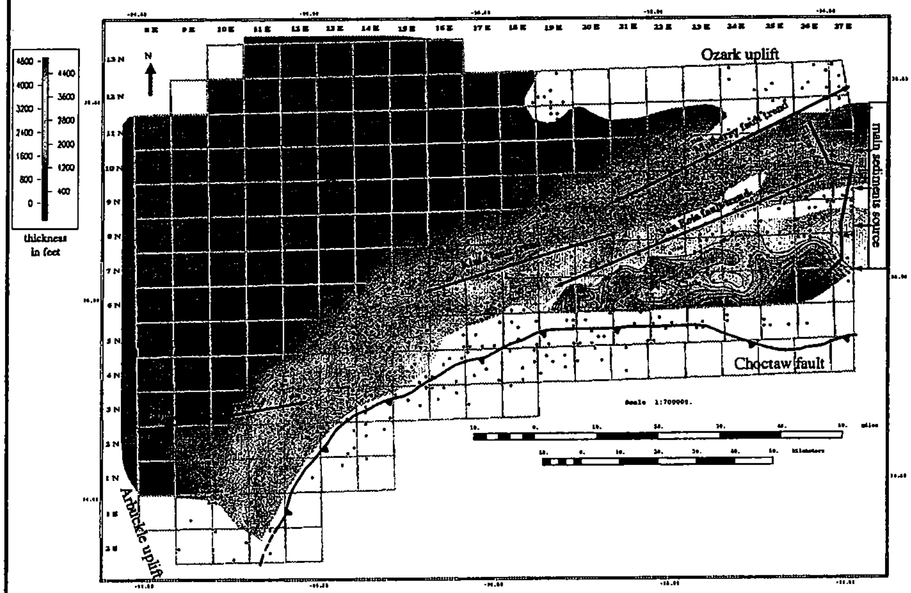
Structure contour map on the base of upper Atoka TST. A series of synclines (dark blue areas) seperated by highs are aligned in a zone trending ENE-WSW (light blue area) on the downthrown side of the major syndepositional fault trends shown in Fig. 51. If the plate collision during the Ouachita orogeny 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.

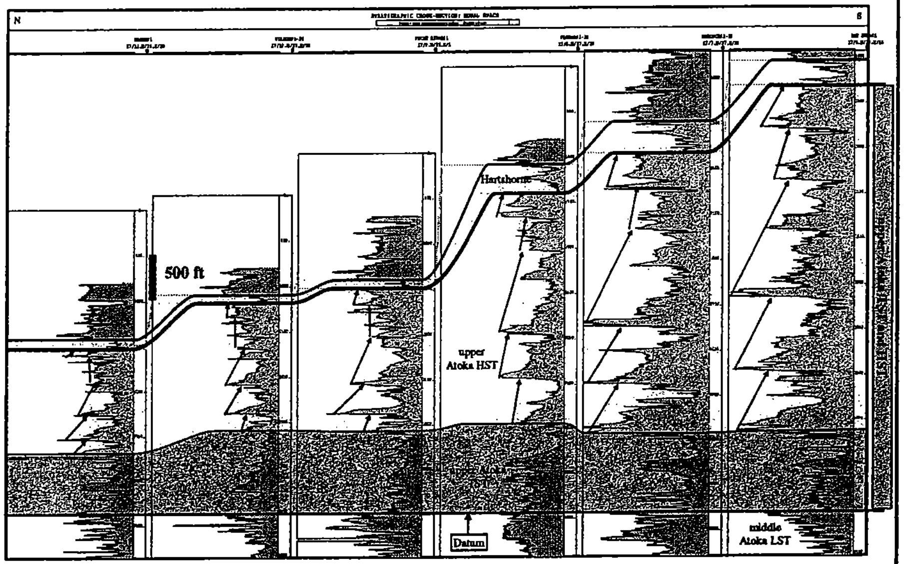


Isopach map of the upper Atoka TST and HST in the Arkoma basin in Oklahoma. It shows a general thickening trend to the south, where the synclinal areas illustrated in Fig. 64 occur, with over 4000 feet of sediments deposited south of the San Bois fault trend with the main sediment source from the east. 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.

