OKLAHOMA GEOLOGICAL SURVEY
OPEN-FILE REPORT OF7-2002

PRACTICAL RESERVOIR CHARACTERIZATION FOR THE INDEPENDENT OPERATOR

Presented by

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

June 24-25, 2002
Norman, Oklahoma

(CD of presentation will not be provided)

APPLIED RESERVOIR CHARACTERIZATION FOR THE INDEPENDENT OPERATOR: WITH EMPHASIS ON COMPARTMENTALIZED RESERVOIRS AND ROUTINE TECHNIQUES FOR DETECTING COMPARTMENTS

UNIT 1: INTRODUCTION TO RESERVOIR CHARACTERIZATION

UNIT 2: EXAMPLES OF COMPARTMENTALIZED RESERVOIRS

UNIT 3: GEOLOGIC CONTROLS ON POROSITY AND PERMEABILITY

UNIT 3A: SEISMIC POROSITY DETECTION IN A CARBONATE RESERVOIR

UNIT 4: FLOW UNIT DETERMINATION & CHARACTERIZATION

UNIT 5: BASICS OF SEQUENCE STRATIGRAPHY

UNIT 6: FLUVIAL DEPOSITS AND RESERVOIRS

UNIT 7: EOLIAN DEPOSITS AND RESERVOIRS

UNIT 8: SHOREFACE DEPOSITS AND RESERVOIRS

UNIT 9: DELTAIC DEPOSITS AND RESERVOIRS

UNIT 10: DEEP-WATER (TURBIDITE) DEPOSITS AND RESERVOIRS

UNIT 11: BOREHOLE IMAGE LOGS AND APPLICATIONS

UNIT 12: DIPMETER LOGS AND APPLICATIONS

UNIT 13: STRUCTURALLY COMPARTMENTALIZED RESERVOIRS

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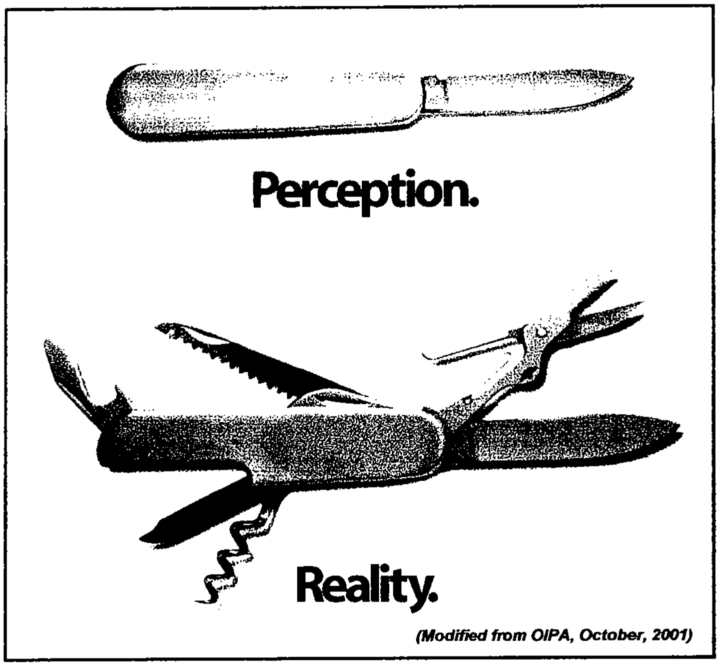

Perception.

Reality.

(Modified from OIPA, October, 2001)

DAY 1:

APPLIED RESERVOIR CHARACTERIZATION FOR THE INDEPENDENT OPERATOR

WITH EMPHASIS ON COMPARTMENTALIZED RESERVOIRS AND ROUTINE TECHNIQUES FOR DETECTING COMPARTMENTS

Roger M. Slatt
School of Geology and Geophysics
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DAY 1 COURSE OUTLINE

UNIT 1: INTRODUCTION
UNIT 2: EXAMPLES OF COMPARTMENTALIZED RESERVOIRS
UNIT 3: GEOLOGIC CONTROLS ON POROSITY & PERMEABILITY
UNIT 4: FLOW UNIT DETERMINATION & CHARACTERIZATION
UNIT 5: BASICS OF SEQUENCE STRATIGRAPHY
UNIT 6: INCISED VALLEY FILL RESERVOIRS
UNIT 7: SHOREFACE RESERVOIRS
UNIT 8: DEEP-WATER (TURBIDITE) RESERVOIRS

DAY 1 COURSE OUTLINE (Cont.)

UNIT 9: BOREHOLE IMAGE & DIPMETER LOGS: APPLICATIONS
UNIT 10: STRUCTURALLY COMPARTMENTED RESERVOIRS
UNIT 11: BASICS OF GEOLOGICAL MODELING
UNIT 12: CARBONATE POROSITY DETECTION FROM 3D SEISMIC
UNIT 13: THE LEWIS SHALE AS A PETROLEUM SYSTEM

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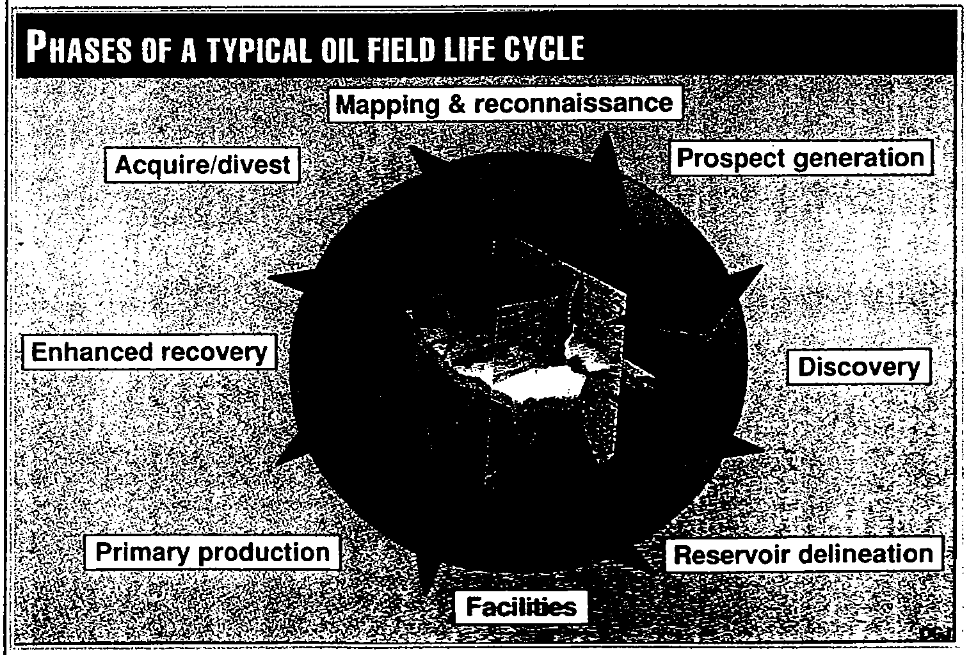
RESERVOIR CHARACTERIZATION:

"THE PROCESS OF CREATING AN INTERDISCIPLINARY HIGH-RESOLUTION GEOSCIENCE MODEL THAT INCORPORATES, INTERRELATES, AND RECONCILES VARIOUS TYPES OF GEOLOGICAL AND ENGINEERING INFORMATION FROM PORE TO BASIN SCALE.

AAPG Memoir 71



PHASES OF A TYPICAL OIL FIELD LIFE CYCLE

THE SNEIDER FOCUS

Robert Sneider's company moved from exploration to property acquisition during 1980's downturn. Acquisition possibilities had the following traits:

- Might be a waterflood candidate;
- Existing waterflood yielding poor results with existing spacing;
- Unrecognized pay in low resistivity reservoir rocks;
- Unrecognized structural or stratigraphic compartments;
- Unrecognized field extensions that might be defined by new 2D or 3D seismic surveys;

Results: purchase of 46 mature fields with >625MMBOE added at cost of $2.69/BOE

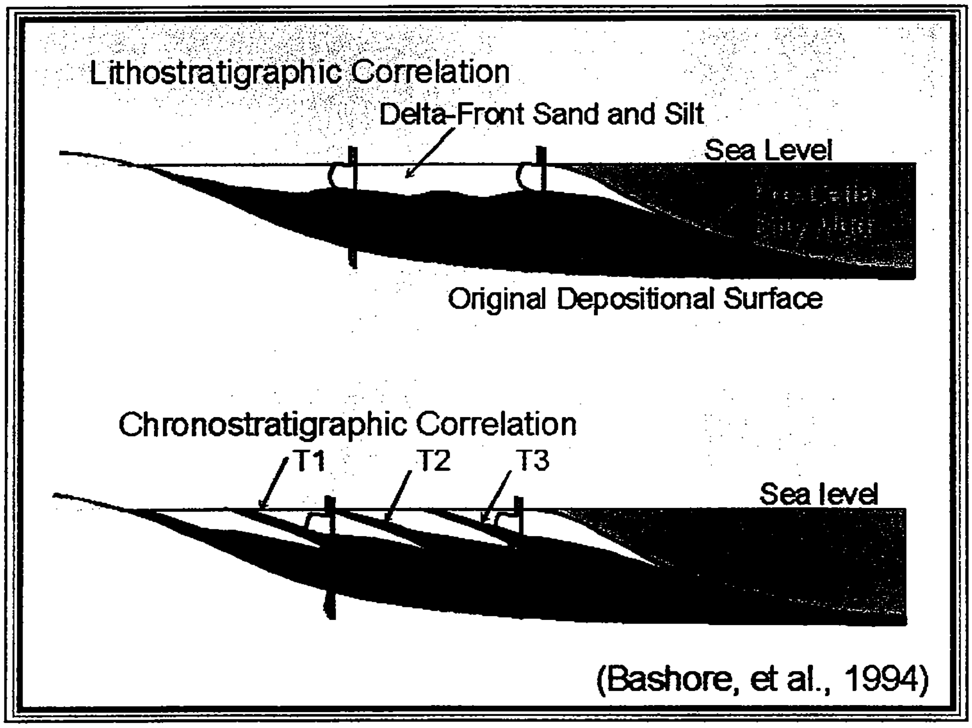
(Durham, May, 2001, AAPG Explorer, p. 28)

COMPARTMENTALIZED RESERVOIR

A *compartmentalized reservoir* is defined as a reservoir that is segmented into discrete, isolated geologic units, with each unit commonly having its own production characteristics.

FROM CONCEPTUAL TO QUANTITATIVE RESERVOIR CHARACTERIZATION

- HOW BIG IS THE CONTAINER?
- HOW WILL THIS RESERVOIR STYLE PERFORM?
- HOW WIDELY MUST WE SPACE OUR EXPENSIVE DEVELOPMENT WELLS IN THIS GEOLOGIC SETTING?
- SHOULD WE DRILL A VERTICAL, SLANT, OR HORIZONTAL WELL?
- HOW CAN WE FAST-TRACK DEVELOPMENT OF THIS RESERVOIR?
- WHAT WENT WRONG??

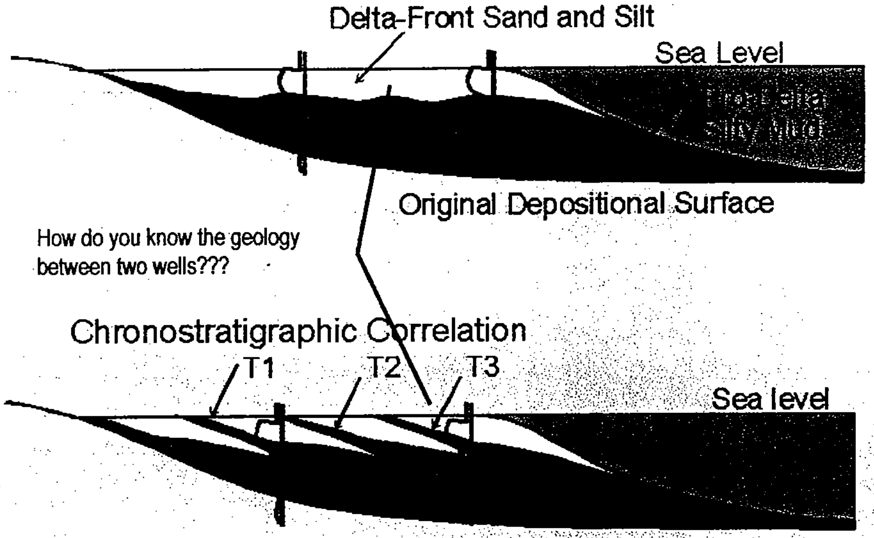


Lithostratigraphic Correlation

Chronostratigraphic Correlation

(Bashore, et al., 1994)

Lithostratigraphic Correlation

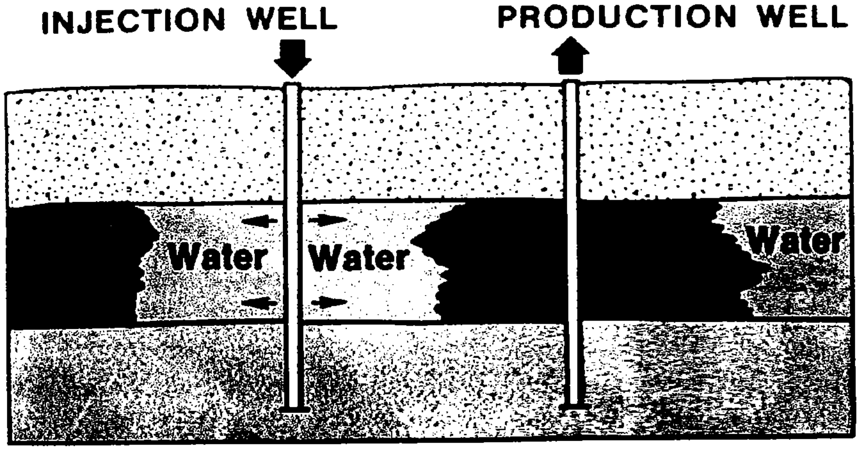


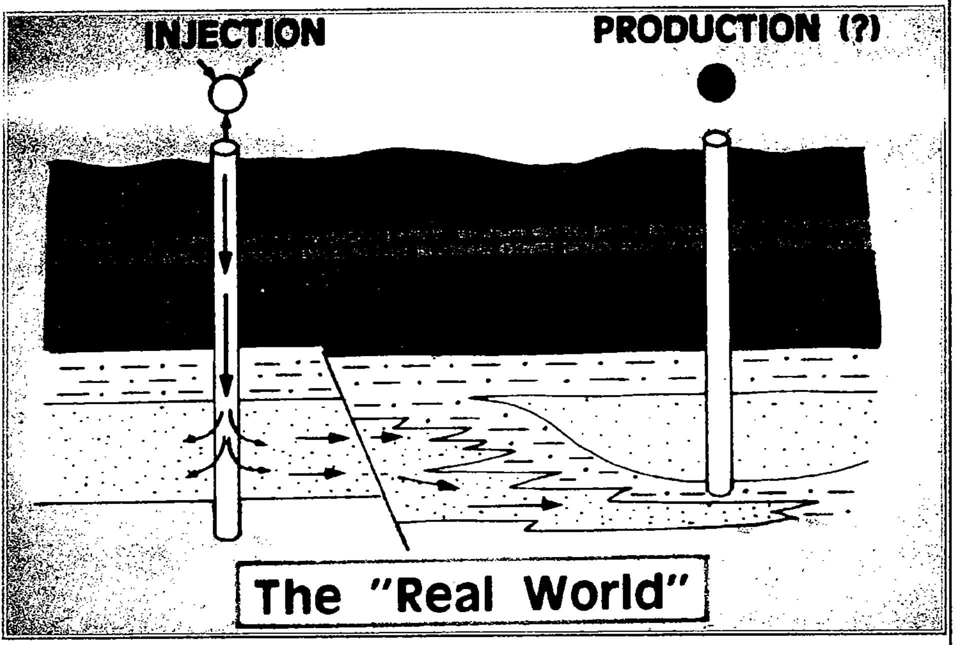
How do you know the geology between two wells???

Chronostratigraphic Correlation

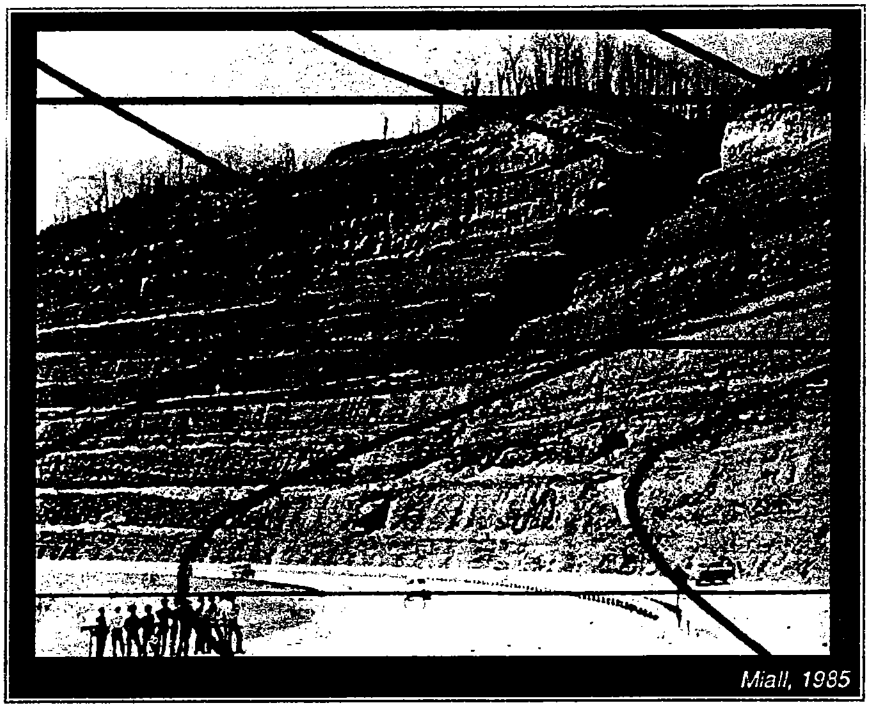
(Bashore, et al., 1994)

WATERFLOOD

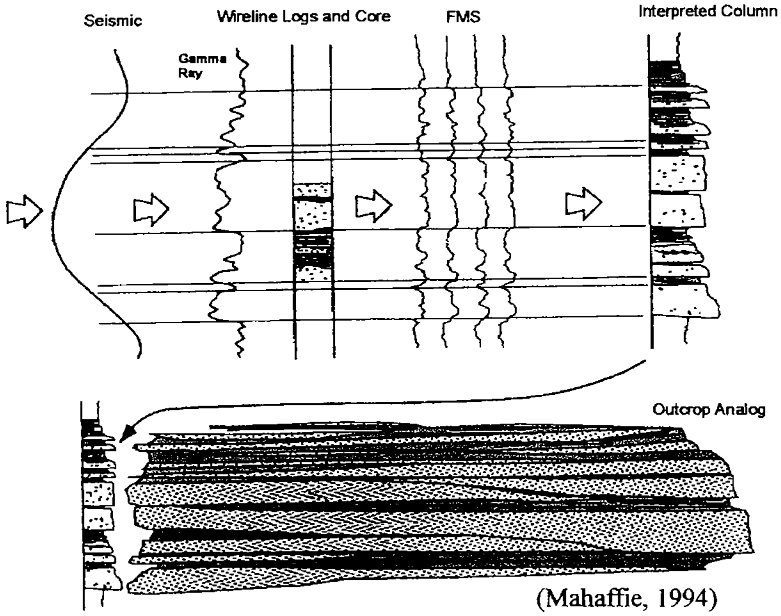




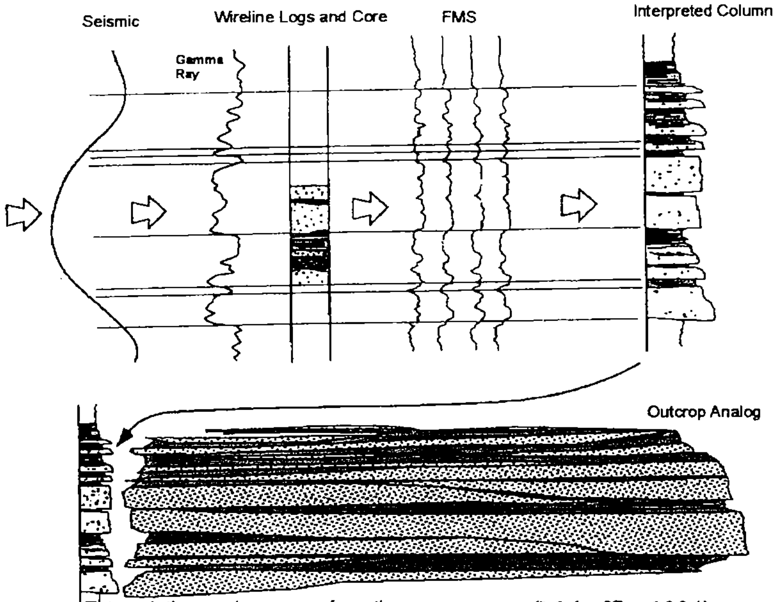
Reservoir performance is governed by features that are often beneath seismic resolution or detection ('sub-seismic scale")



Miall, 1985



(Mahaffie, 1994)



Extrapolating geology away from the wellbore (between wells) is difficult!!