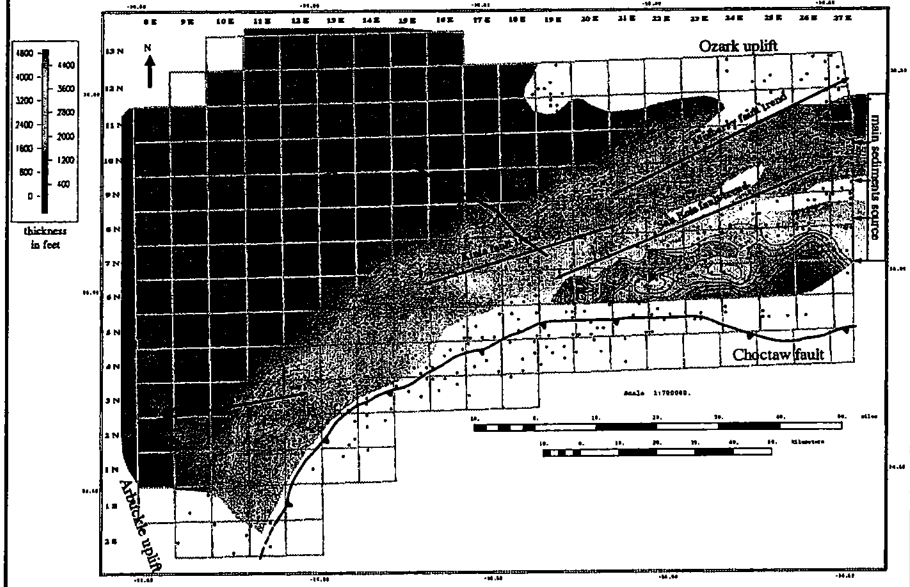


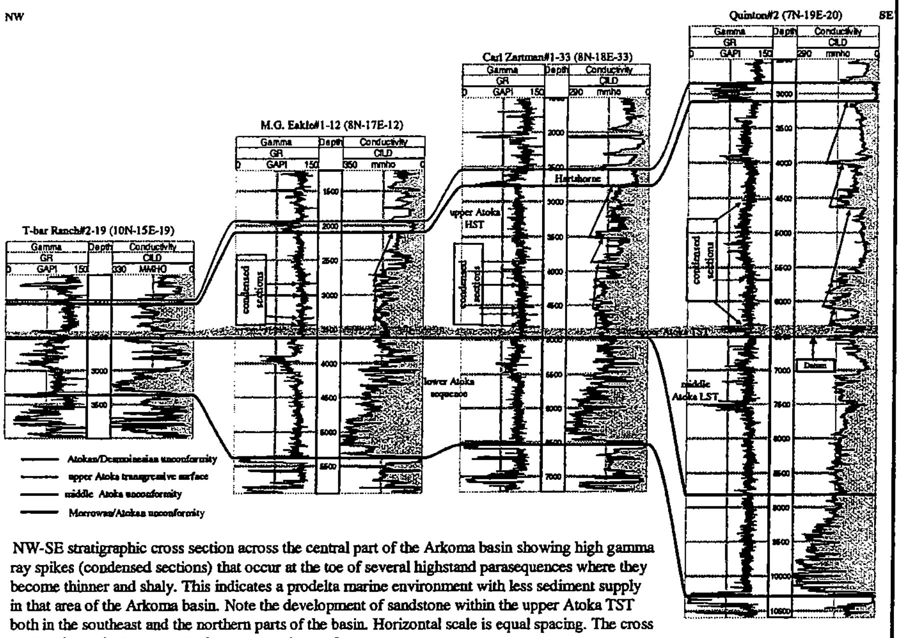
An E-W regional stratigraphic cross section in the southeastern part of the Arkoma basin showing that the upper Atoka TST becomes thicker toward the east (over 1000 feet in Walton#1-8 well). It thins significantly and becomes shaly to the west where it is capped by condensed section marking the maximum 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 a 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.



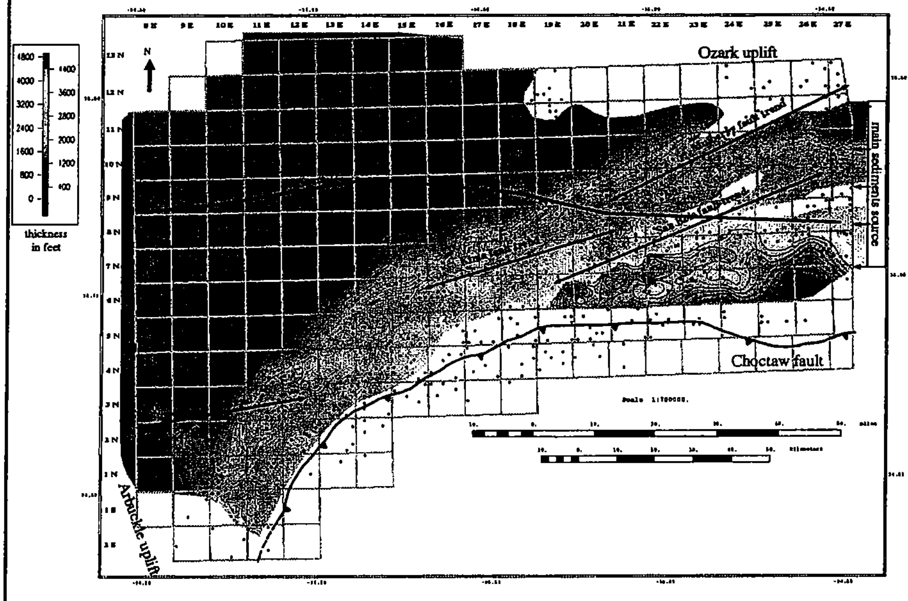


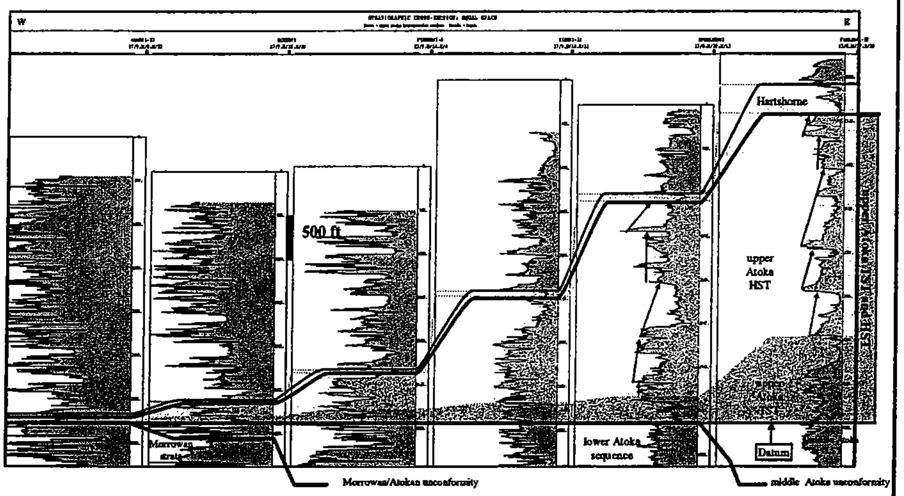
A N-S regional stratigraphic cross section across the eastern part of the Arkoma basin shows that the upper Atoka TST is well-developed and thick in this part of the basin. In the south of the cross section, the upper Atoka HST is composed of at least five thick aggradational parasequences. These parasequences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



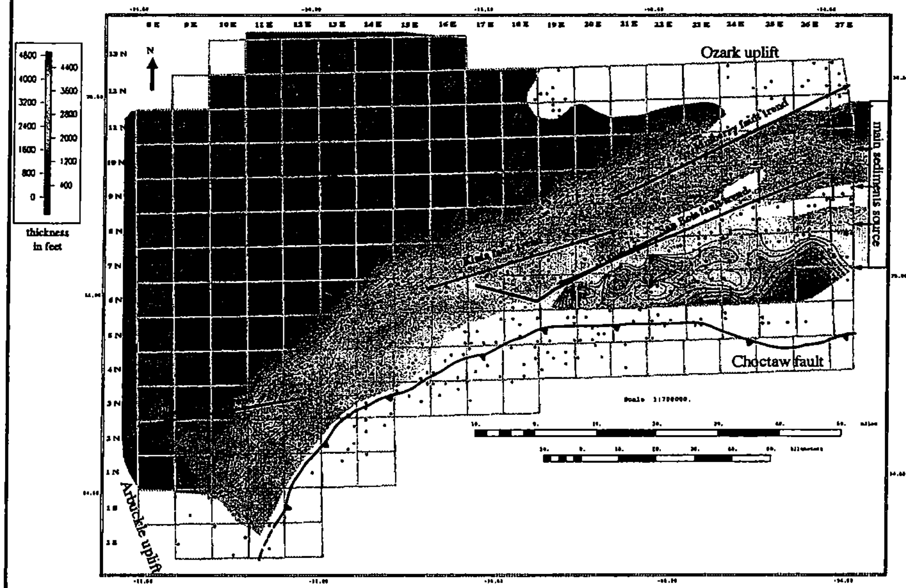


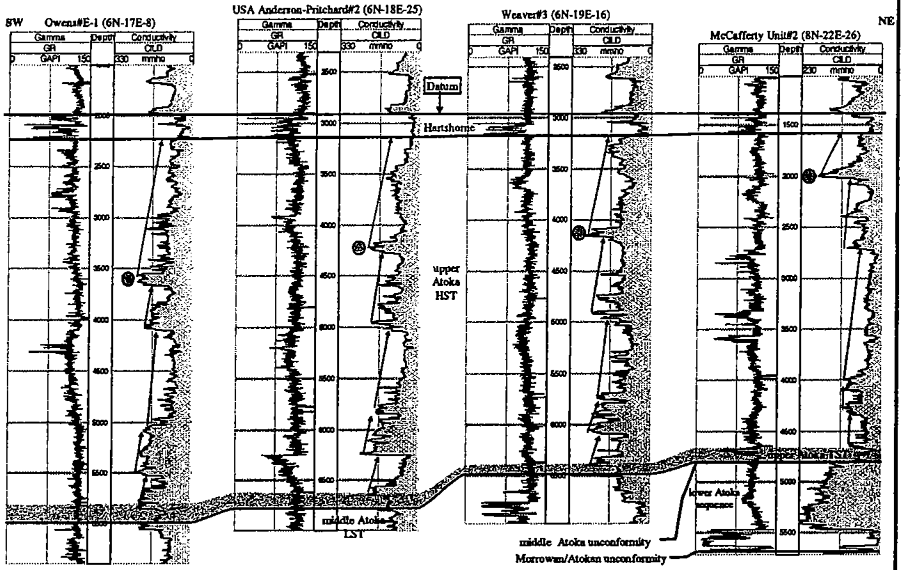
NW-SE stratigraphic cross section across the central part of the Arkoma basin showing high gamma ray spikes (condensed sections) that occur at the toe of several highstand parasequences where they become thinner and shaly. This indicates a prodelta marine environment with less sediment supply in that 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.



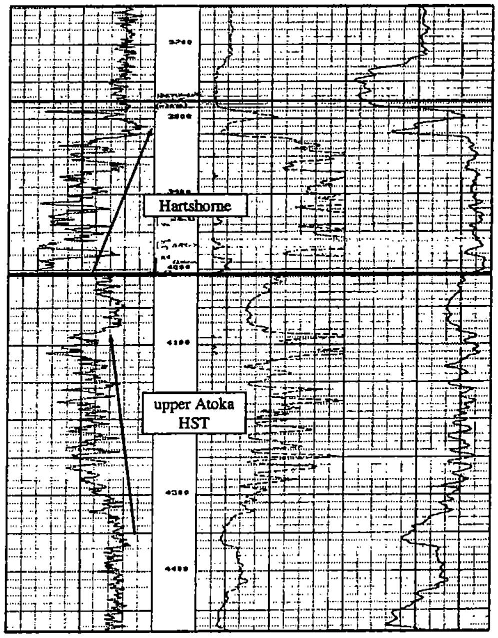


An E-W regional stratigraphic cross section showing that the thickness of the upper Atoka section changes significantly across the northern part of the Arkoma basin. The highstand parasequences with several sandstone intervals in the east become very thin and merge together forming a shaly interval marked 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 strata (Cook#1-33 well) in the northwestern part of the Arkoma basin The cross section datum is the upper Atoka transgressive surface.





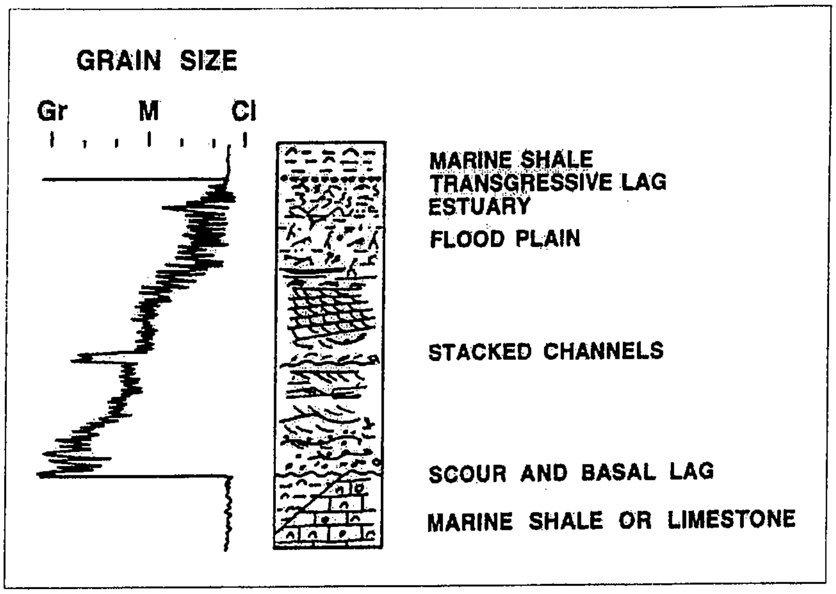
NE-SW stratigraphic cross section in the southern part of the Arkoma basin. Note the conductivity marker at the base of the topmost parasequence of the upper Atoka HST (green circle). Tracking this marker helps in defining the nature of the upper Atoka-Hartshorne contact as an unconformity surface. It 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



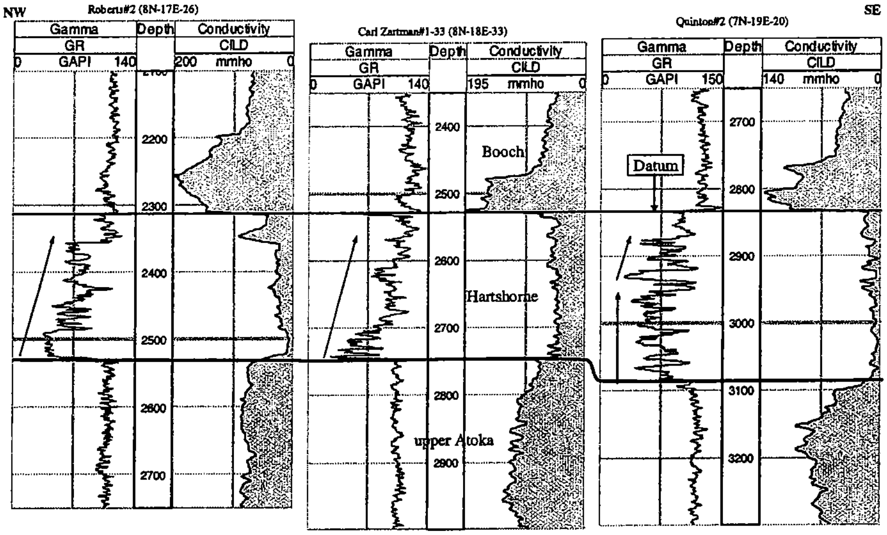
An example from Rouse#1 well (6N-15E-23) showing the clear distinction between the upper parasequence of the upper Atoka HST and the Hartshorne Formation. The upper Atoka parasequence shows a coarsening-upward pattern, while the Hartshorne Formation shows a fining upward pattern. In wells where the Hartshorne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