(Mahaffie, 1994)

RECOGNIZING COMPARTMENTALIZED RESERVOIRS

DYNAMIC RESERVOIR PROPERTIES

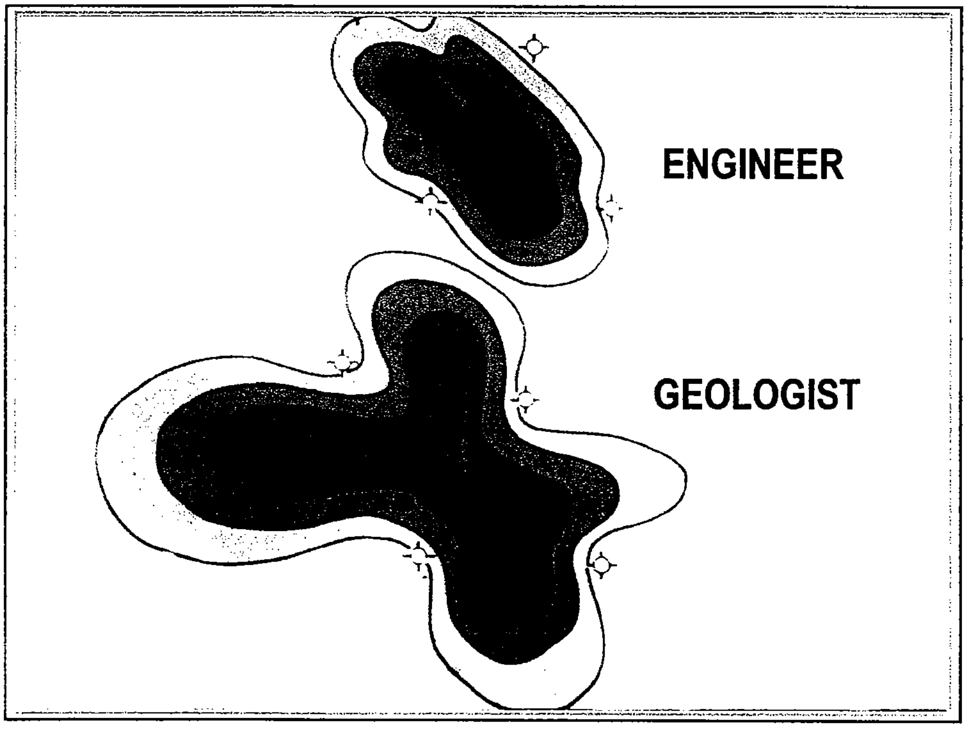
-Pressures	**(RFT, DST, PTA)**
-4D Seismic	**(Time lapse surveys)**
-Fluid geochemistry	**(Produced fluids)**
-Saturations	**(Well logs, cores)**
-Fluid Contacts	**(Well logs, cores, seismic)**
-GOR/WOR	**(IP, other tests)**

RECOGNIZING COMPARTMENTALIZED RESERVOIRS

STATIC RESERVOIR PROPERTIES

- -Stratigraphy
- -Geometry
- -Lithology
- -Porosity and Permeability
- -Capillarity
- -Structure

Determined by subsurface well log mapping and correlations, sample analysis, seismic, borehole imaging, outcrop analogs



ROGER'S RULES OF RESERVOIR CHARACTERIZATION

- THINK SMALL
- THINK IN TERMS OF THE ROCKS (INSTEAD OF PAPER OR SCREEN IMAGES)
- THINK IN TERMS OF NUMBERS
- SEEING IS BELIEVING
- COMPUTERS ARE TOOLS, NOT BRAINS (DON'T BECOME A NINTENDO GEOLOGIST!!)
- "WHERE OIL IS FIRST FOUND IN THE MINDS OF MEN (AND WOMEN)" by Wallace Pratt
- "SWEAT THE ASSET" by Andrew Cullen

RESERVOIR CHARACTERIZATION DISCIPLINES

- GEOLOGY
- GEOPHYSICS
- PETROPHYSICS
- PETROLEUM ENGINEERING
- GEOSTATISTICS
- GEOCHEMISTRY
- COMPUTER SCIENCE
- BEHAVIORAL SCIENCE

Two stonecutters were asked what they were doing. The first said, "I'm cutting this stone into blocks." The second replied, "I'm on a team that's building a cathedral."

--Author unknown

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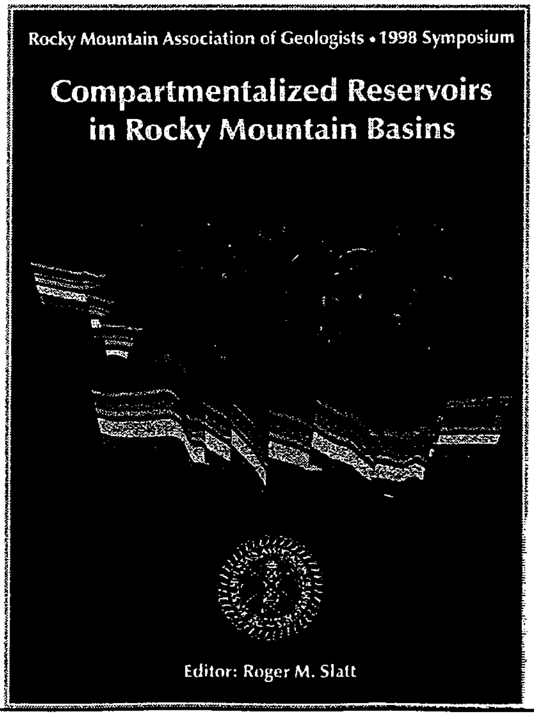
EXAMPLES OF COMPARTMENTALIZED RESERVOIRS AND THEIR IDENTIFICATION AND CHARACTERIZATION



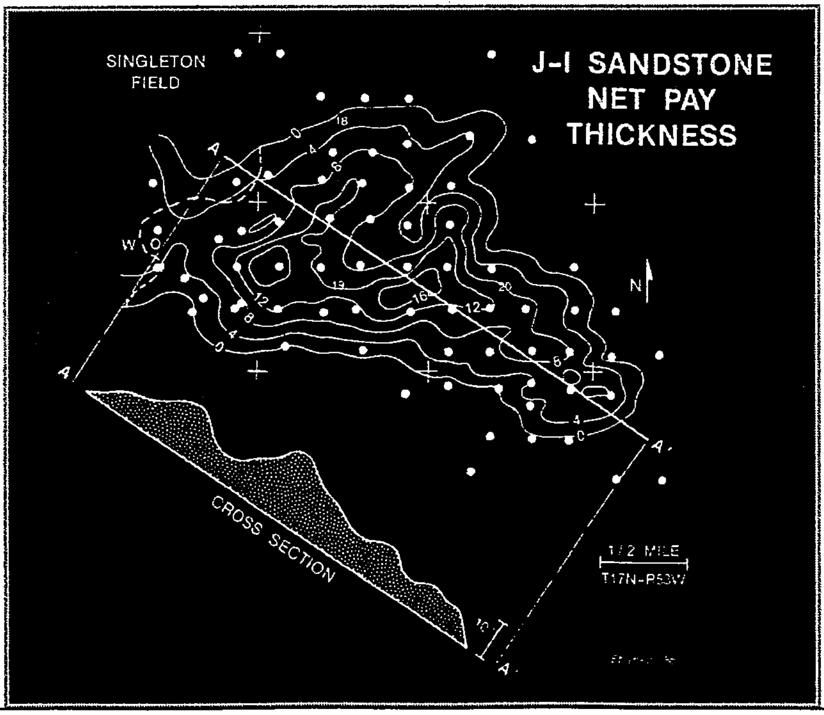
Rocky Mountain Association of Geologists • 1998 Symposium

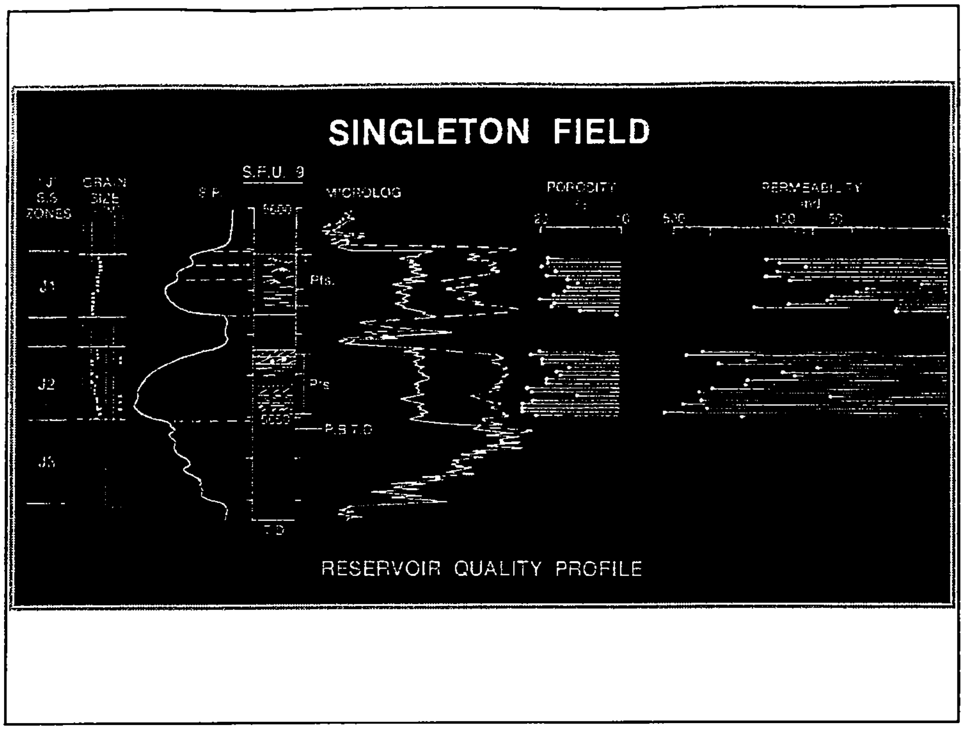
Compartmentalized Reservoirs in Rocky Mountain Basins

Editor: Roger M. Slatt

COMPARTMENTALIZED RESERVOIRS

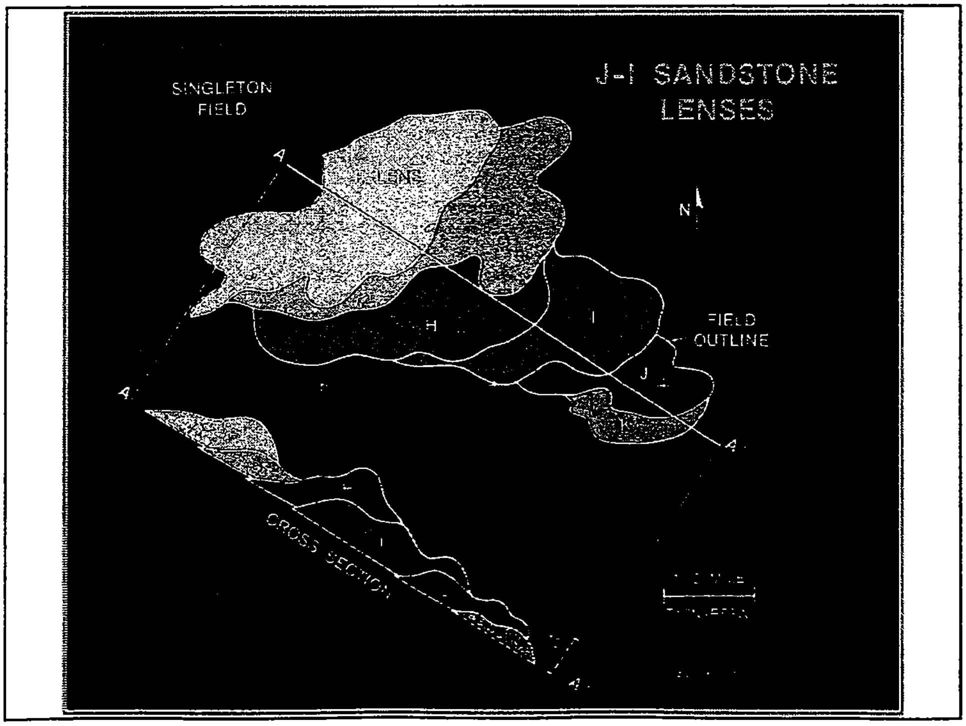
- THE RULE, RATHER THAN THE EXCEPTION (SLATT, 1998)
- COMMON TO MOST TYPES OF SEDIMENTARY DEPOSITS
- STRUCTURAL COMPARTMENTS ALSO COMMON
- CAN BE DETECTED BY A VARIETY OF METHODS
  - -STATIC RESERVOIR PROPERTIES
  - -DYNAMIC RESERVOIR PROPERTIES



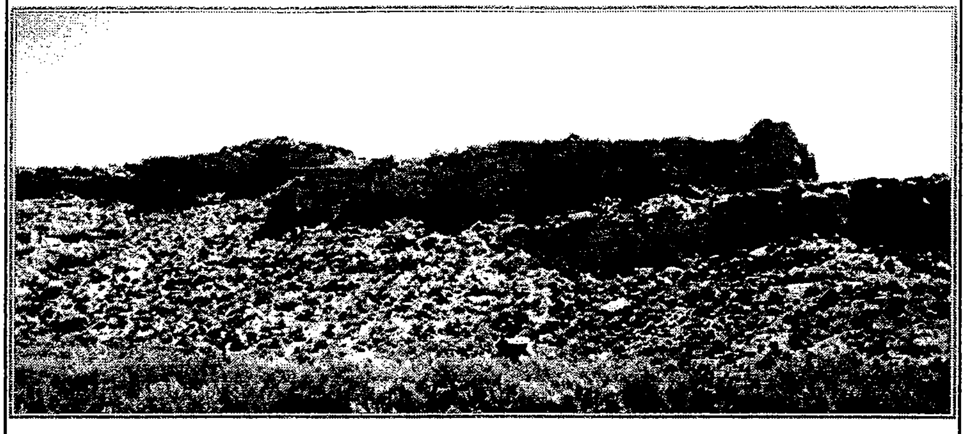


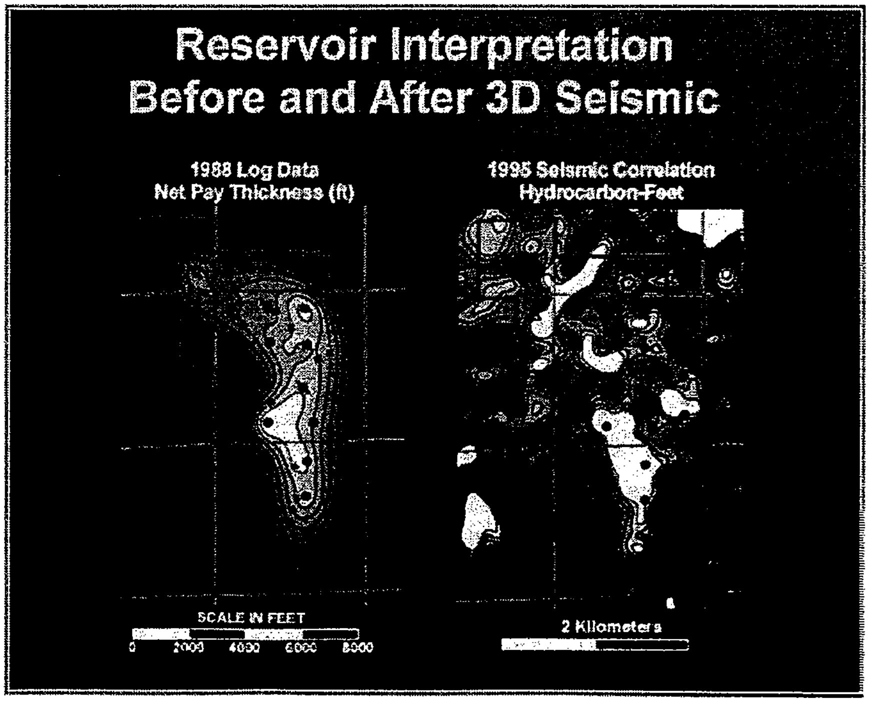
SINGLETON FIELD

RESERVOIR QUALITY PROFILE



J-I SANDSTONE LENSES





Reservoir Interpretation Before and After 3D Seismic

1988 Log Data
Net Pay Thickness (ft)

1995 Seismic Correlation
Hydrocarbon-Feet

ECONOMICS

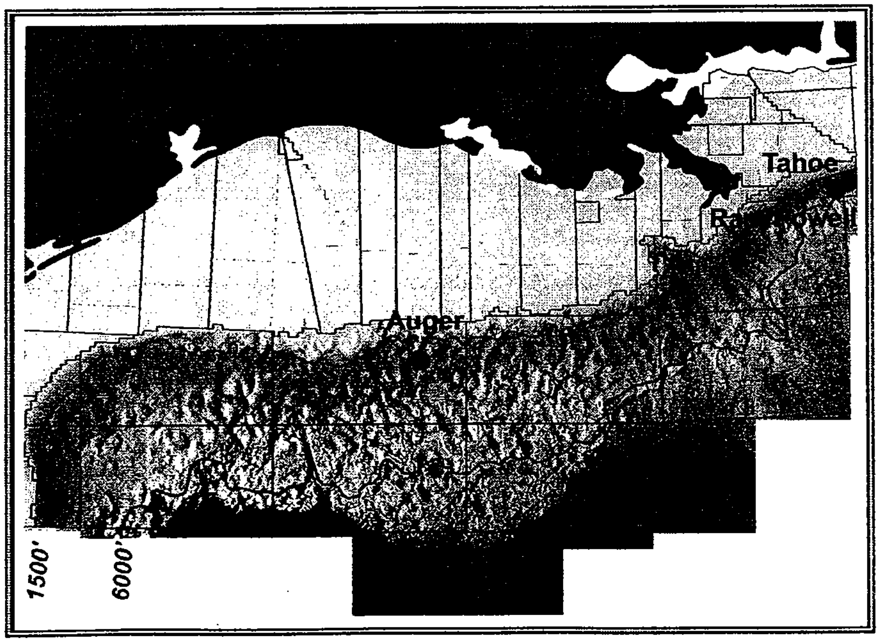
TARGETED VS BLANKET INFILL DRILLING

• 8 Targeted Wells	• 20 Infill Wells
• 640,0000 bbl	• 768,000 bbl
• 9% of OOIP	• 11% of OOIP
• $1,800,000 Cap Ex	• $4,500,000 Cap Ex
• $1,902,000 LOE	• $3,262,000 LOE
• $5,068,000 Profit	• $2,788,000 Profit

$2,280,000 Incremental

3D Seismic Cost $250,000

$17.00 per BBL $225,000 per Completed Well

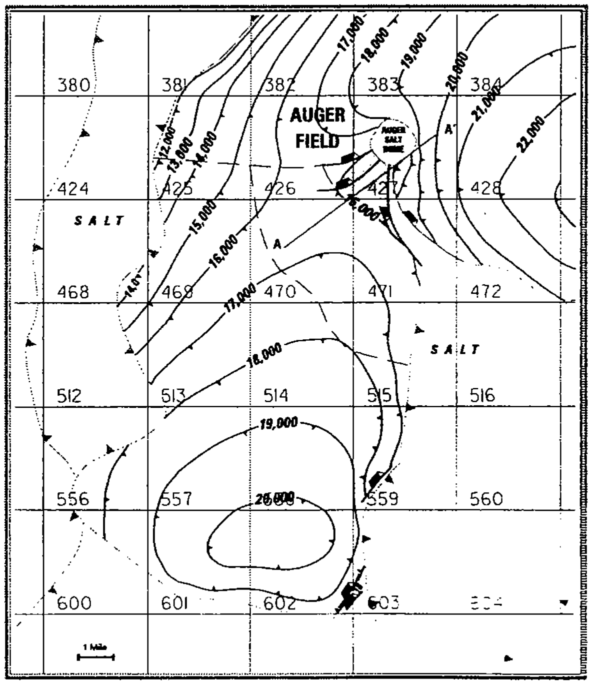


(Kendrick, 2000)

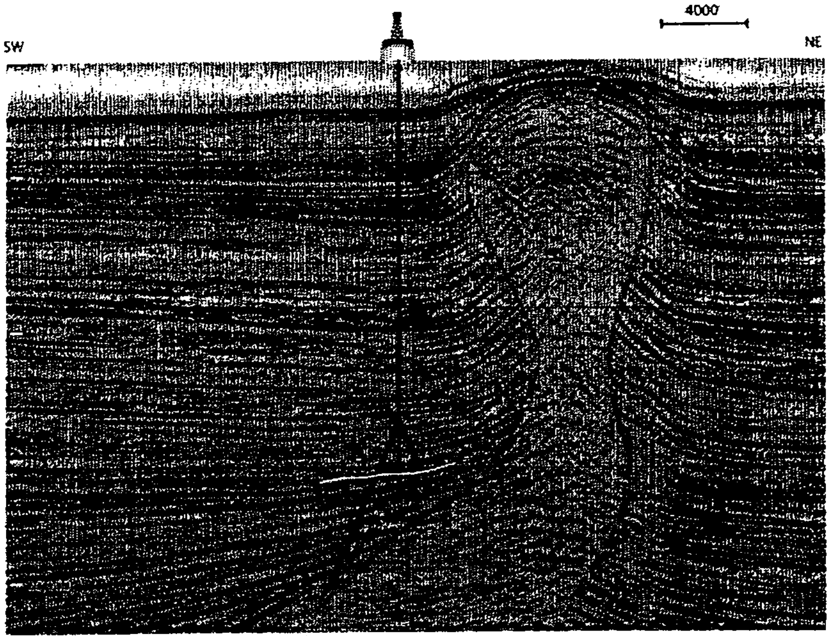
- ***S Sand, Auger Field; Gulf of Mexico***

-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??

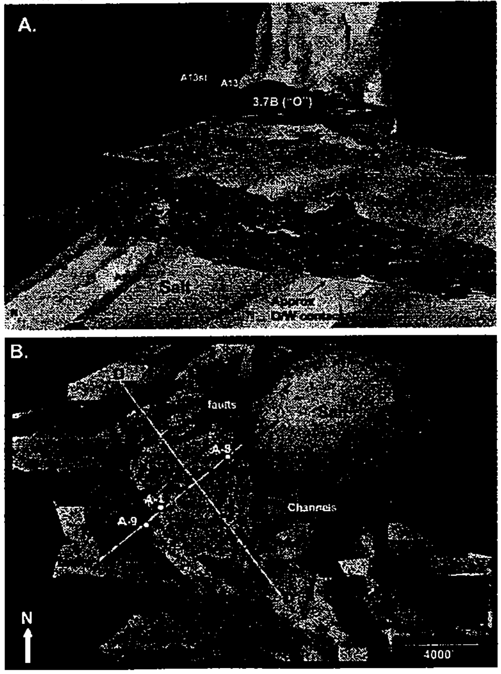
(Kendrick, 2000)



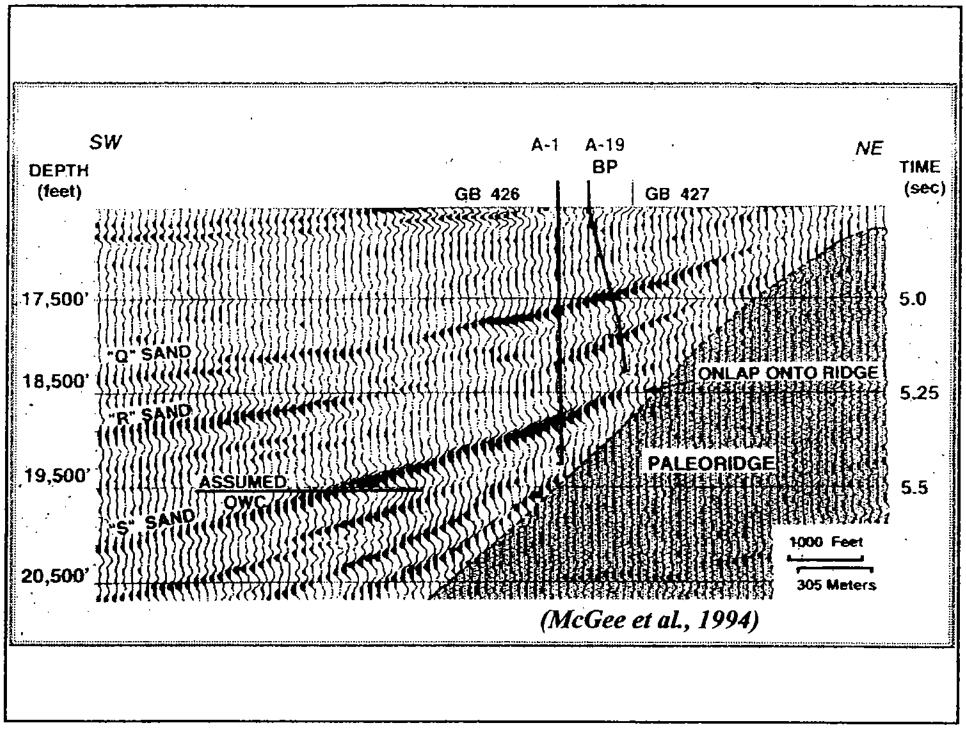
(Kendrick, 2000)



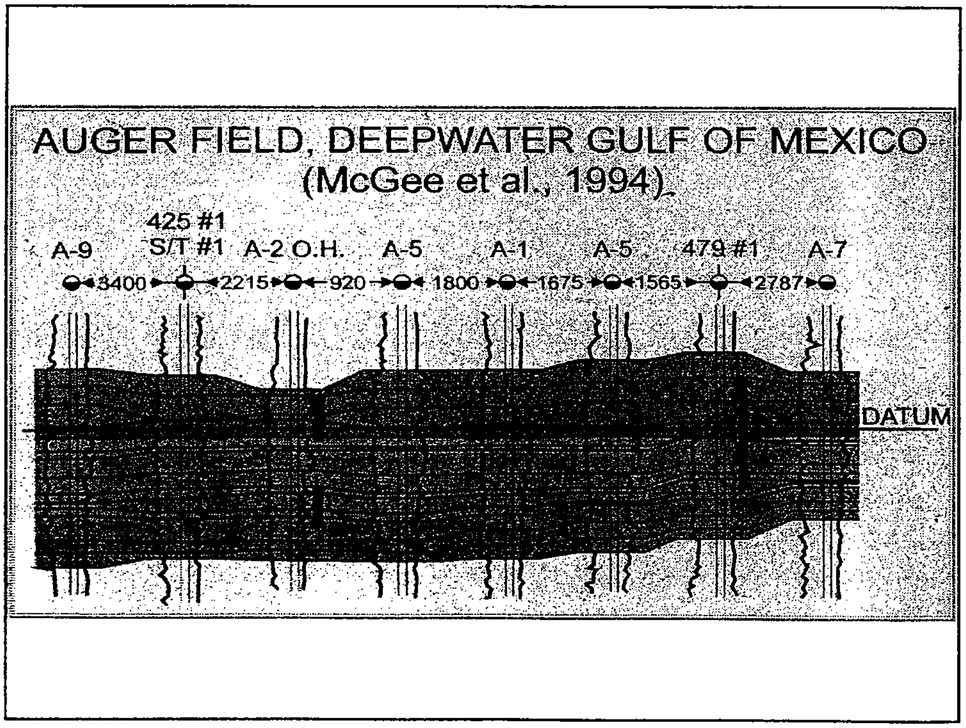
(Kendrick, 2000)



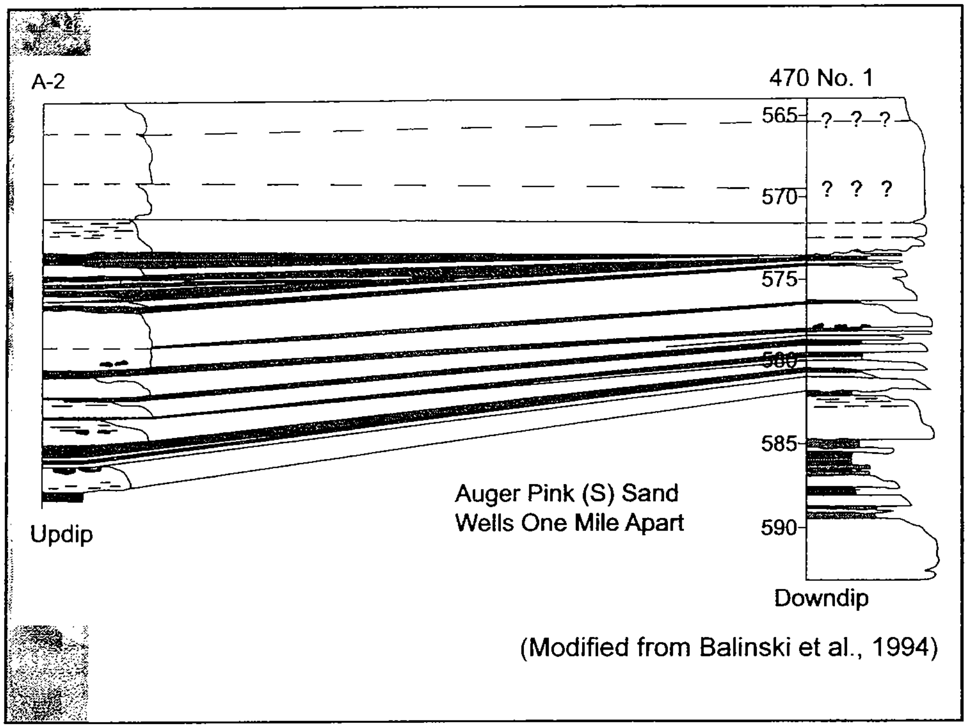
(Booth et al., 2000)



(McGee et al., 1994)

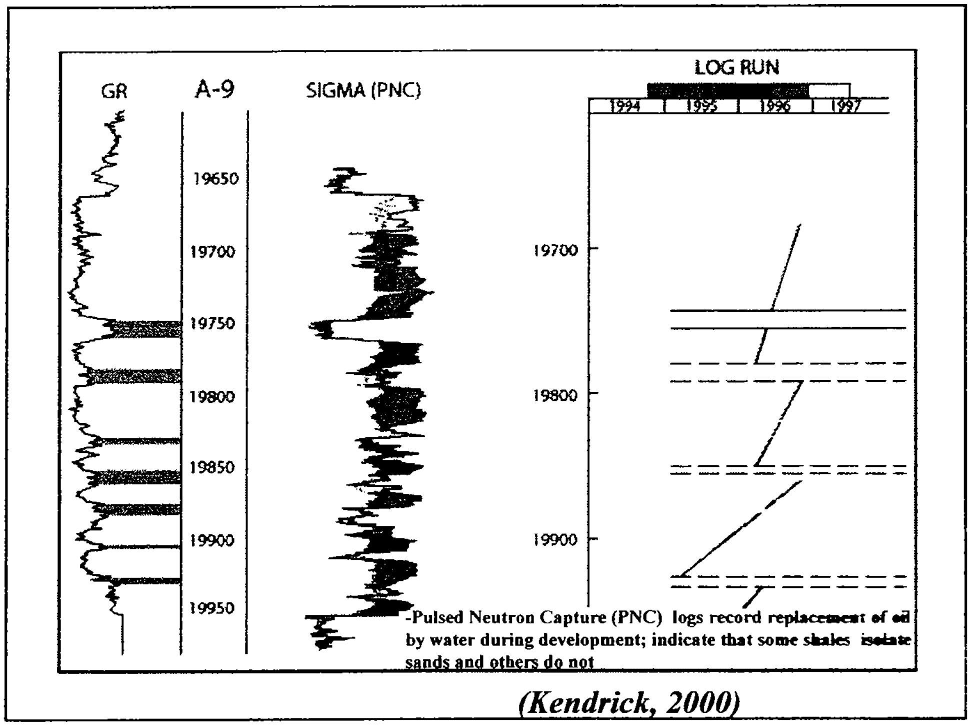


AUGER FIELD, DEEPWATER GULF OF MEXICO (McGee et al., 1994)



Auger Pink (S) Sand
Wells One Mile Apart

(Modified from Balinski et al., 1994)



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(Kendrick, 2000)

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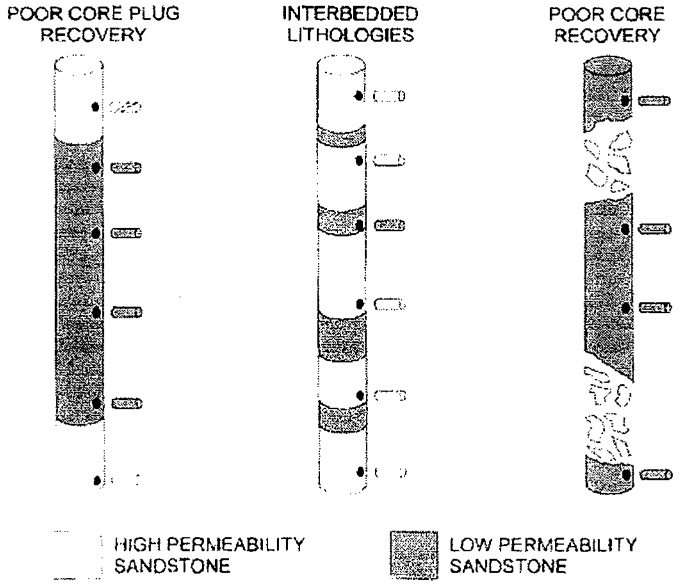
GEOLOGIC CONTROLS ON POROSITY AND PERMEABILITY

LESSONS LEARNED

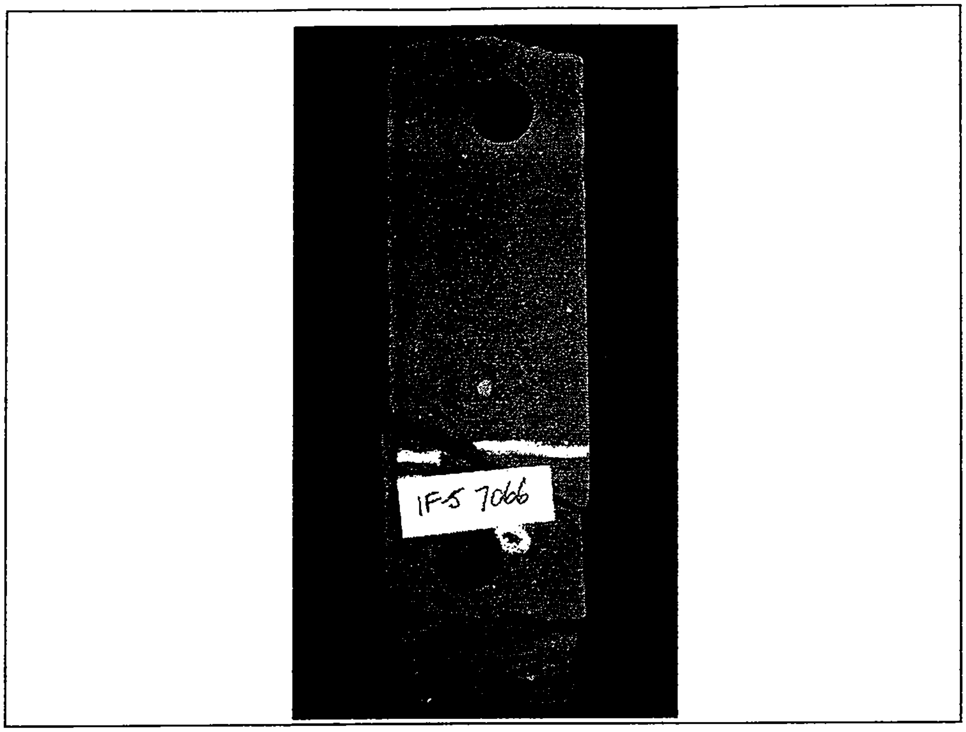
- KNOW HOW MEASUREMENTS ARE MADE;
- POROSITY & PERMEABILITY ARE CONTROLLED BY GRAIN SIZE DIST. AND SED. PROCESSES;
- POROSITY AND PERMEABILITY ARE MODIFIED BY DIAGENESIS, BUT USUALLY RETAIN ORIGINAL GRAIN SIZE VS. PORO./PERM RELATIONS;
- PERMEABILITY IS MORE SENSITIVE TO GRAIN SIZE VARIATIONS THAN IS POROSITY;
- GROSS INTERVAL POROSITY CAN BE MAPPED SEISMICALLY.

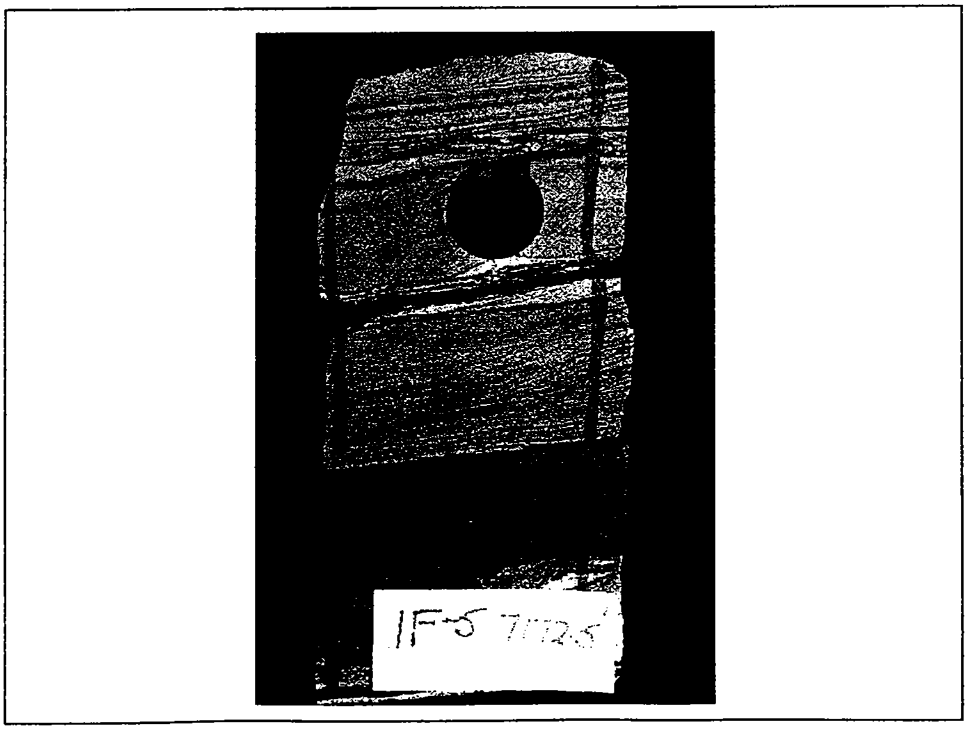
A WORD ABOUT HOW THE MEASUREMENTS ARE MADE

CORE PLUG SAMPLING BIAS



Vavra & Kaldi


IF-5 7066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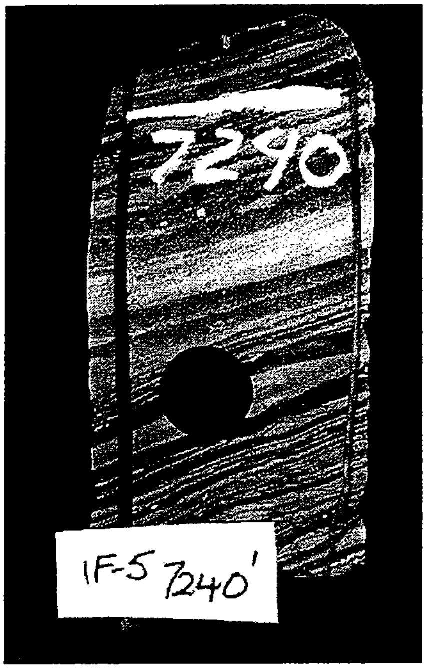
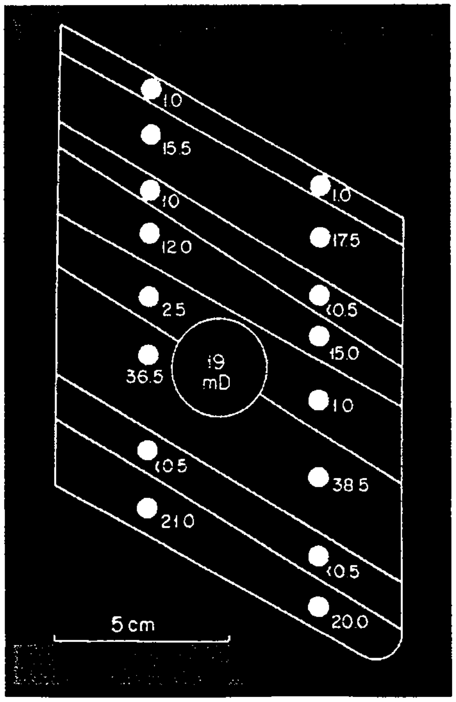
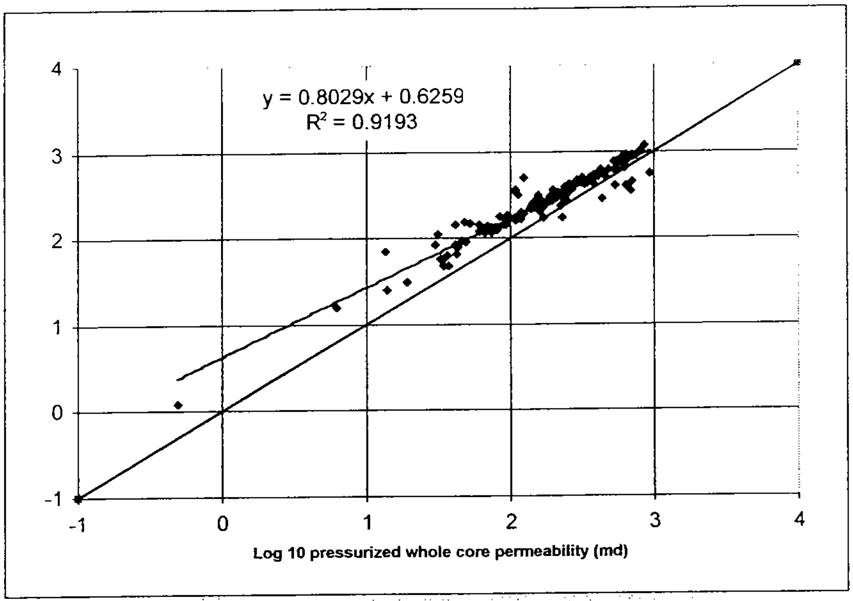


Pressure-decay mini-permeameter takes spot measurement of perm.