Hartshorne-Booch

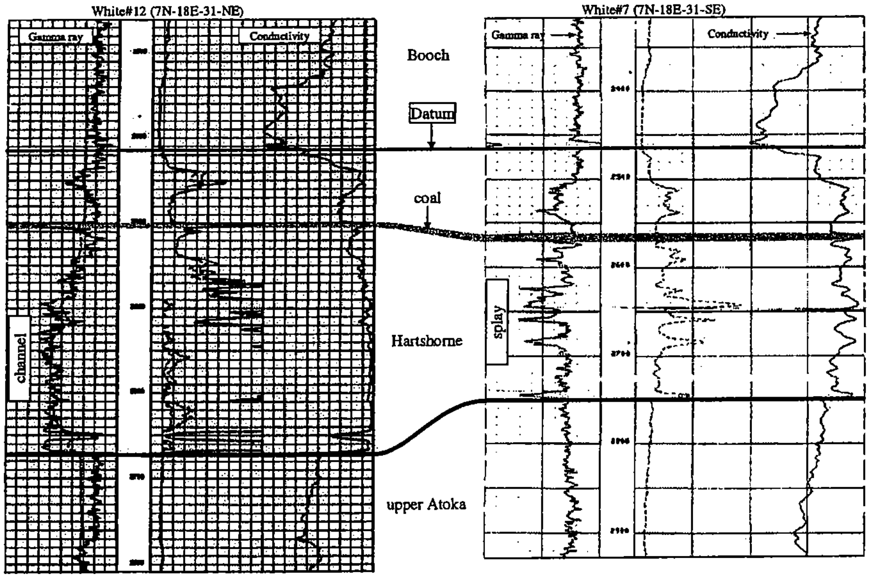
The Hartshorne and Booch intervals represent the lower part of the Desmoinesian Krebs group. The Hartshorne interval is recognized in this work based on the characteristic low-conductivity and fining-upward gamma ray log patterns. It was divided into three units where the thickest Hartshorne channel system occurs in the southern part of the Arkoma Basin, as incised-valley filling marks the Atokan/ Desmoinesian unconformity. 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. The aggradational to progradational Booch parasequences constitute the highstand systems tract above the Hartshorne LST and TST. Thus, the Booch-Hartshorne interval would represent a third-order sequence.



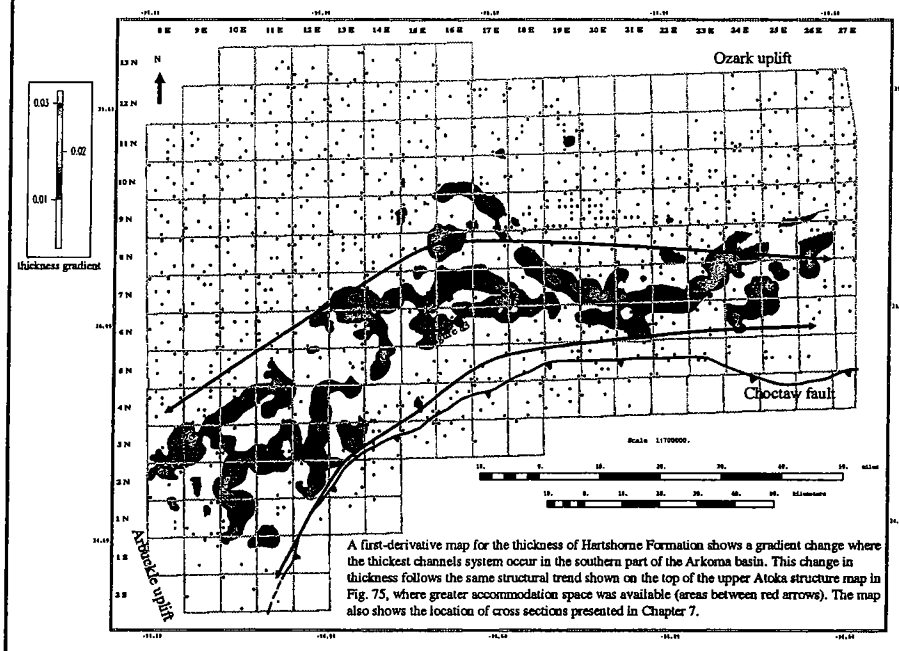
Typical vertical profile through a valley-fill deposit (after Krystinik and Blakeney, 1990). This fining-upward stacking pattern compares to that of the Hartshorne Formation in Figs. 78, 81, and 84.



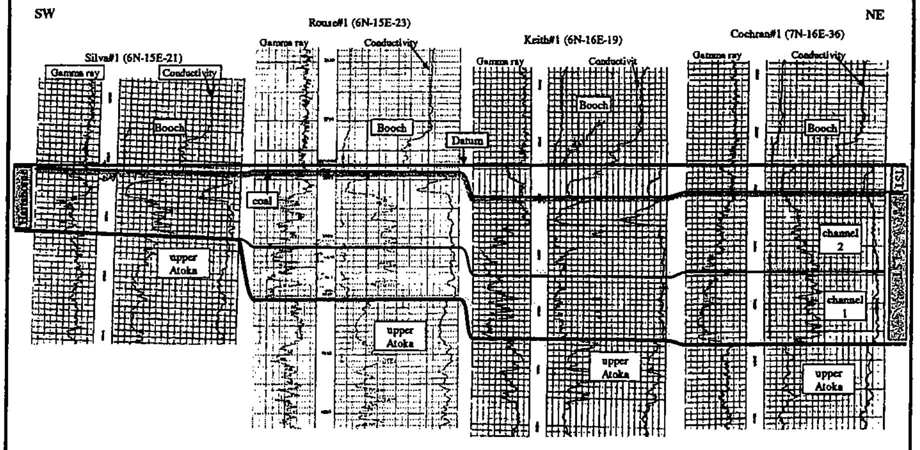
NW-SE stratigraphic cross section for the Hartshorne Formation showing its characteristic low conductivity pattern, and a fining upward pattern on the gamma ray log. Datum is the Hartshorne top. Horizontal scale is equal spacing. For location, see Fig. 80.