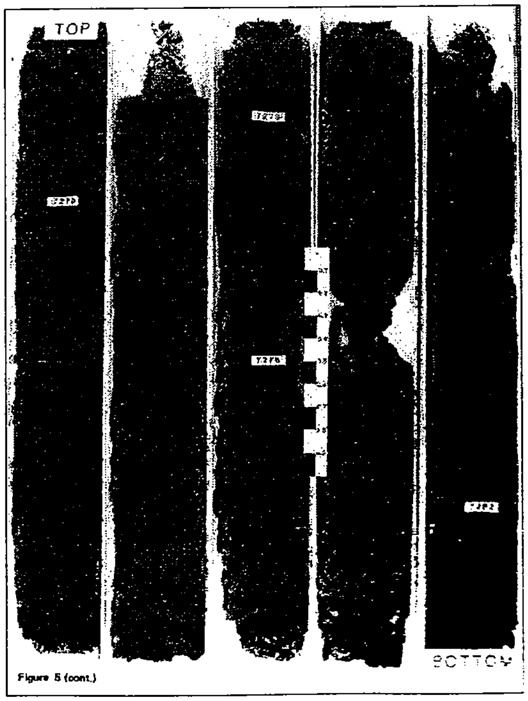
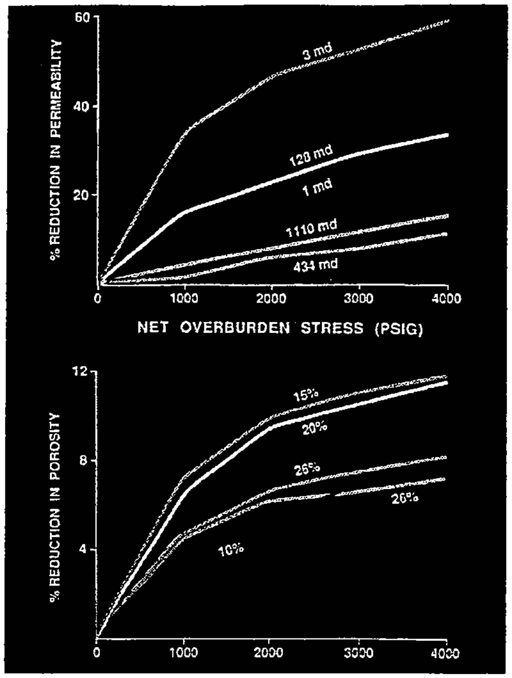
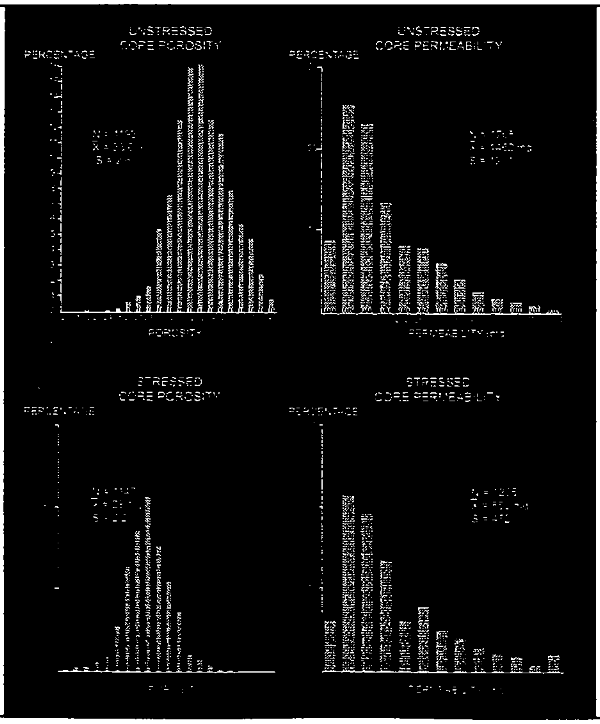


Figure 5 (cont.)


% REDUCTION IN PERMEABILITY
60
40
20
3 md
128 md
1 md
1110 md
434 md
0
1000
2000
3000
4000
NET OVERBURDEN STRESS (PSIG)
% REDUCTION IN POROSITY
12
8
4
15%
20%
26%
28%
10%
0
1000
2000
3000
4000


UNSTRESSED
CORE POROSITY
PERCENTAGE
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CORE PERMEABILITY
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GRAIN-SIZE CONTROL ON POROSITY & PERMEABILITY

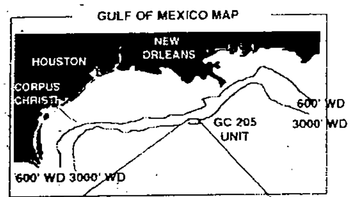


Figure 1 - Green Canyon 205 Unit location in the North Central Gulf of Mexico.

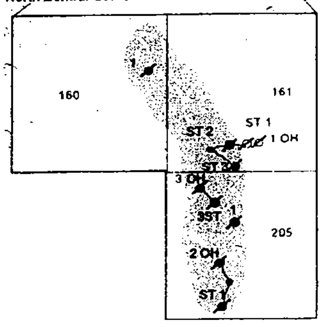


Figure 2 - Productive area (shaded) and exploration delineation well locations within the three block GC 205 Unit

(REEDY & PEPPER. 1996)

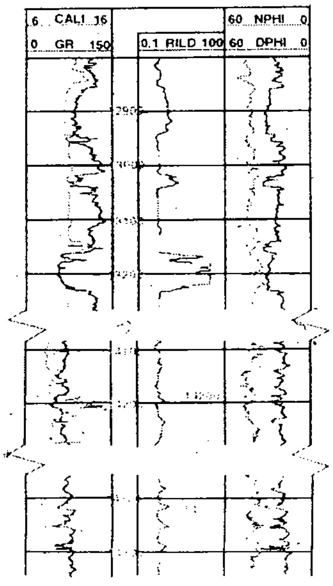
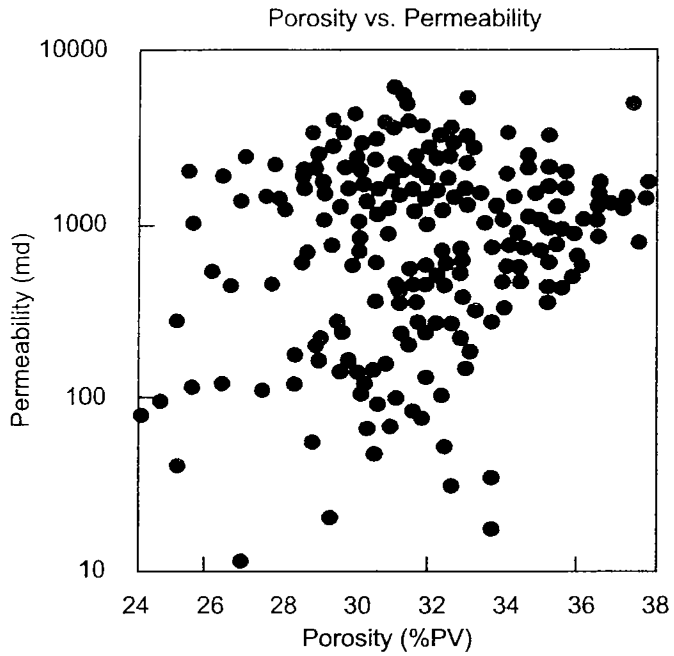
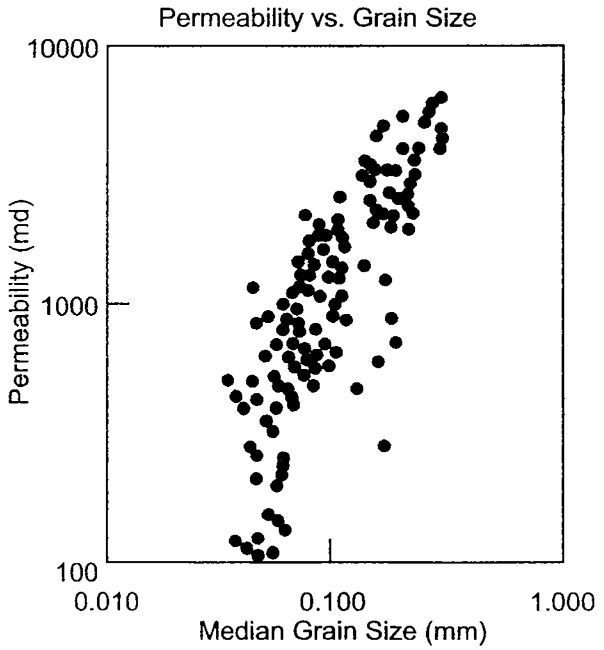


Figure 3 - Well logs from the GC 205 #1 discovery well showing five of the recognized productive sands (Arrows indentify the depths for the core photographs in Figure 4.)



Porosity vs. Permeability

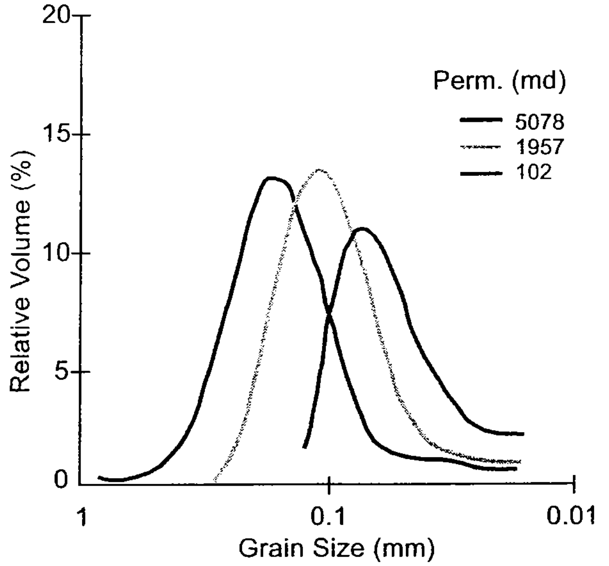
(Reedy & Pepper, 1996)



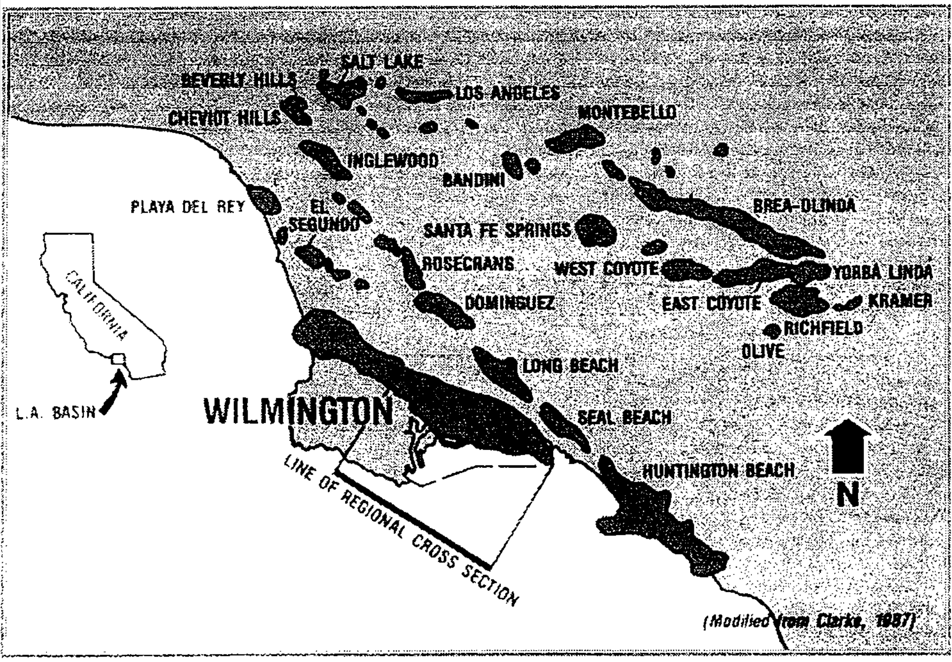
Permeability vs. Grain Size

(Reedy & Pepper, 1996)

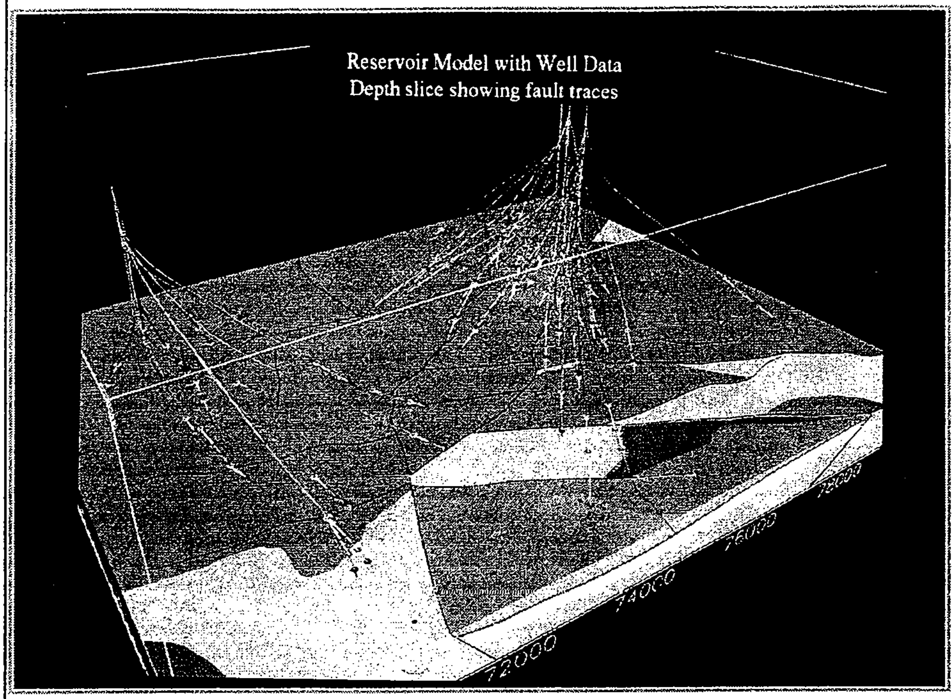
Laser Particle Size Distributions GC 205 #3 ST1 Well



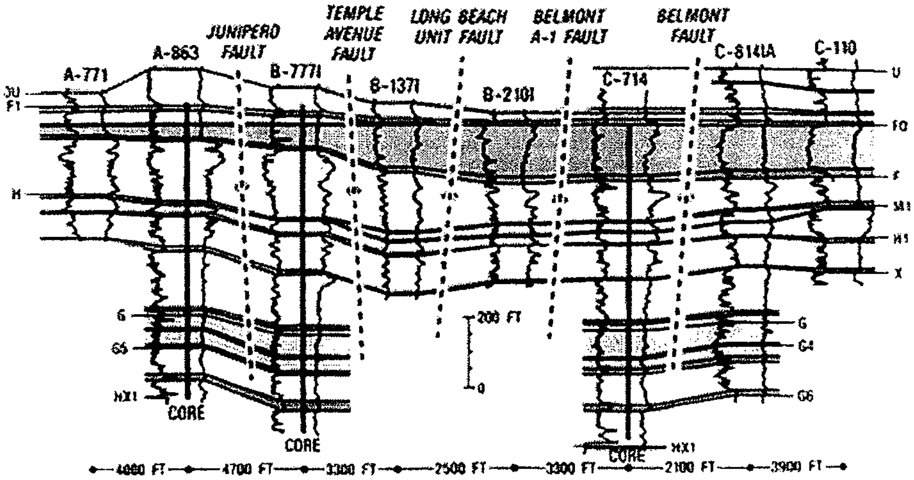
(modified from Reedy and Pepper, 1996)

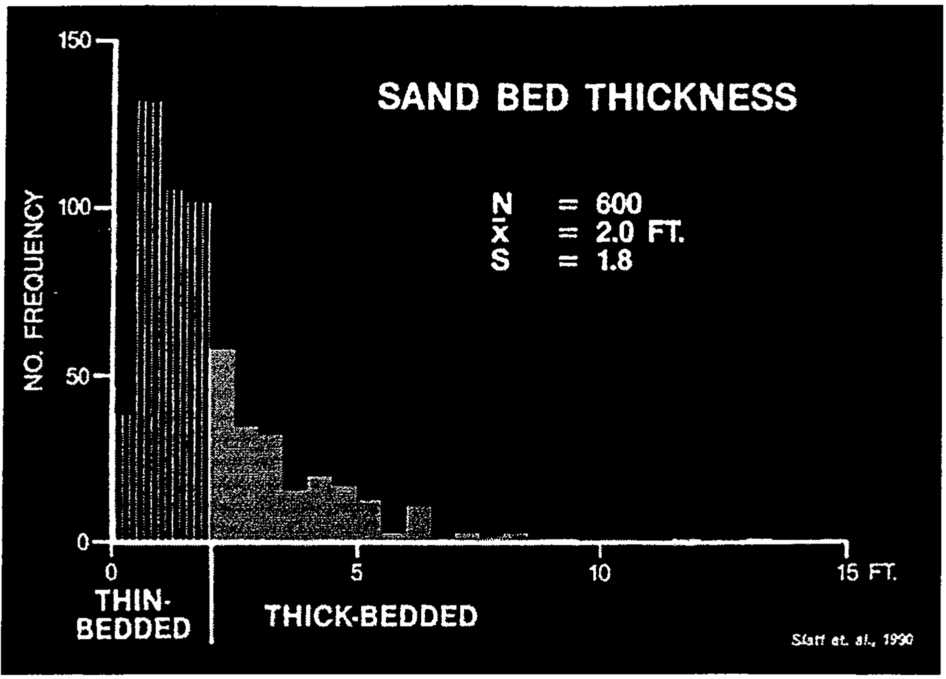


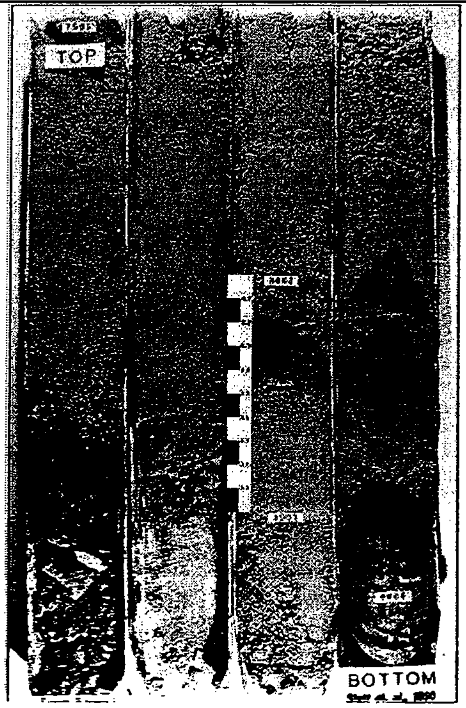
Reservoir Model with Well Data
Depth slice showing fault traces



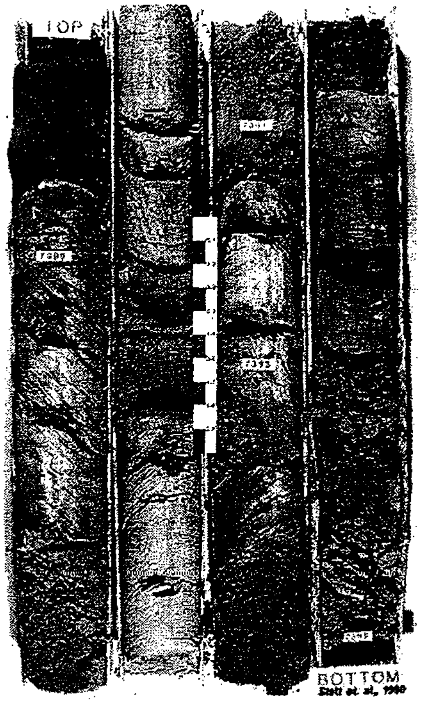
E-W REGIONAL CROSS SECTION



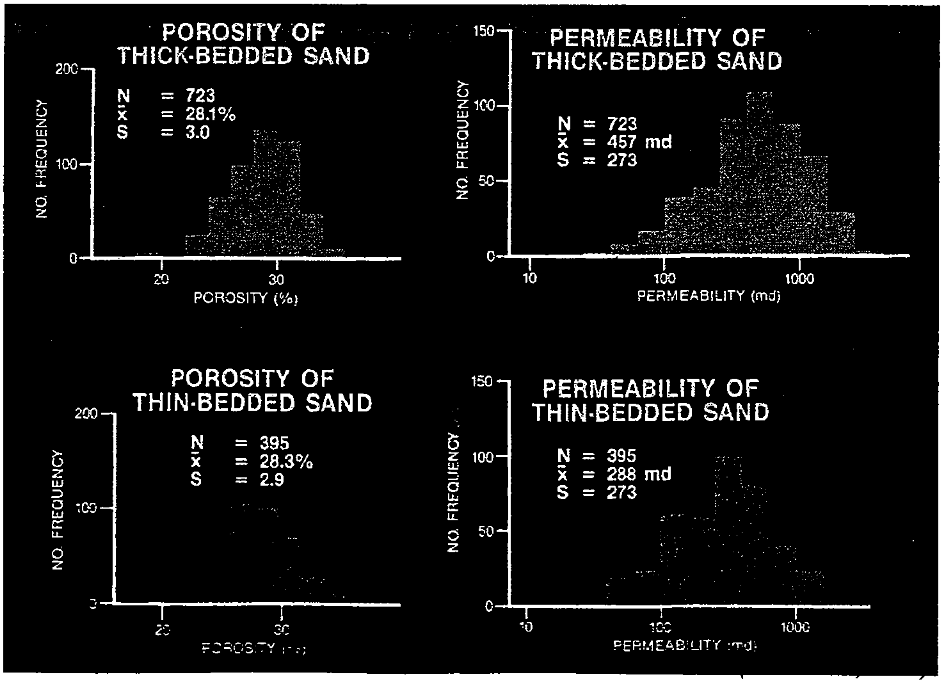


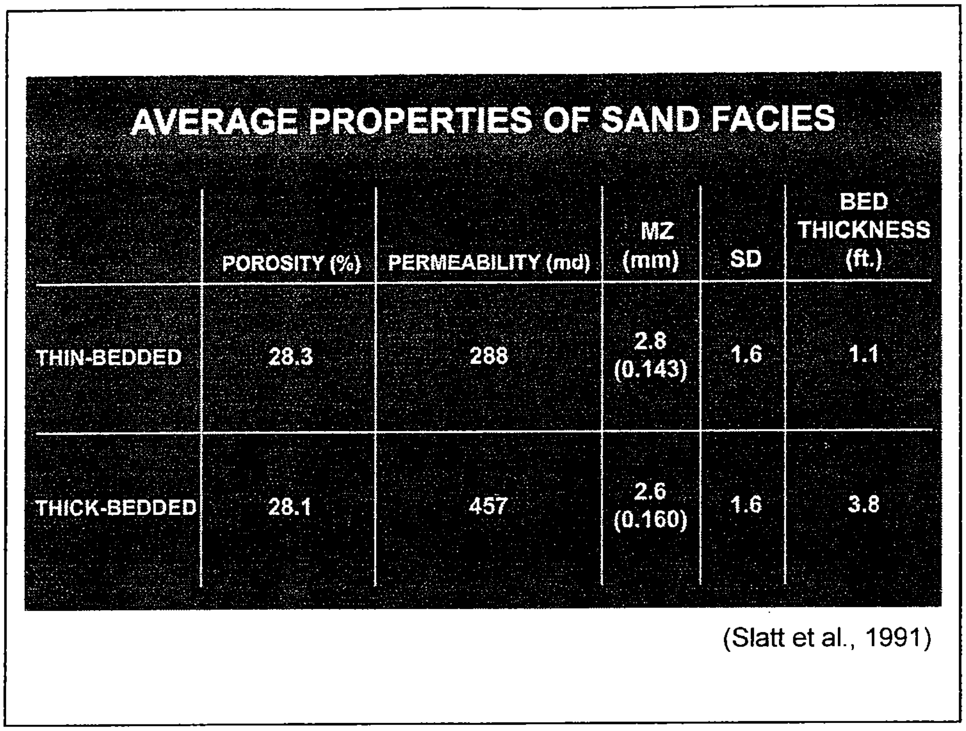


(Slatt et al., 1990)



(Slatt et al., 1990)

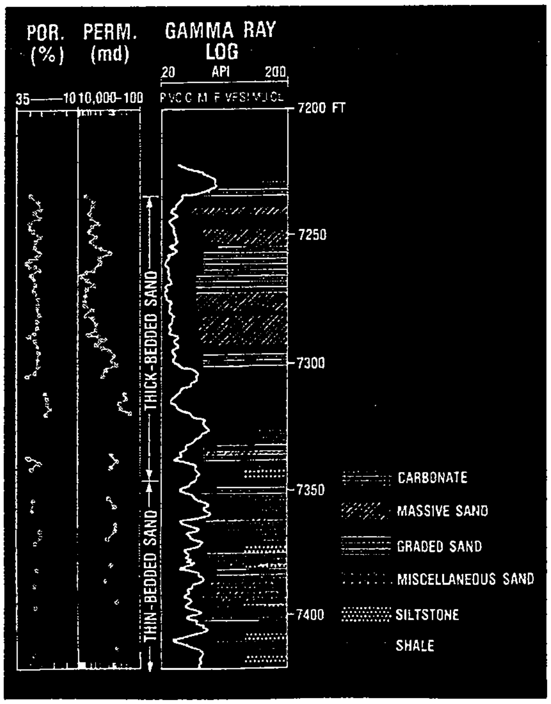


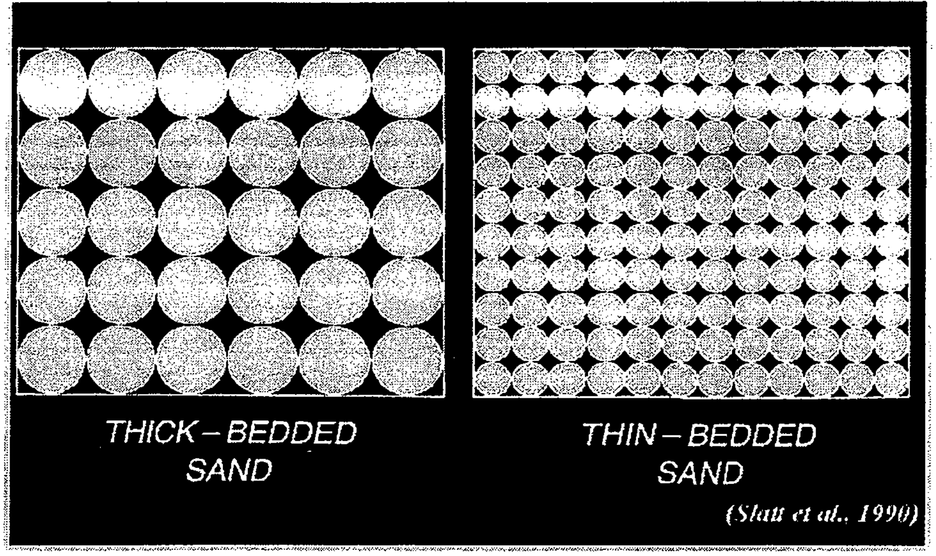


AVERAGE PROPERTIES OF SAND FACIES

	POROSITY (%)	PERMEABILITY (md)	MZ (mm)	SD	BED THICKNESS (ft.)
THIN-BEDDED	28.3	288	2.8 (0.143)	1.6	1.1
THICK-BEDDED	28.1	457	2.6 (0.160)	1.6	3.8

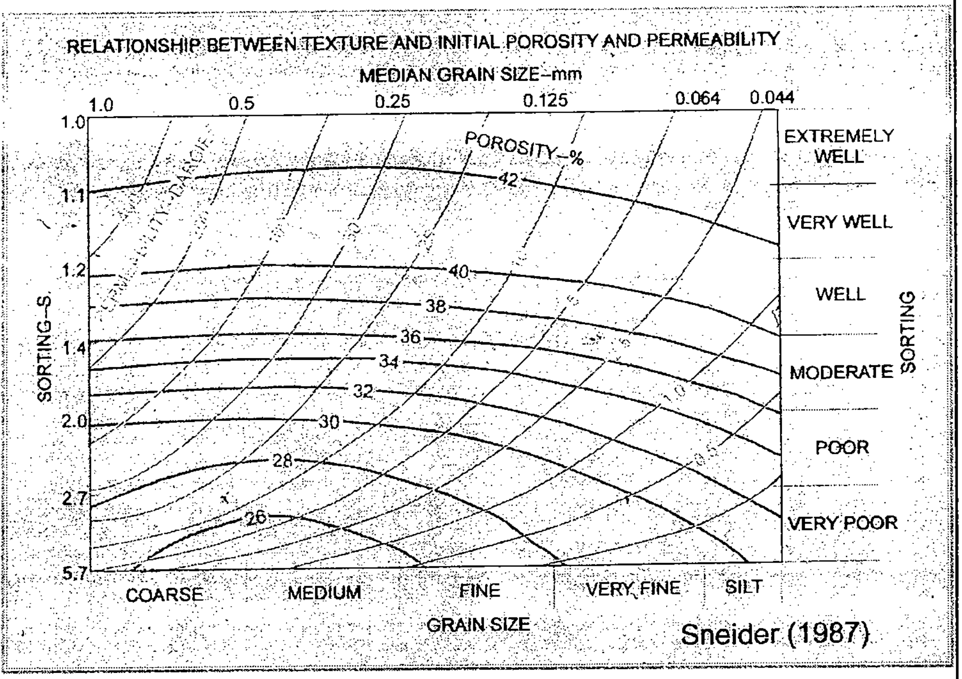
(Slatt et al., 1991)





Yellow = grains
Purple = pores

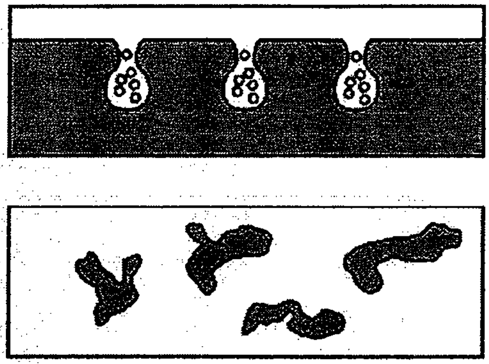
The two areas are equal



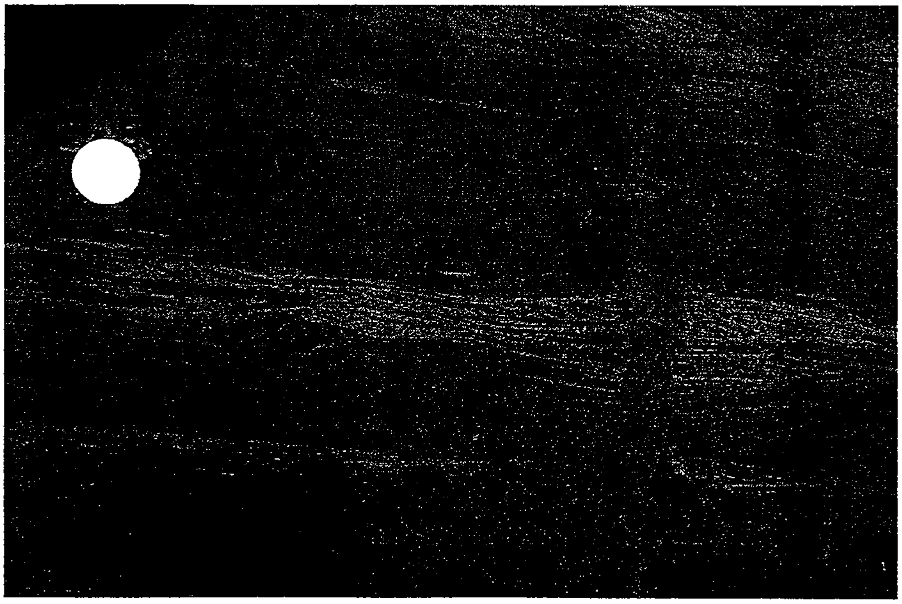
Sneider (1987)

BURROWING ORGANISMS AFFECT POROSITY-PERM.

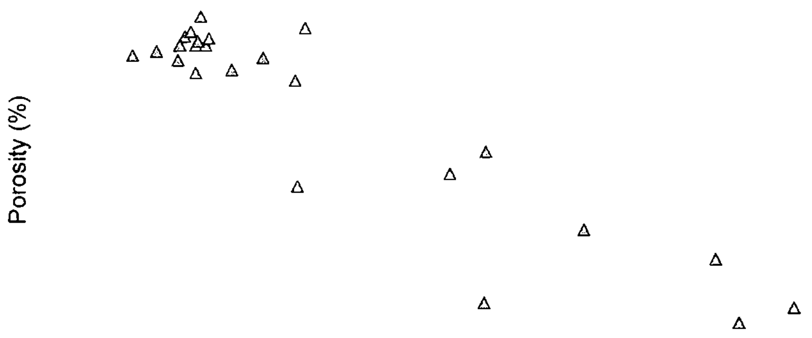
Biogenic Structures can increase or decrease K

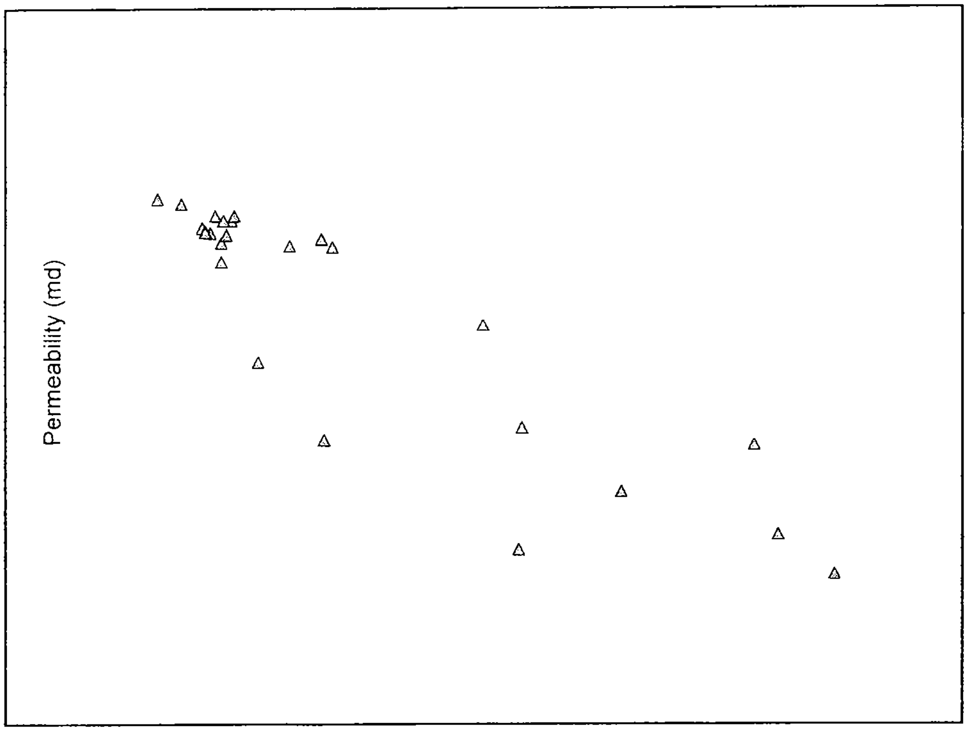


Pemberton (1999)



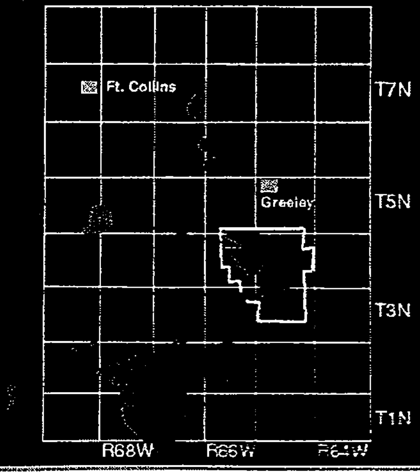
POST-DEPOSITIONAL BURIAL COMPACTION & CEMENTATION REDUCE POROSITY-PERMEABILITY

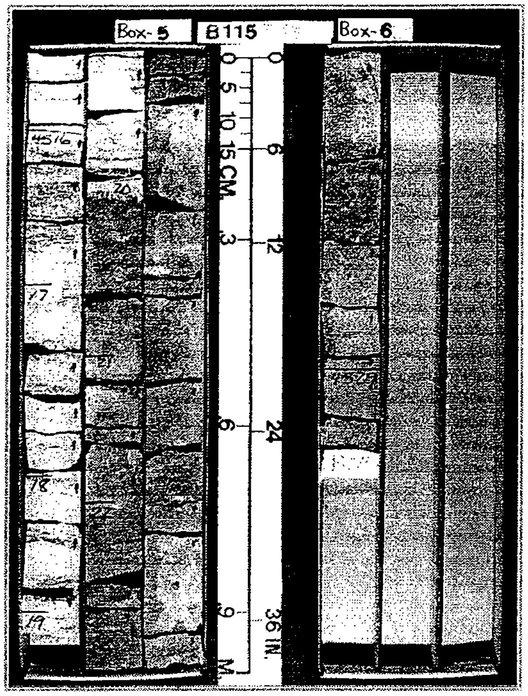


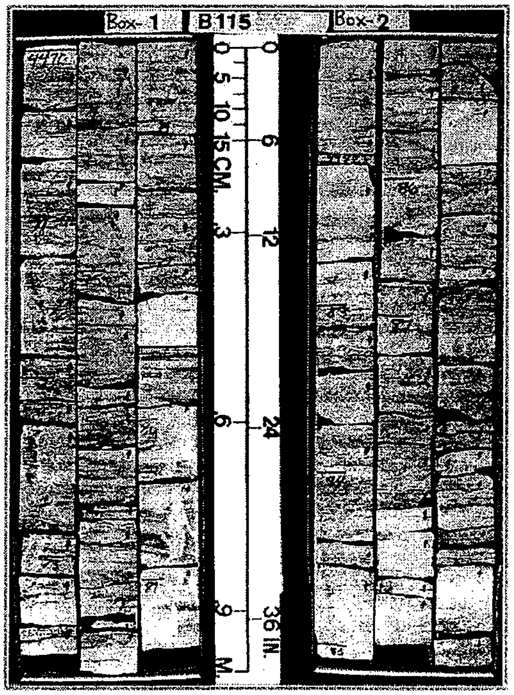


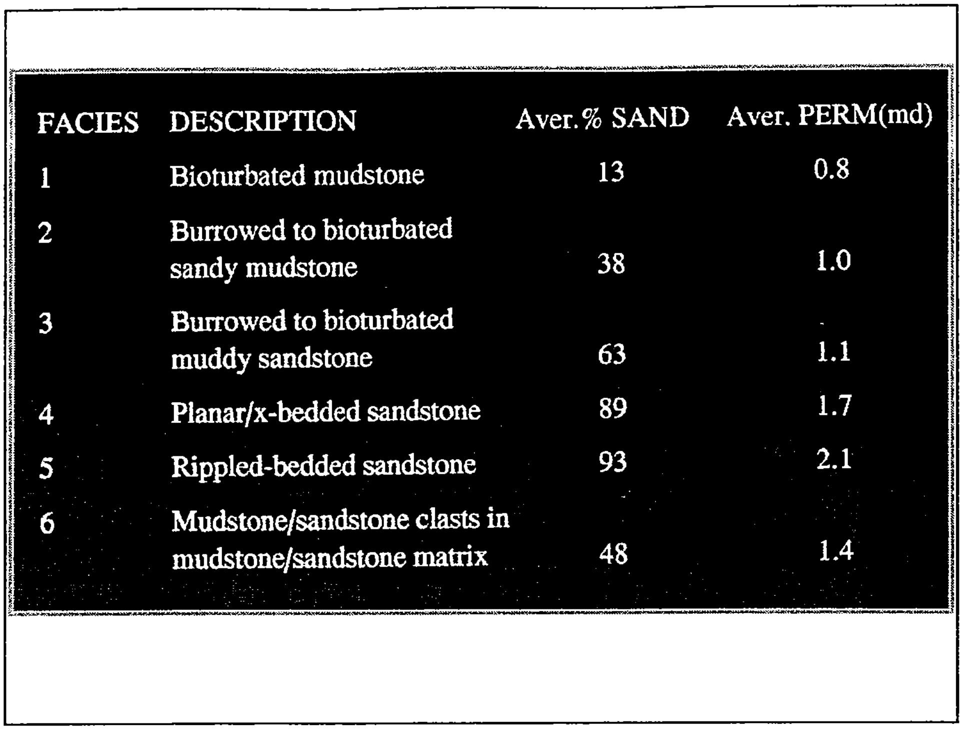
Hambert Field

Aristocrat Field

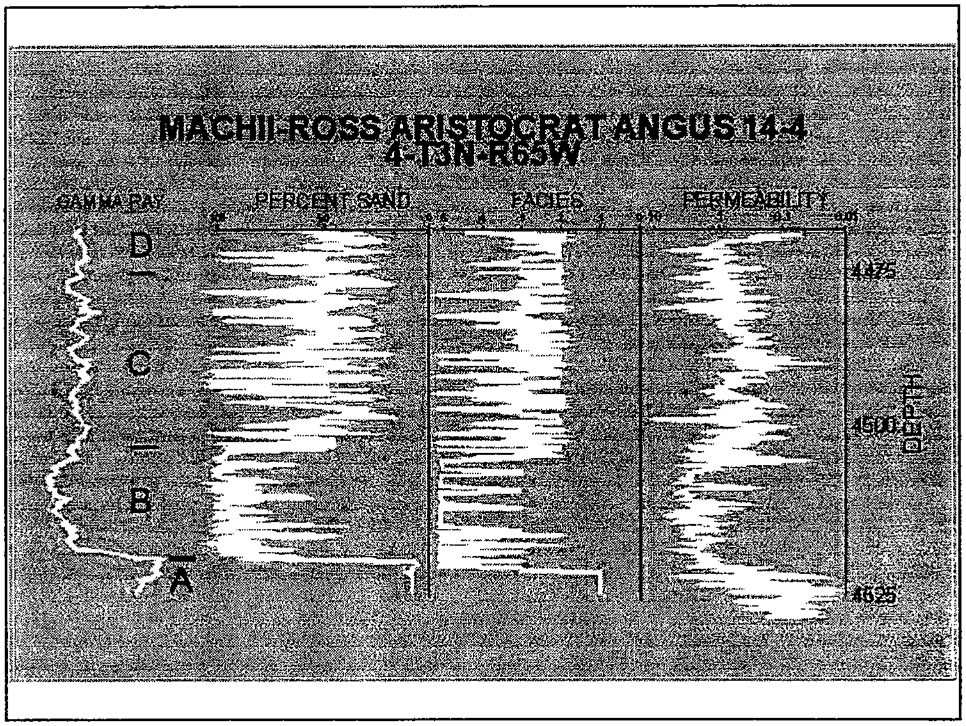



Box-5
B115
Box-6
0 5 10 15 CM.
0 6 12 24 36 IN.
3
6
9
4576
77
78
79
20
21
22

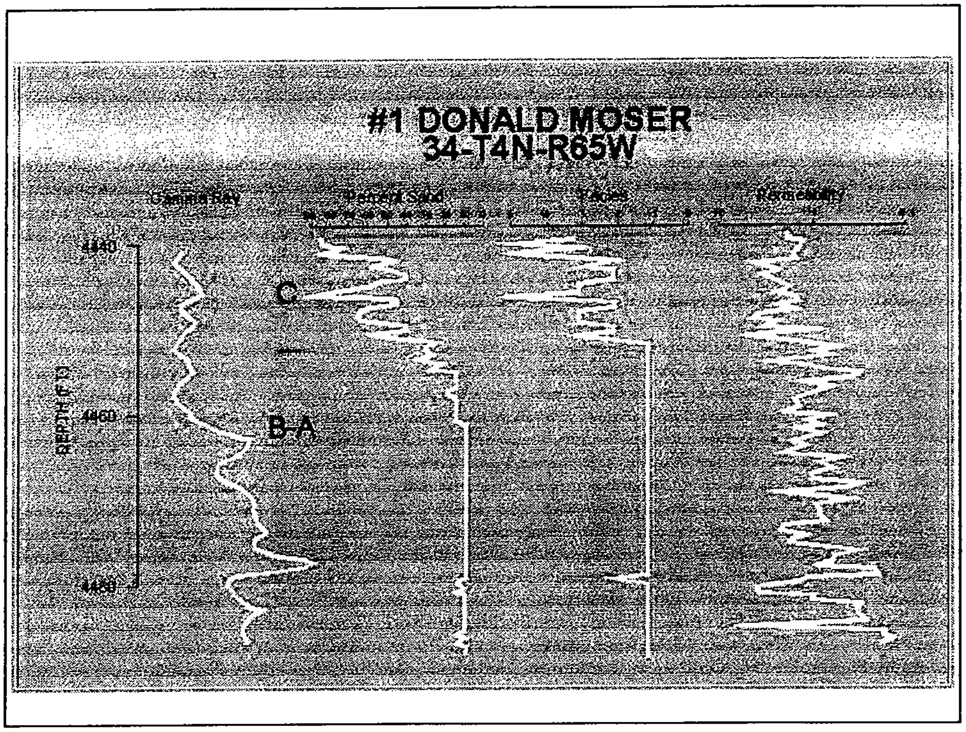

Box-1
B115
Box-2
0 5 10 15 CM.
0 6 12 24 36 IN.
3
6
9
4470



FACIES	DESCRIPTION	Aver.% SAND	Aver. PERM(md)
1	Bioturbated mudstone	13	0.8
2	Burrowed to bioturbated sandy mudstone	38	1.0
3	Burrowed to bioturbated muddy sandstone	63	1.1
4	Planar/x-bedded sandstone	89	1.7
5	Rippled-bedded sandstone	93	2.1
6	Mudstone/sandstone clasts in mudstone/sandstone matrix	48	1.4