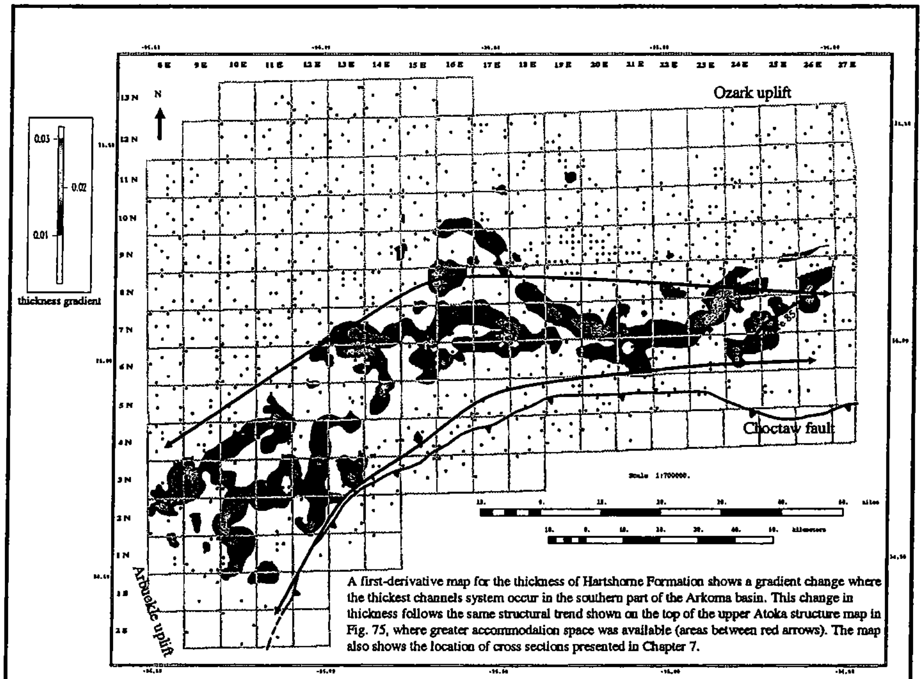
Two wells drilled in the same section (about a half-mile apart) showing the high variability of the development of sandstone in the Hartshorne interval. Datum is the Hartshorne top.



A first-derivative map for the thickness of Hartshorne Formation 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.



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.



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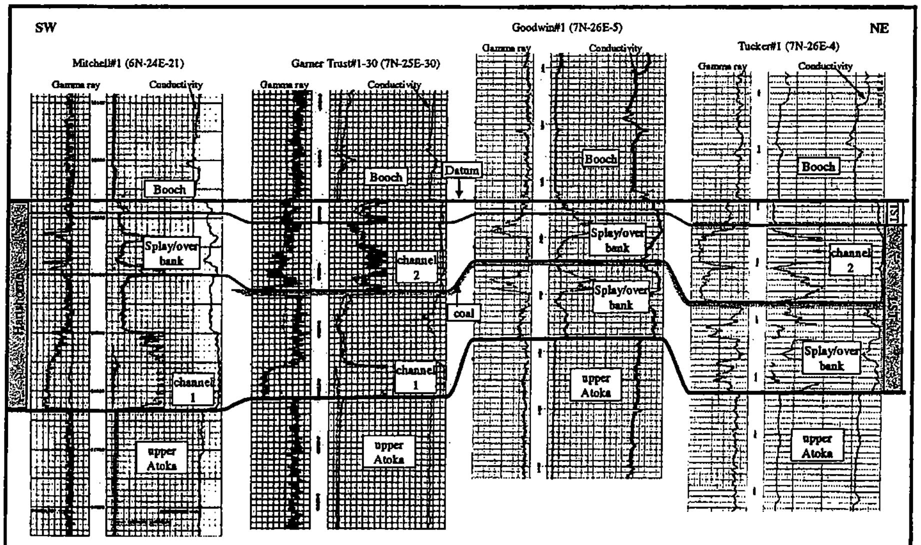
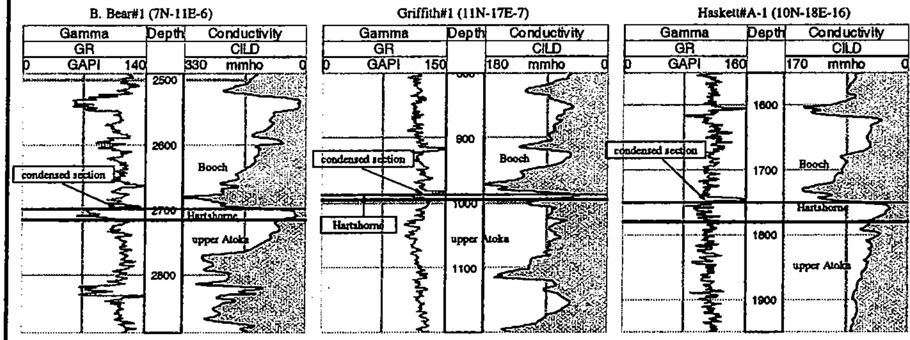
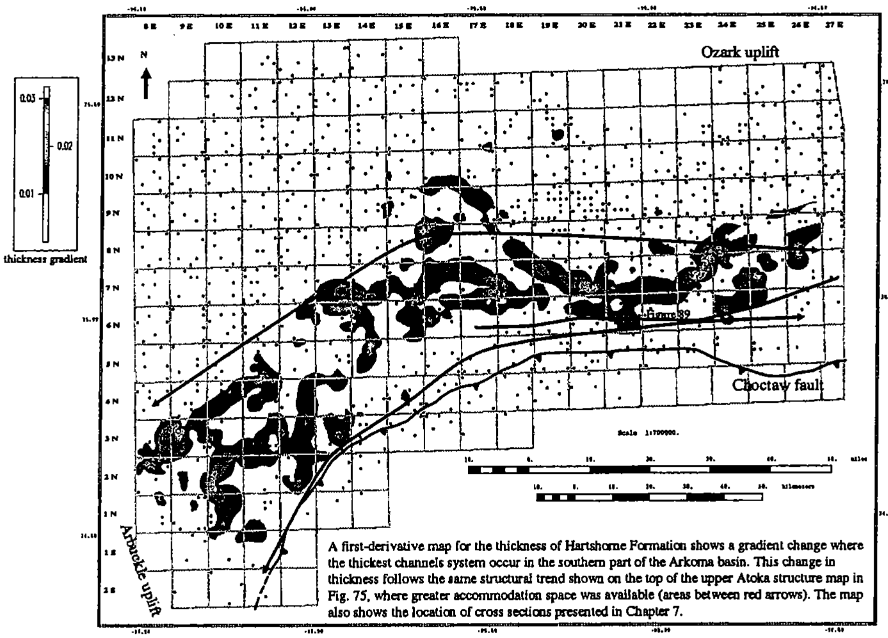


NE-SW stratigraphic cross section in the eastern part of the Arkoma basin showing the Hartshorne LST channels and their equivalent splay/overbank deposits. These channels do not follow the same axis as indicated by the switching and variability of thick sandstone deposition between channels as in the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



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.