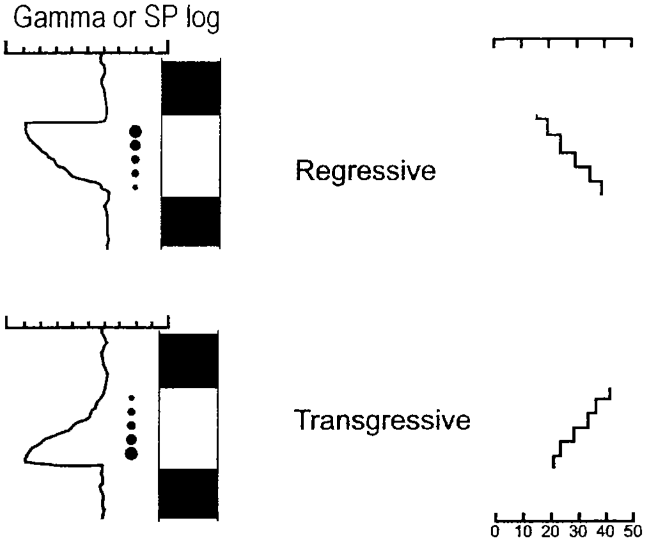


MACHII-ROSS ARISTOCRAT ANGUS 14-4
4-T3N-R65W



#1 DONALD MOSER
34-T4N-R65W

APPLICATION OF KNOWING POROSITY & PERMEABILITY DISTRIBUTION



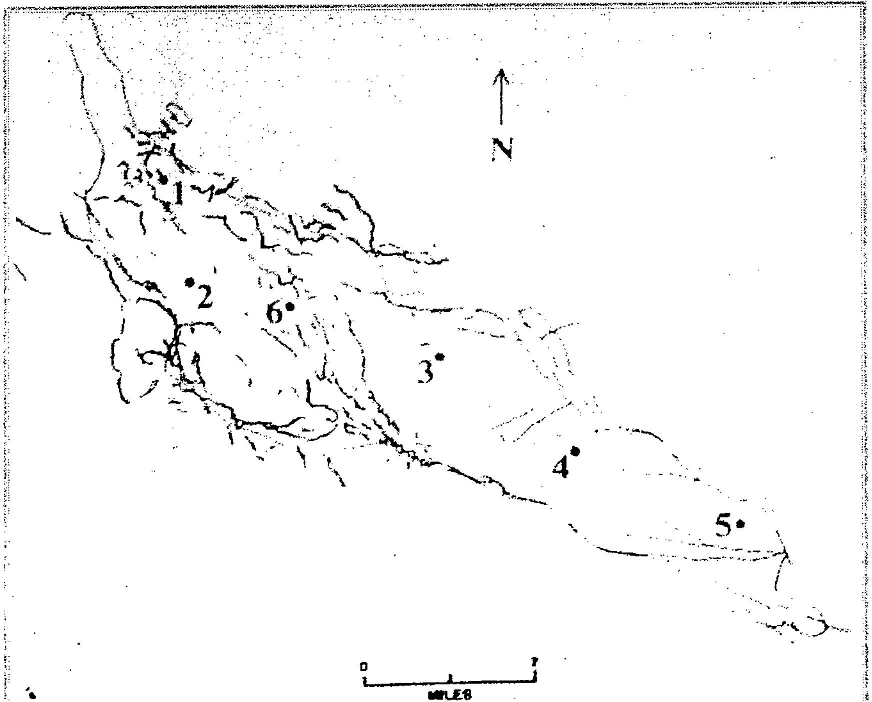
Black dots refer to
relative grain-size
of sands at each strat.
level

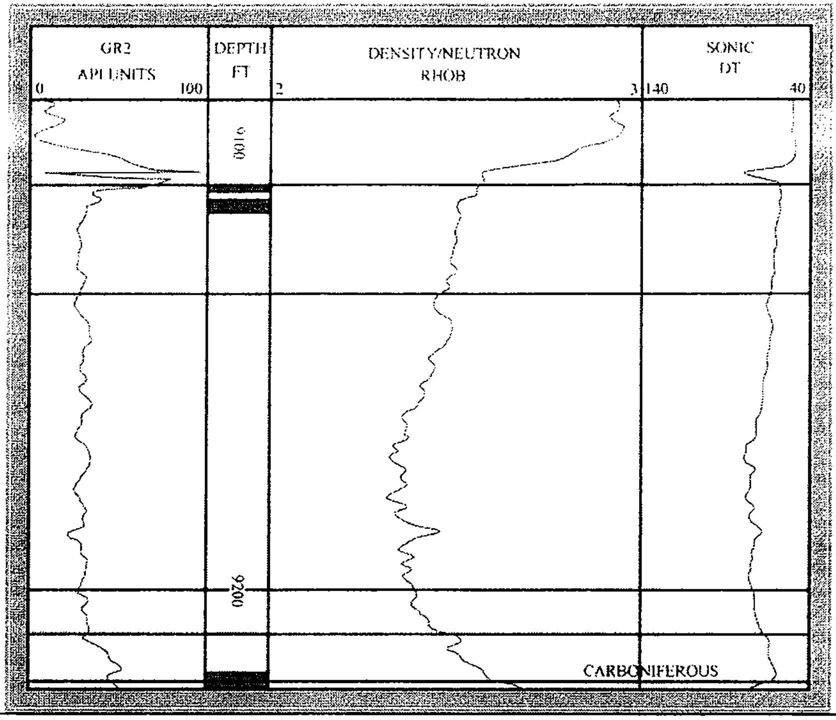
Oil saturation (%)

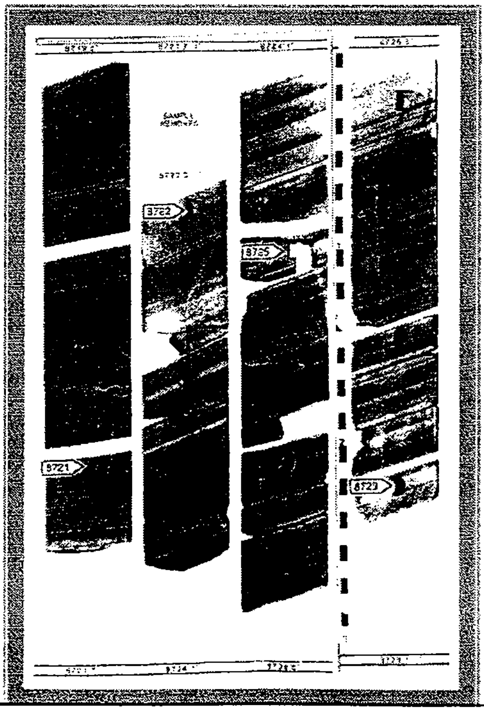
Remaining oil saturation after waterflood

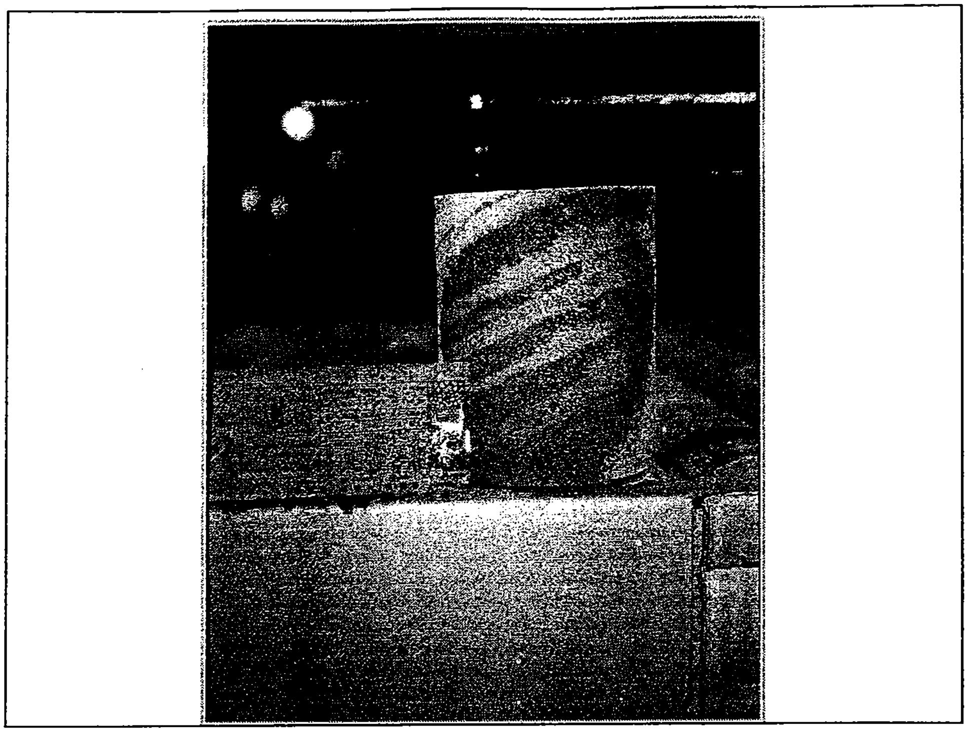
SEISMIC POROSITY DETECTION

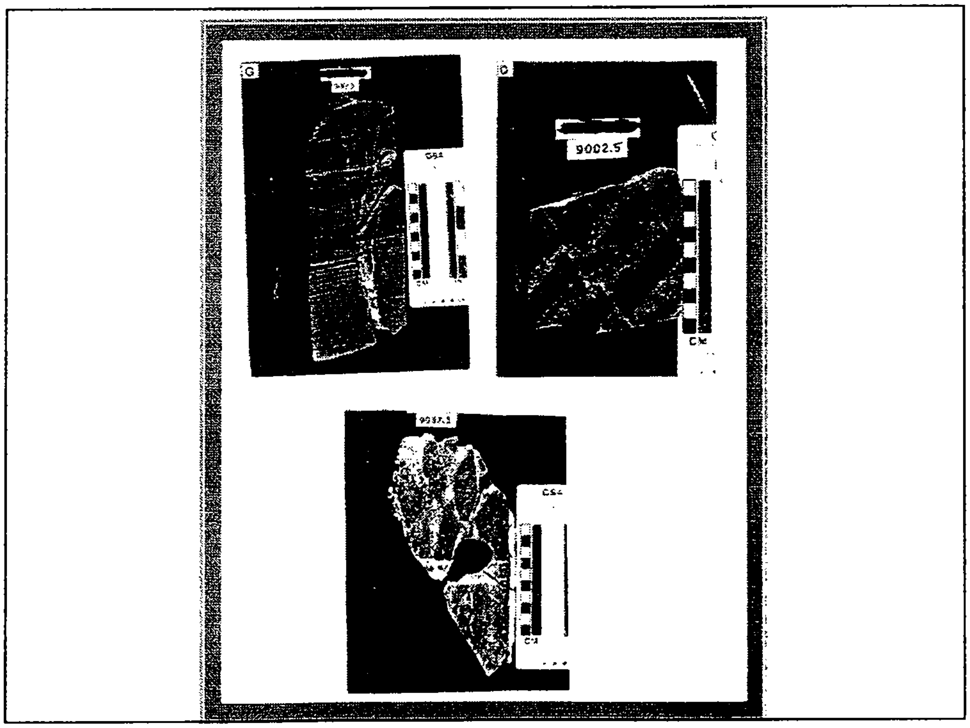

RAVENSPURN
CLEETON
ROUGH
WEST SOLE
AMETHYST
AUDREY
VIKING
PICKERILL
SOLE PIT
INDEFATIGABLE
SEAN
VULCAN
HEWETT
THAMES
LEMAN
BACTON
England
0 10 20 30 40 Miles
0 10 20 30 40 50 60 Kms

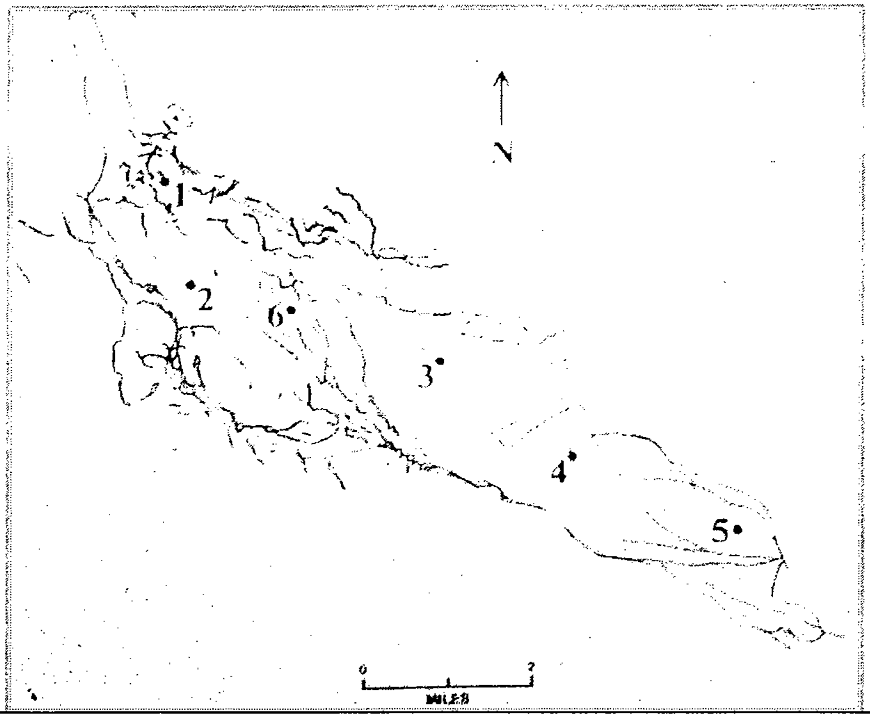

N
1
2
6
3
4
5
0
2
MILES


GR2
API UNITS
0
100
DEPTH
FT
9100
9200
DENSITY/NEUTRON
RHOB
2
3
SONIC
DT
140
40
CARBONIFEROUS


SAMPLE REMOVED
8722
8725
8721
8723




G
CS4
C
9002.5
9037.1
CS4



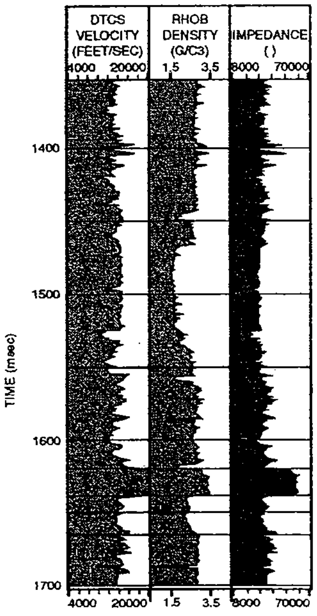
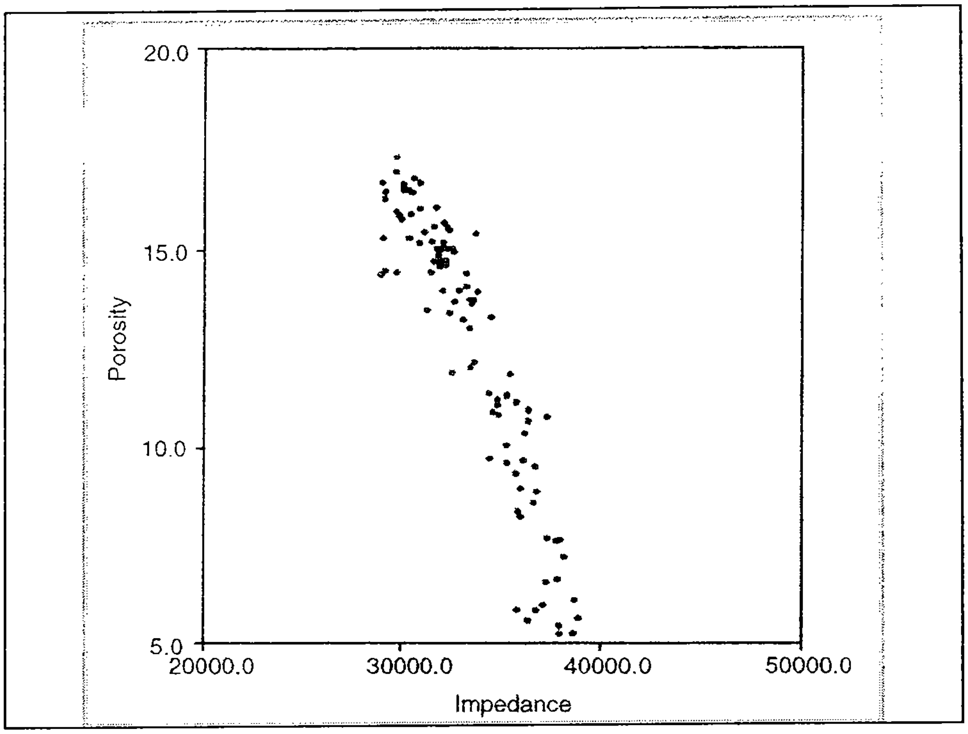
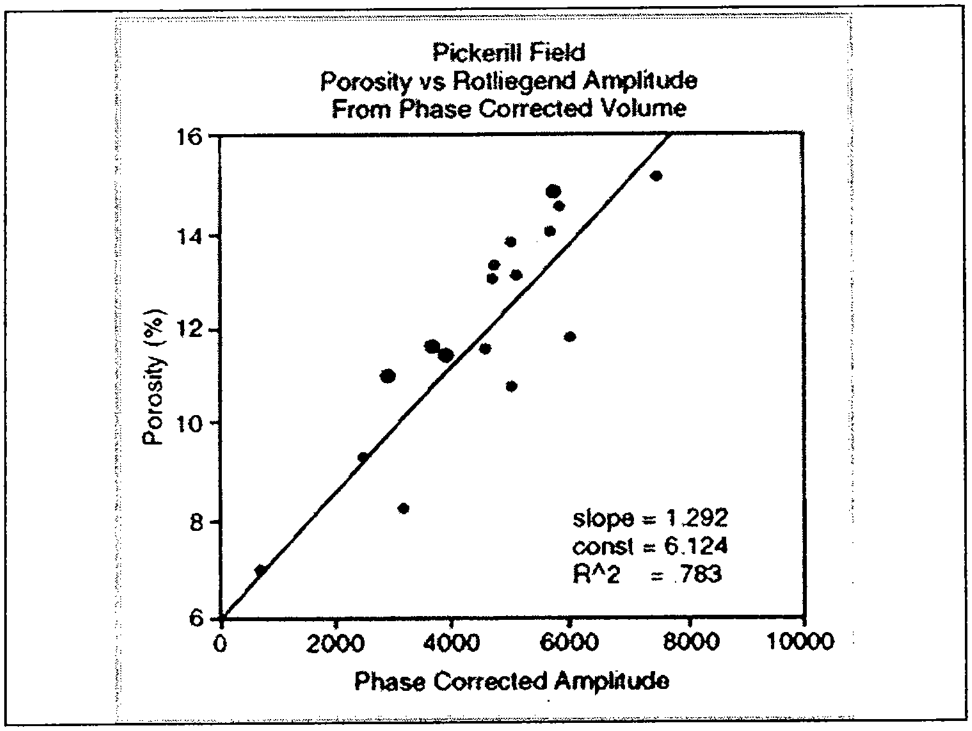


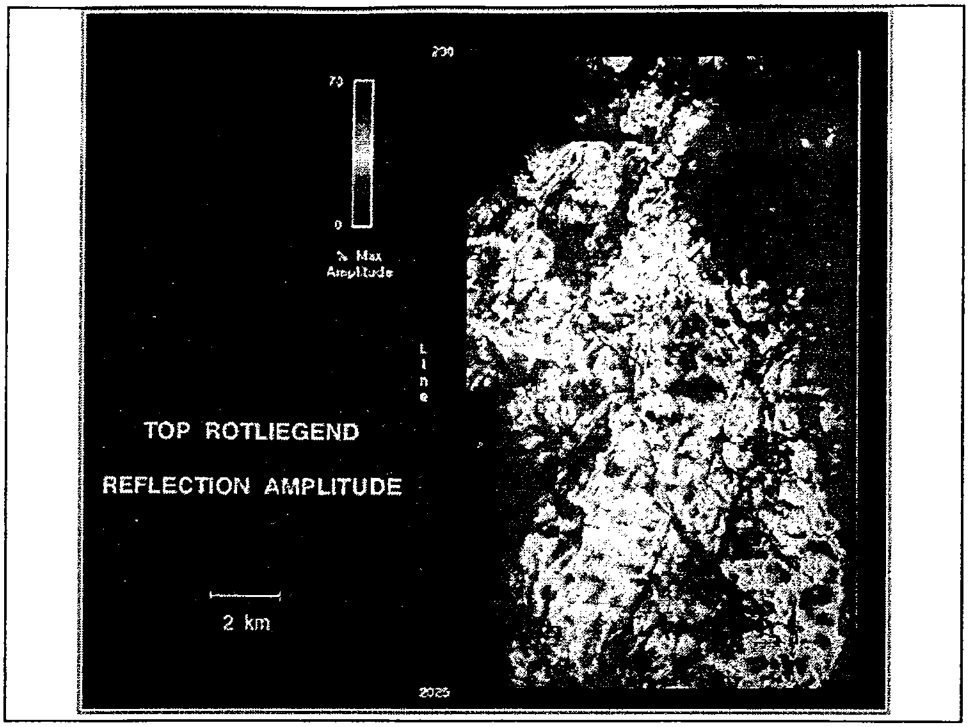
FIGURE 20. A typical suite of logs from one of the exploration wells in the Pickerill field.



20.0
15.0
10.0
5.0
Porosity
20000.0
30000.0
40000.0
50000.0
Impedance

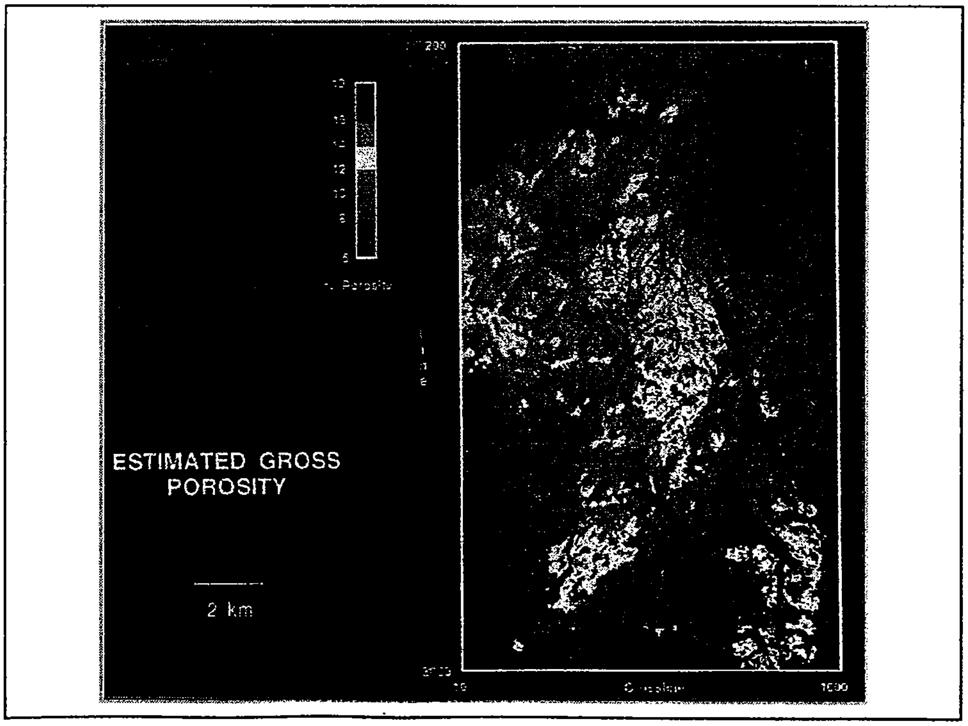


Pickerill Field
Porosity vs Rotliegend Amplitude
From Phase Corrected Volume
16
14
12
10
8
6
Porosity (%)
0
2000
4000
6000
8000
10000
Phase Corrected Amplitude
slope = 1.292
const = 6.124
R^2 = .783



TOP ROTLIEGEND

REFLECTION AMPLITUDE



ESTIMATED GROSS
POROSITY

LESSONS LEARNED

- KNOW HOW MEASUREMENTS ARE MADE;
- POROSITY & PERMEABILITY ARE CONTROLLED BY GRAIN SIZE DIST. AND SED. PROCESSES;
- POROSITY AND PERMEABILITY ARE MODIFIED BY DIAGENESIS, BUT USUALLY RETAIN ORIGINAL GRAIN SIZE VS. PORO./PERM RELATIONS;
- PERMEABILITY IS MORE SENSITIVE TO GRAIN SIZE VARIATIONS THAN IS POROSITY;
- GROSS INTERVAL POROSITY CAN BE MAPPED SEISMICALLY.

APPLIED RESERVOIR CHARACTERIZATION FOR THE INDEPENDENT OPERATOR: WITH EMPHASIS ON COMPARTMENTALIZED RESERVOIRS AND ROUTINE TECHNIQUES FOR DETECTING COMPARTMENTS

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UNIT 12: DIPMETER LOGS AND APPLICATIONS

UNIT 13: STRUCTURALLY COMPARTMENTALIZED RESERVOIRS

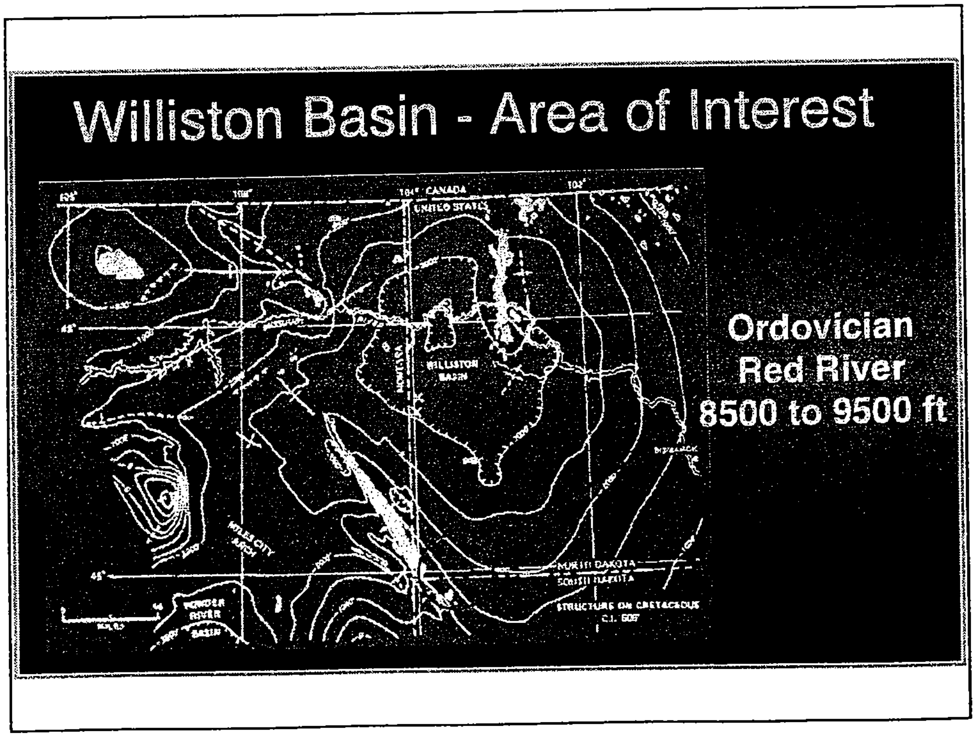
KEY REFERENCES TO INDIVIDUAL UNITS

CARBONATE POROSITY DETECTION FROM 3D SEISMIC:

ORDOVICIAN RED RIVER, WILLISTON BASIN

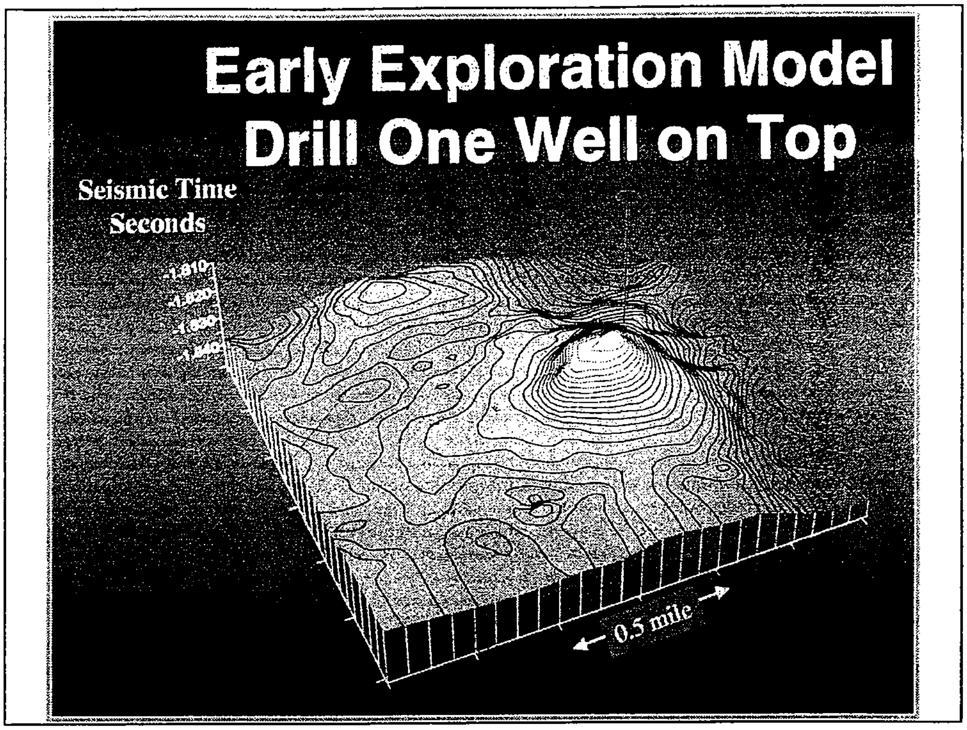
COMPLIMENTS OF:

MARK A. SIPPEL



Williston Basin - Area of Interest

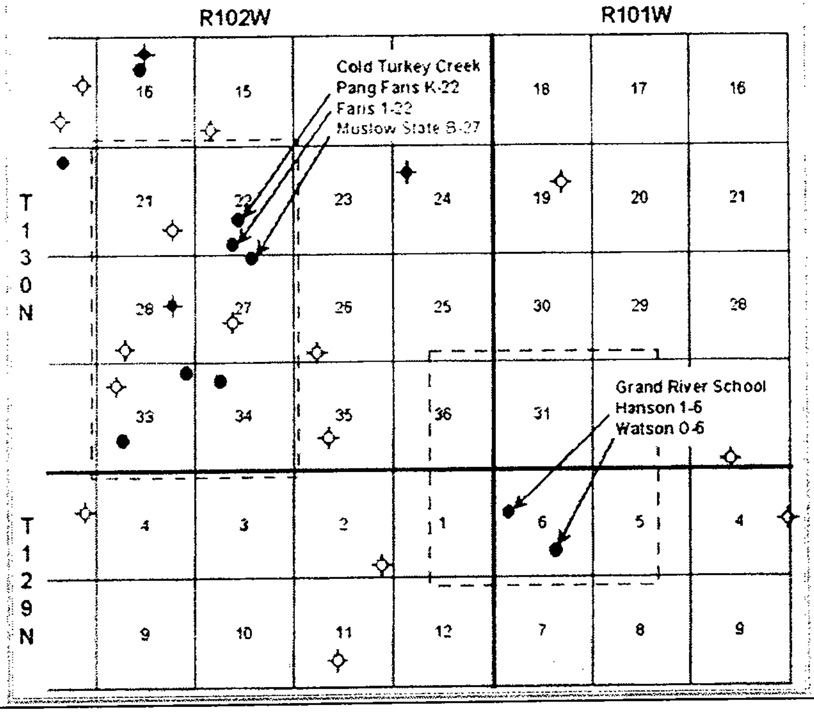
Ordovician
Red River
8500 to 9500 ft

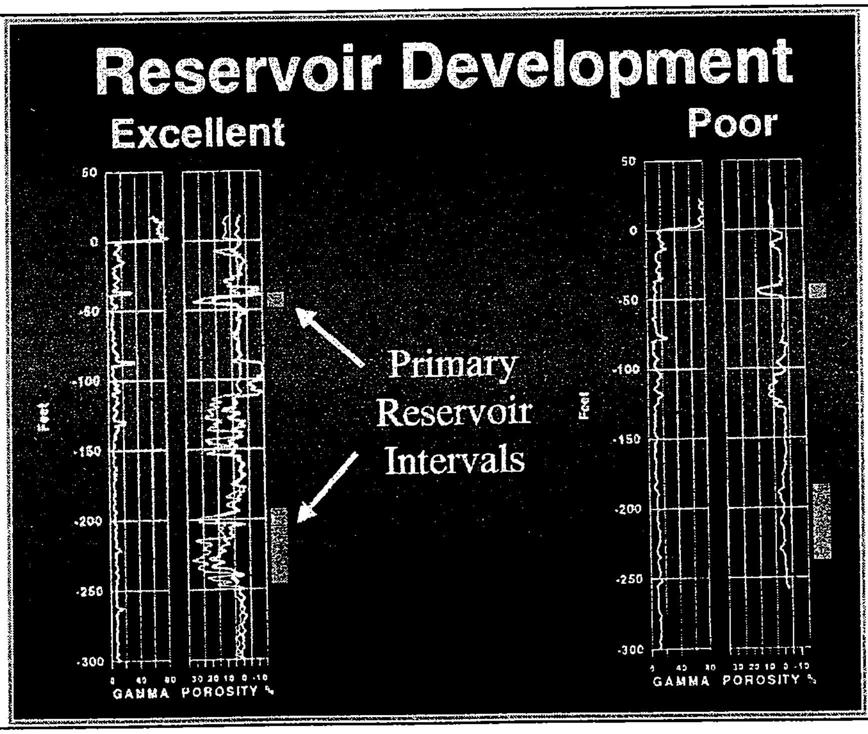


Early Exploration Model Drill One Well on Top

Statement of Problem

- Does a single crestal well drain all reserves on a small Red River structure?
- Where are optimum drilling locations on Red River structures and how are they identified?
- What are potential reserves related to seismic attribute anomalies?