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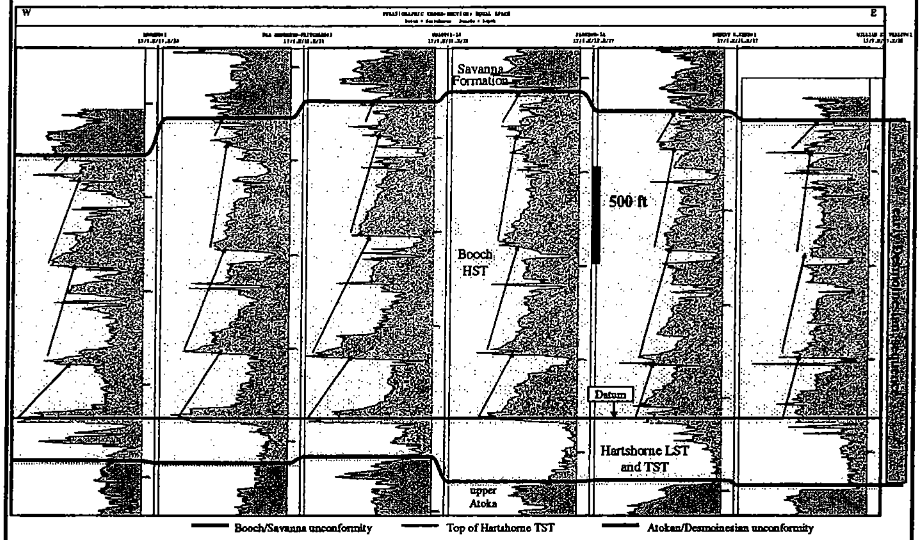
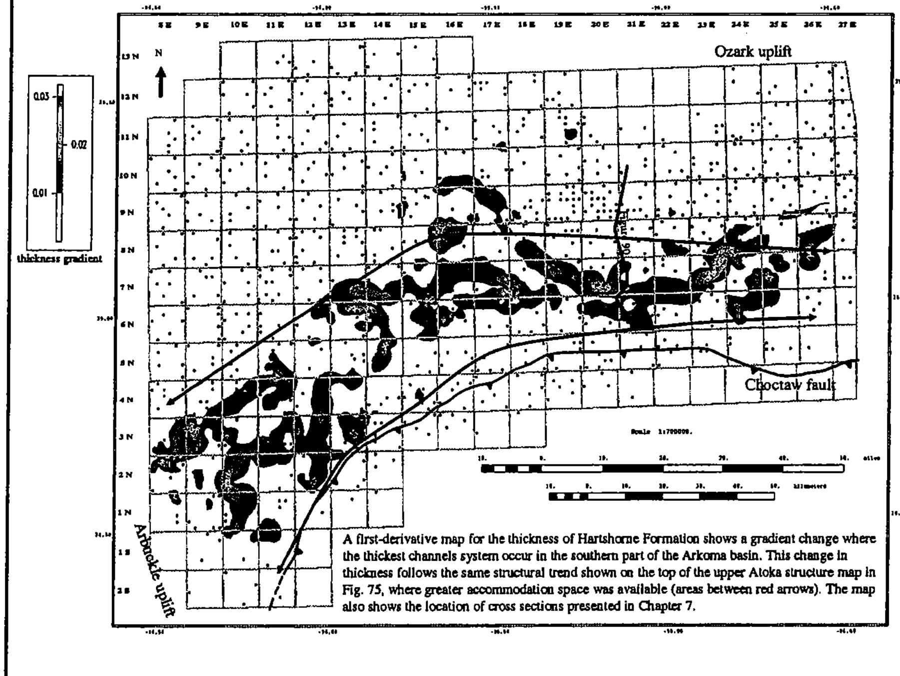
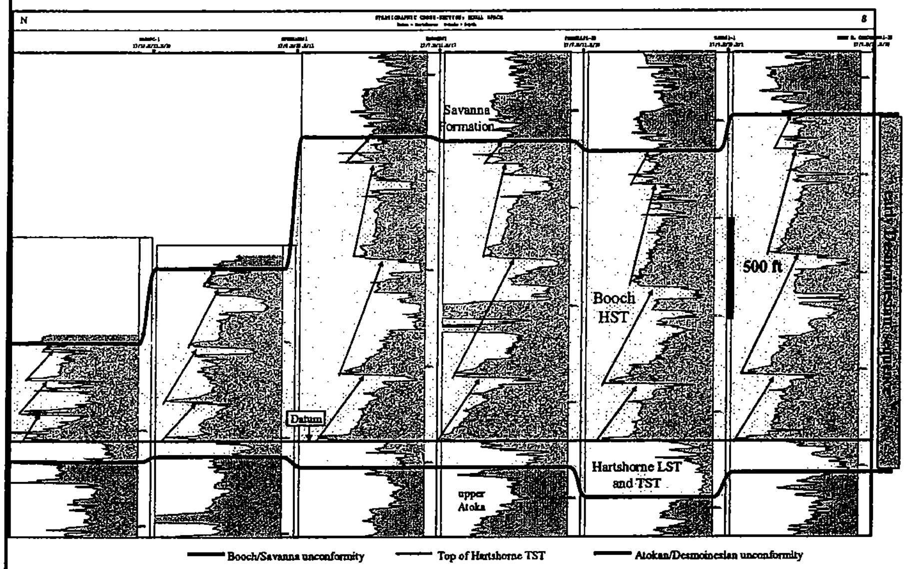


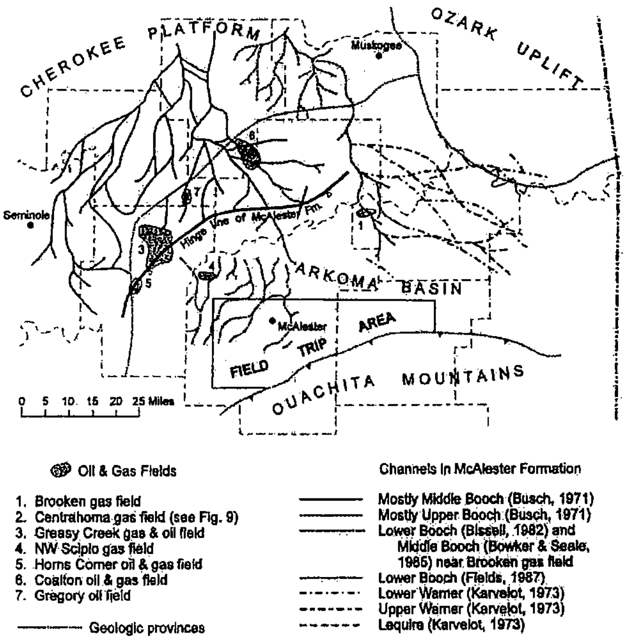
E-W regional stratigraphic cross section showing the thick parasequences of the Booch HST in the southern part of the Arkoma basin. The Booch interval is lithostratigraphically divided into three units: lower, middle, and upper. In this study, the Booch interval is divided into four coarsening-upward 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.



A first-derivative map for the thickness of Hartshorne Formation 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.



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.



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.

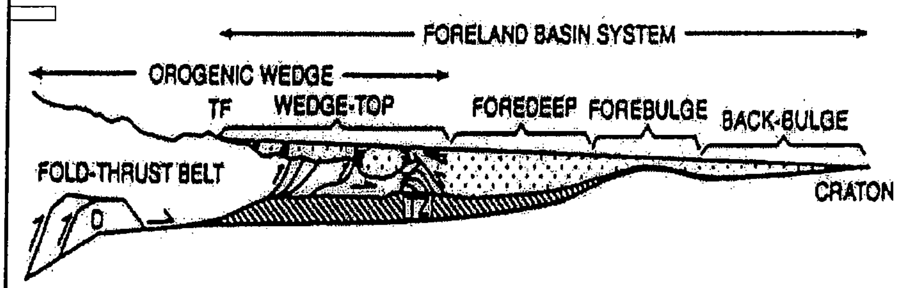
Stratigraphic Framework for the Atoka Formation

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. Despite this active tectonic history 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

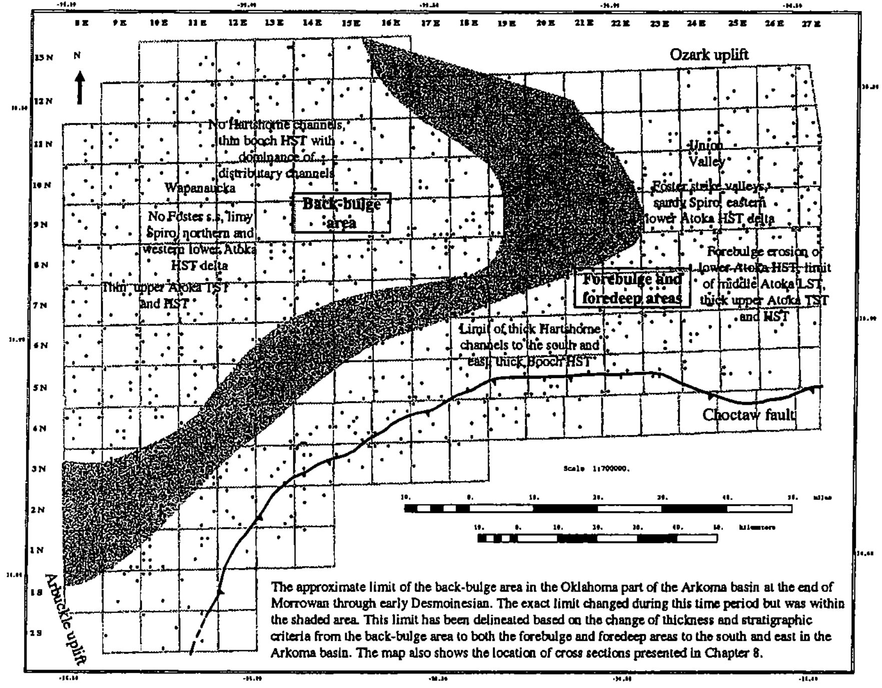
The Atokan section in the Arkoma Basin in Oklahoma is divided into two third-order sequences: the lower Atoka, and middle-upper Atoka sequences. Each is bounded by regional unconformities. The Cromwell sandstone, the Union Valley shale/limestone, and Wapanucka limestone are the Morrowan strata unconformably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

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.

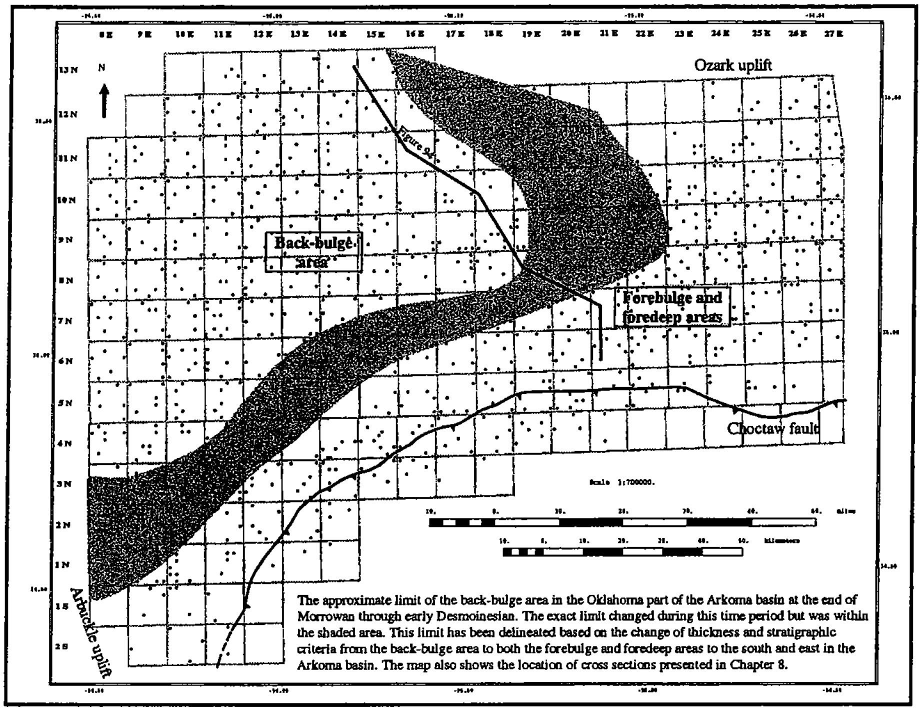
The Arkoma foreland basin is a mature exploration province that still has opportunities for further prospecting. In this study, the different lithostratigraphic sandstone units were arranged based on sequence stratigraphic surfaces with chronostratigraphic significance. This sequence stratigraphic model can aid as a predictive model for the distribution of sandstone throughout this basin in Oklahoma.



Schematic cross section depicting a foreland basin system, with the wedge-top, foredeep, forebulge, and back-bulge depozones. TZ is the frontal triangle zone. TF is the topographic front of the thrust belt. D is a schematic duplex depicted in the hinterland part of the orogenic wedge (after DeCelles and Giles, 1996).



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.



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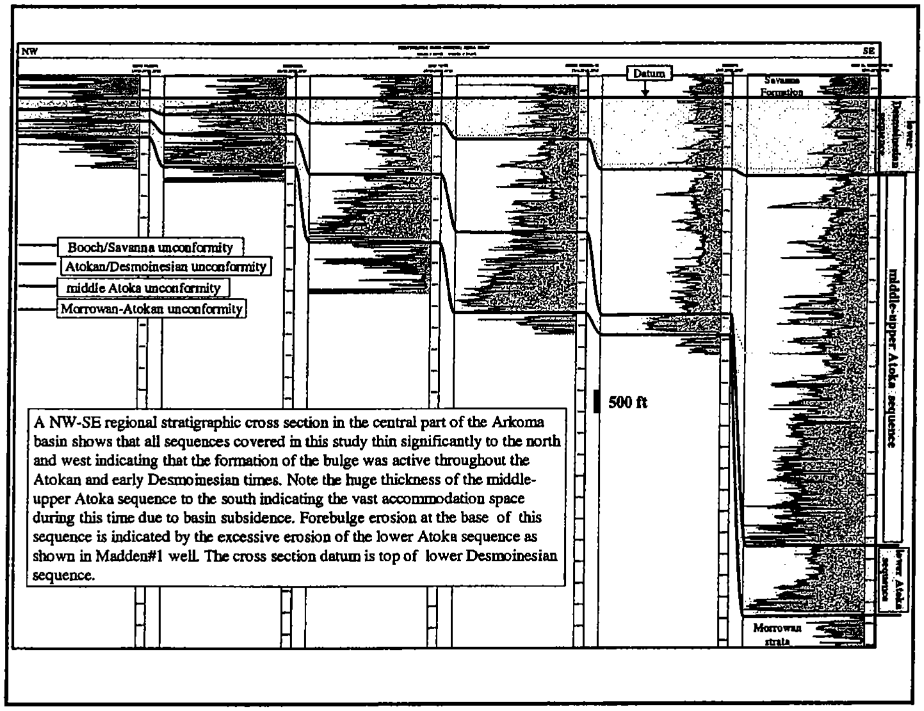
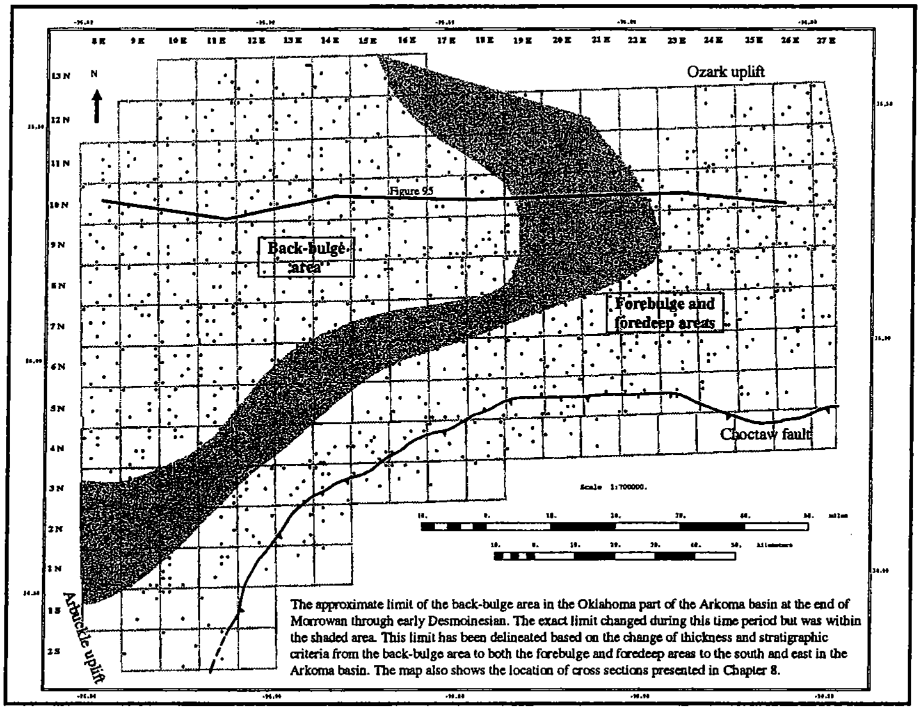


A NW-SE regional stratigraphic cross section in the central part of the Arkoma basin shows that all sequences covered in this study thin significantly to the north and west indicating that the formation of the bulge was active throughout the Atokan and early Desmoinesian times. Note the huge thickness 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.



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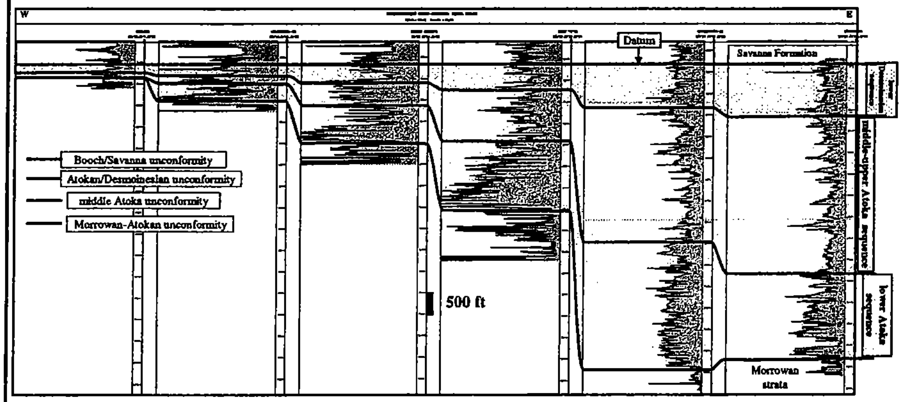
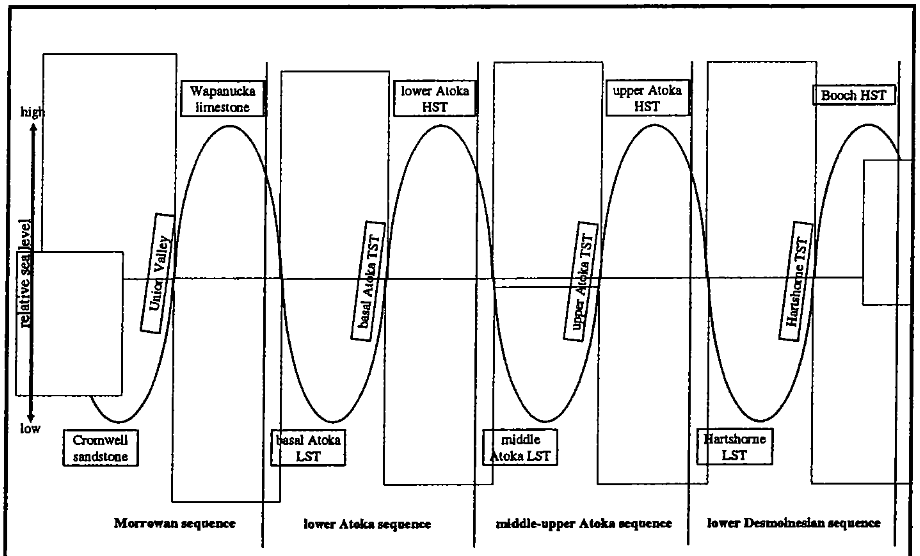


An E-W regional stratigraphic cross section in the northern part of the Arkoma basin shows that all sequences covered in this study thin significantly to the west indicating that the formation of the bulge was active throughout Atokan and early Desmoinesian times. The middle-upper Atoka sequence in the 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.



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

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.