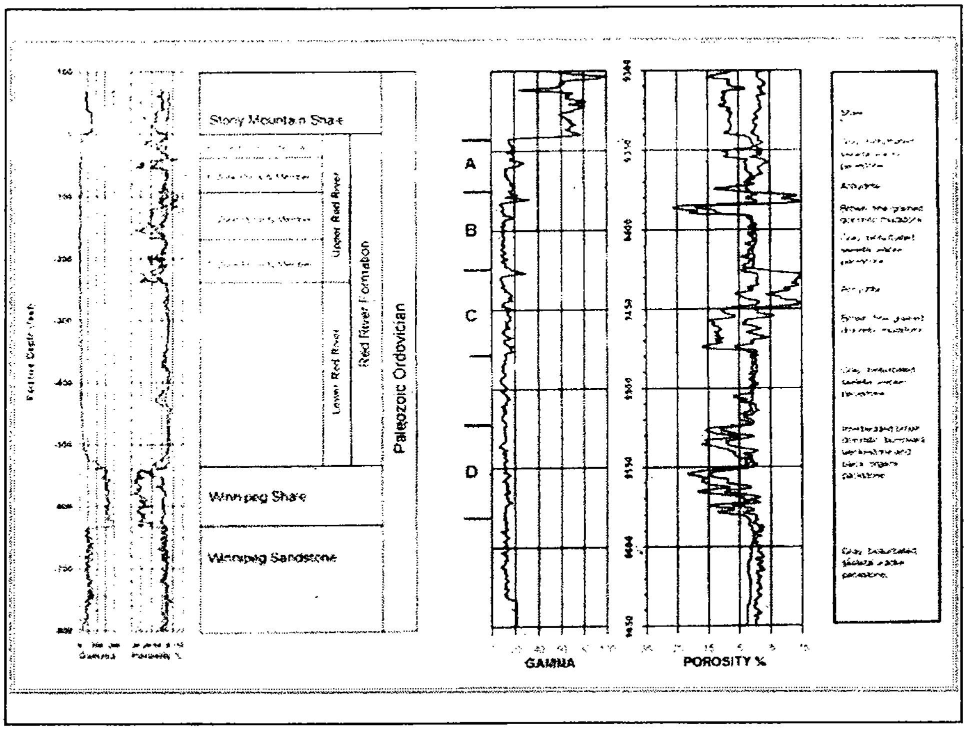


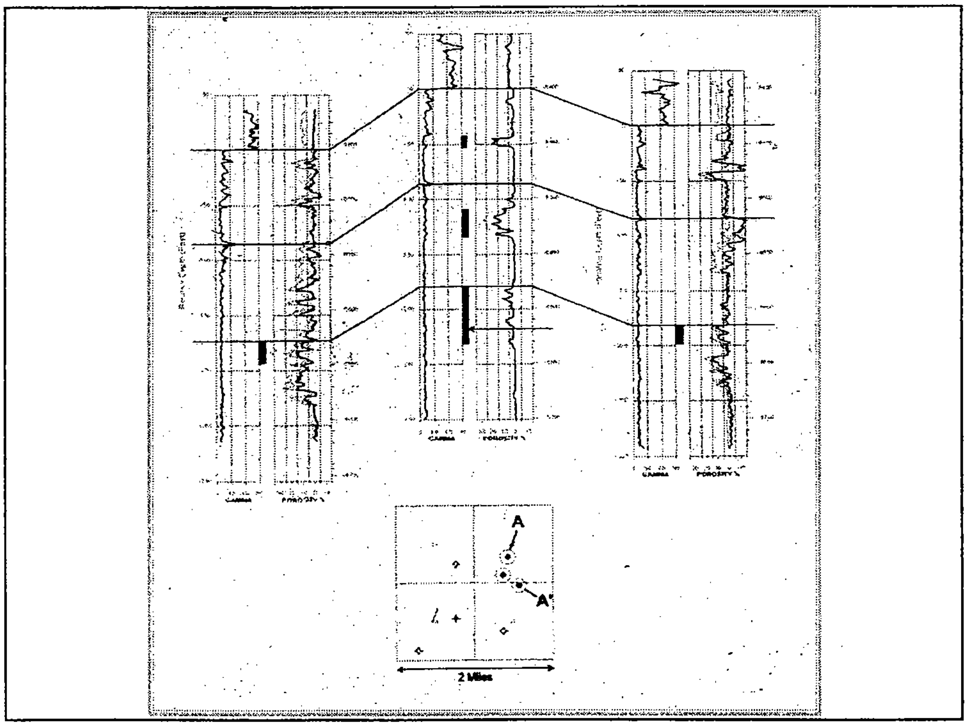
Reservoir Development

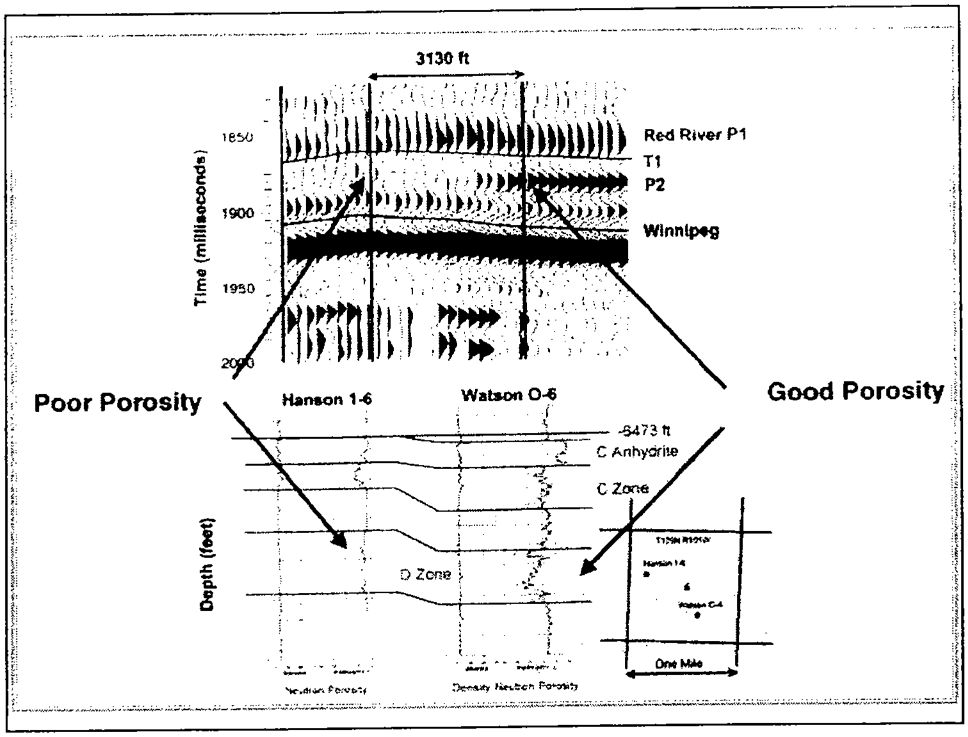
Excellent

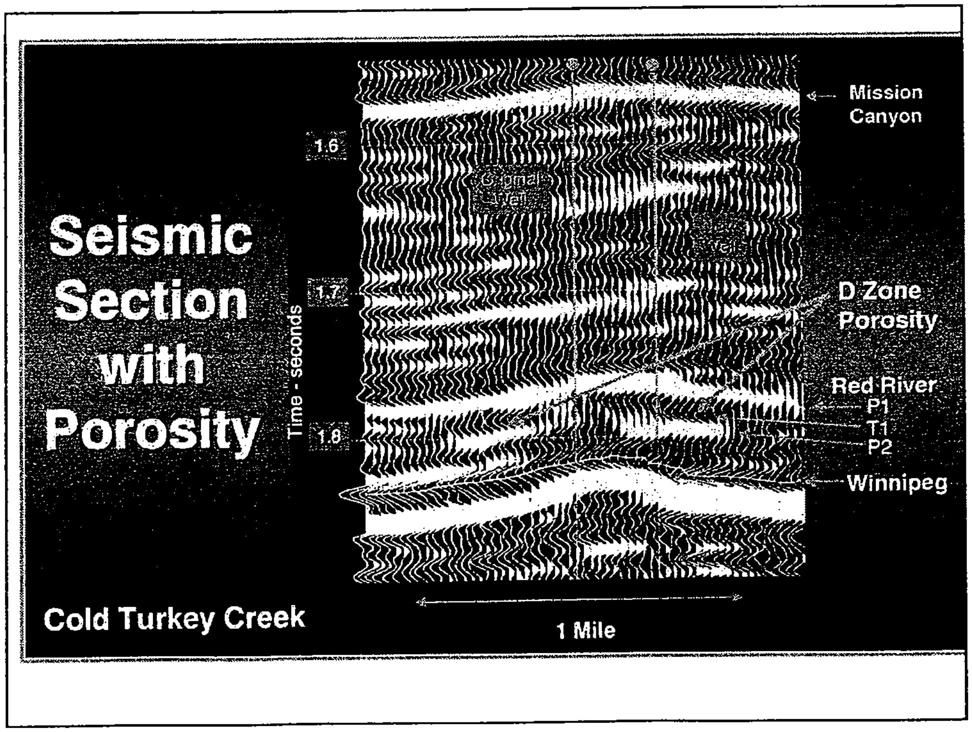
Poor

Primary Reservoir Intervals

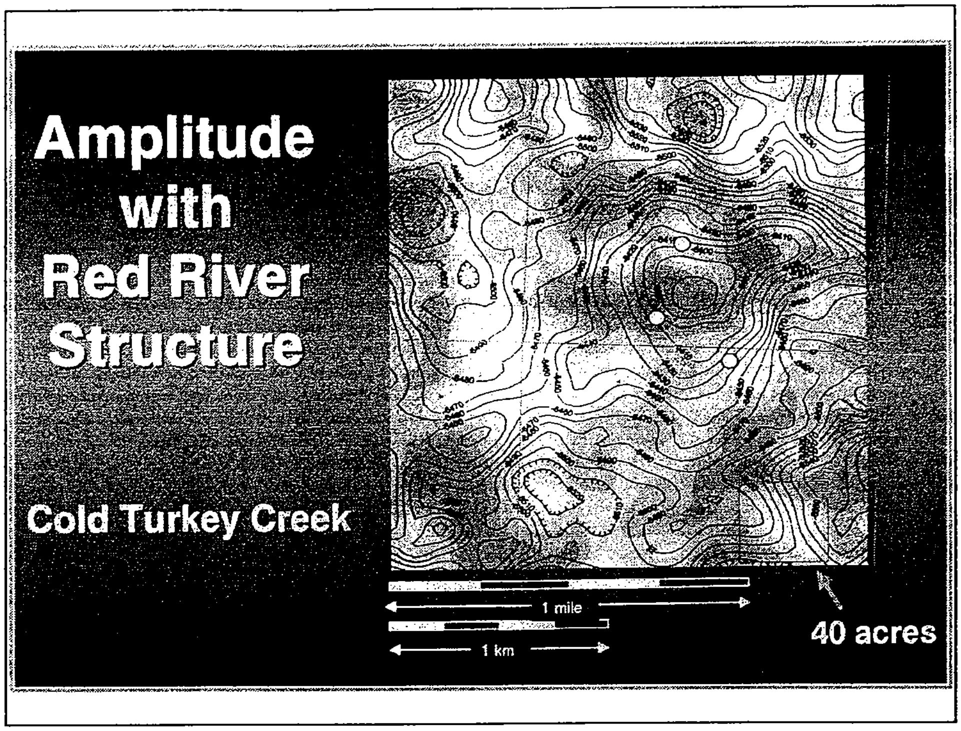

Stony Mountain Shale
Upper Red River
Lower Red River
Red River Formation
Paleozoic Ordovician
Winnipeg Shale
Winnipeg Sandstone
A
B
C
D
GAMMA
POROSITY %


GAMMA
POROSITY %
A
A'
2 Miles



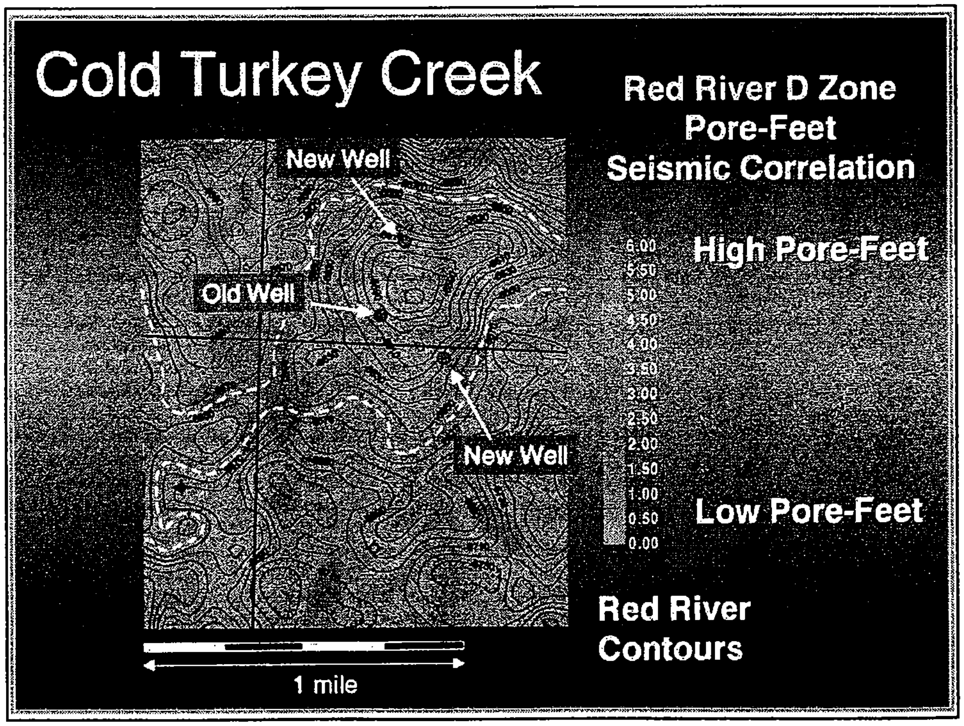


Seismic Section with Porosity



Amplitude with Red River Structure

Cold Turkey Creek

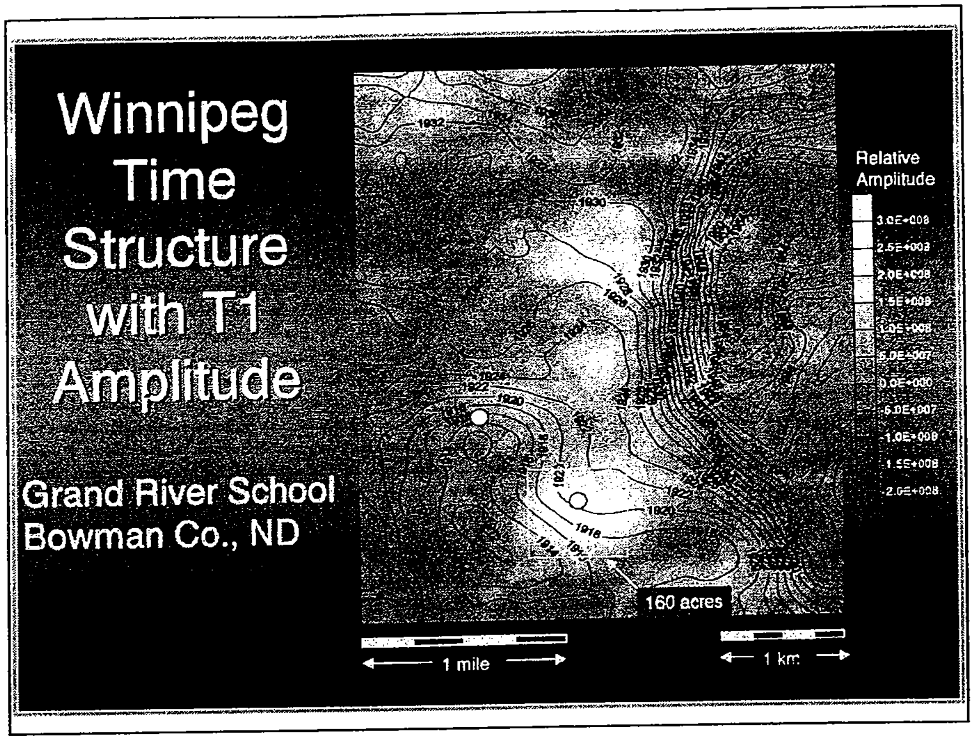


Cold Turkey Creek

Red River D Zone
Pore-Feet
Seismic Correlation

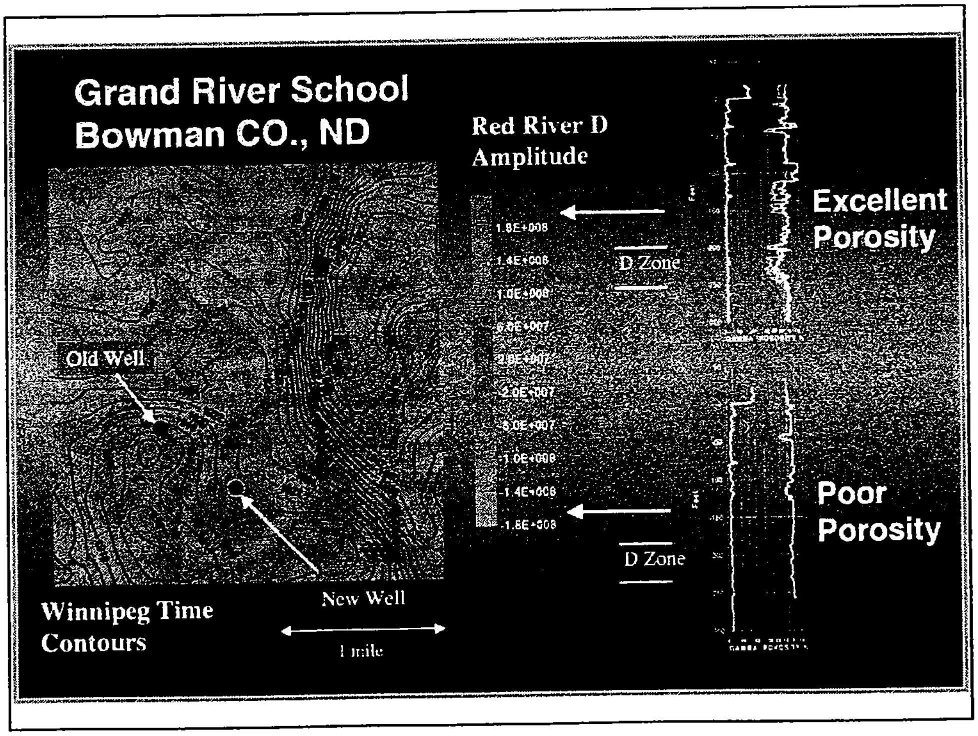
6.00	High Pore-Feet
5.50	
5.00	
4.50	
4.00	
3.50	
3.00	
2.50	
2.00	
1.50	
1.00	
0.50	Low Pore-Feet
0.00	

Red River
Contours



Winnipeg Time Structure with T1 Amplitude

Grand River School
Bowman Co., ND



Grand River School Bowman CO., ND

Red River D Amplitude

Excellent Porosity

Poor Porosity

Winnipeg Time Contours

CONCLUSION

ONCE SEISMIC AMPLITUDE WAS CALIBRATED TO POROSITY, 3D SEISMIC COULD DETECT POROUS RESERVOIR ZONES

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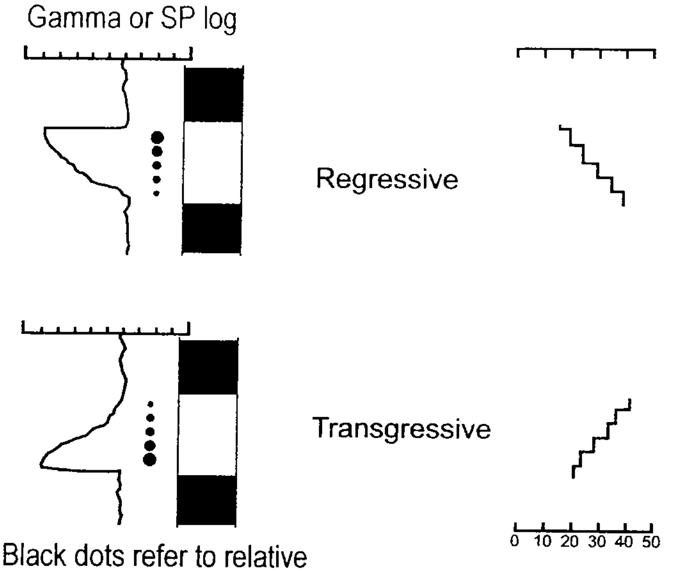
KEY REFERENCES TO INDIVIDUAL UNITS

FLOW UNIT DETERMINATION AND CHARACTERIZATION

LESSONS LEARNED

- RESERVOIRS CAN BE CHARACTERIZED BY A COMBINATION OF GEOLOGICAL AND PETROPHYSICAL PROPERTIES
- MODIFIED LORENZ PLOT REDUCES VARIABLES, AND QUANTIFIES ZONATION FOR SIMULATION
- NEURAL NET USEFUL FOR DEVELOPING PERMEABILITY LOG FOR FLOW UNIT ZONATION. CORE IS REQUIRED FOR CALIBRATION.



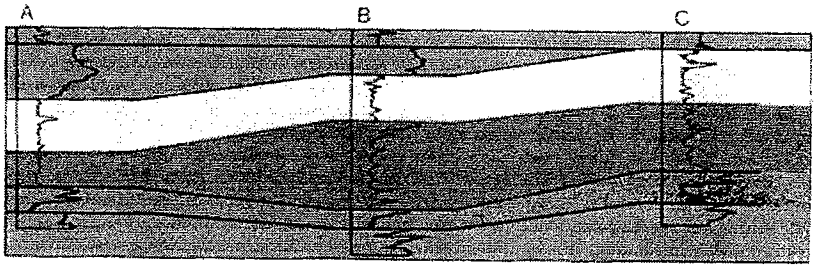
Black dots refer to relative grain-size of sands at each strat. level

Oil saturation (%)

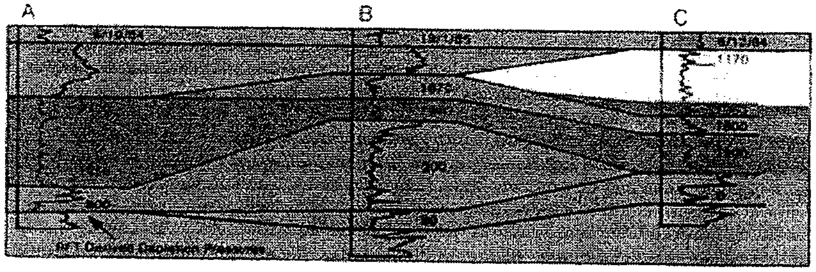
Remaining oil saturation after waterflood

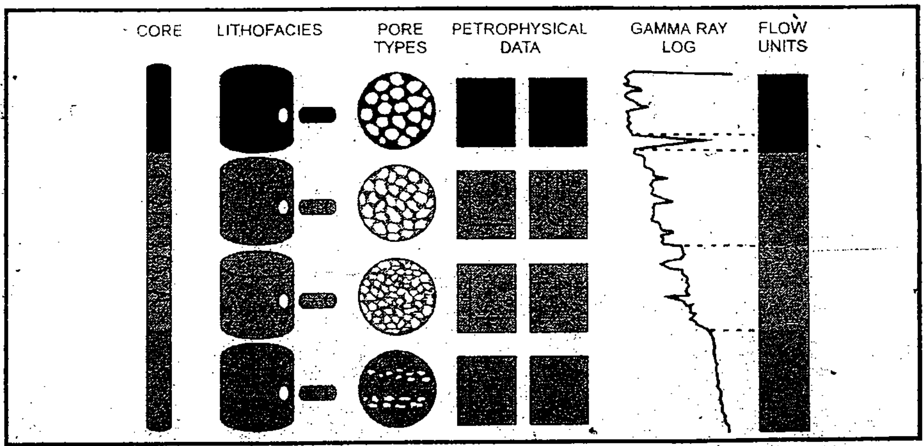
APPLICATION OF RFT TO RESERVOIR CONNECTIVITY STUDIES

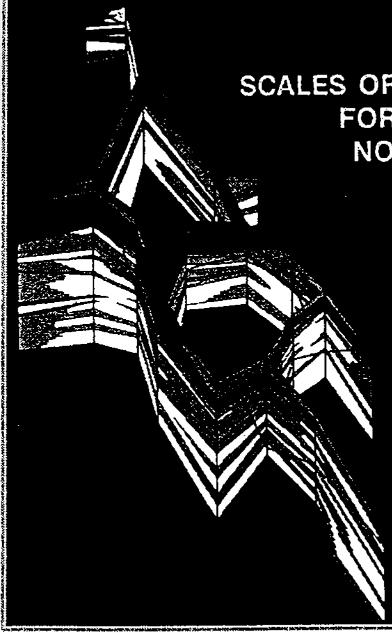
Lithostratigraphic Correlation



Hydrodynamic Correlation based on RFT data

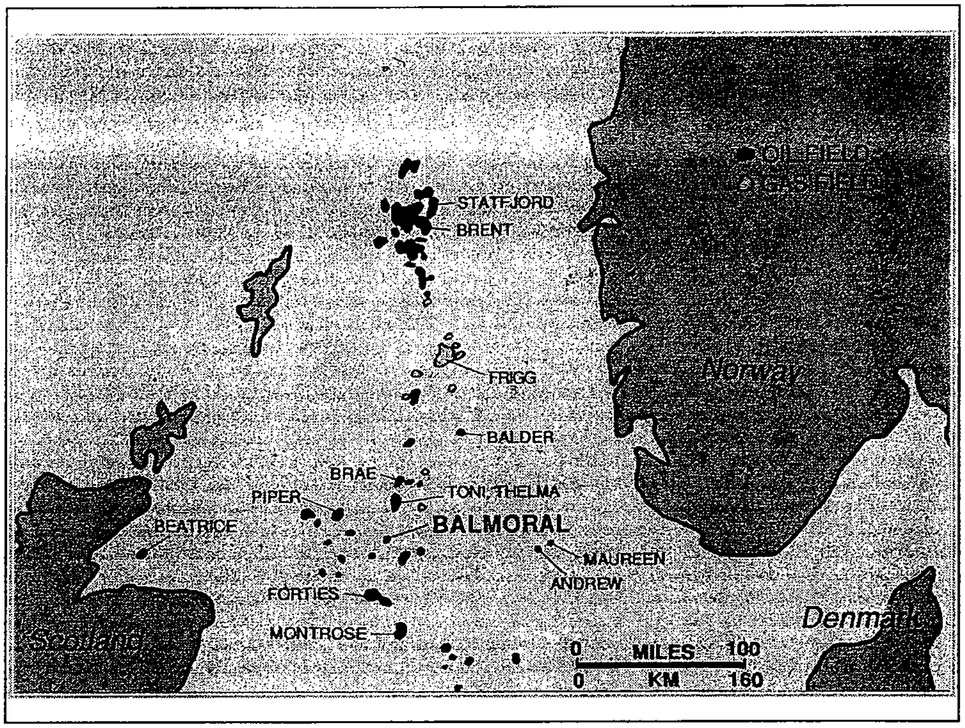


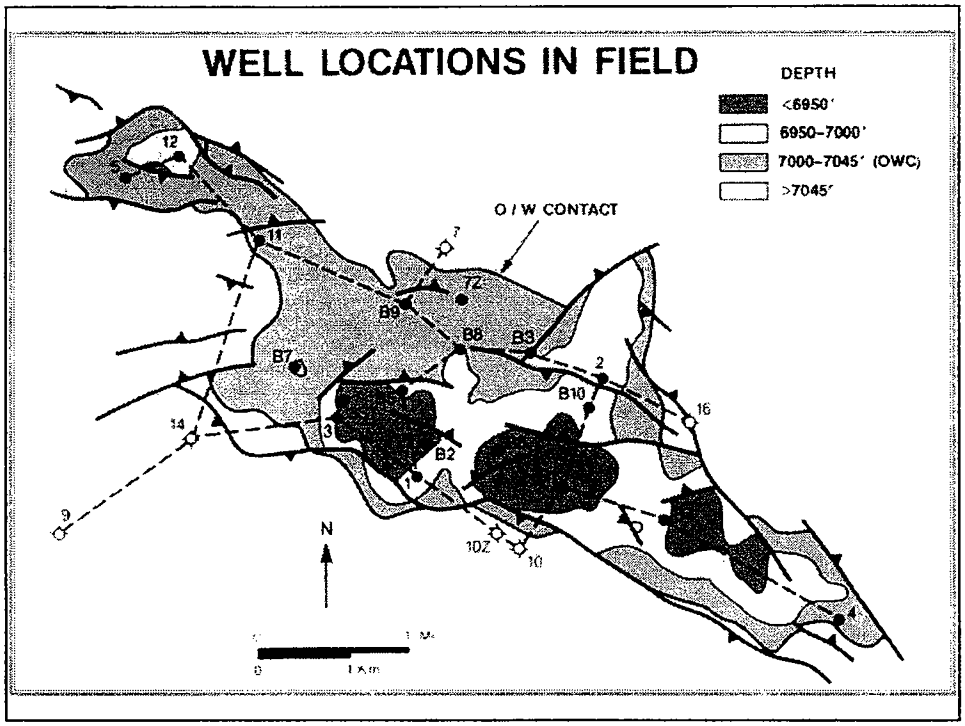




SCALES OF GEOLOGIC RESERVOIR DESCRIPTION FOR ENGINEERING APPLICATIONS: NORTH SEA OIL FIELD EXAMPLE

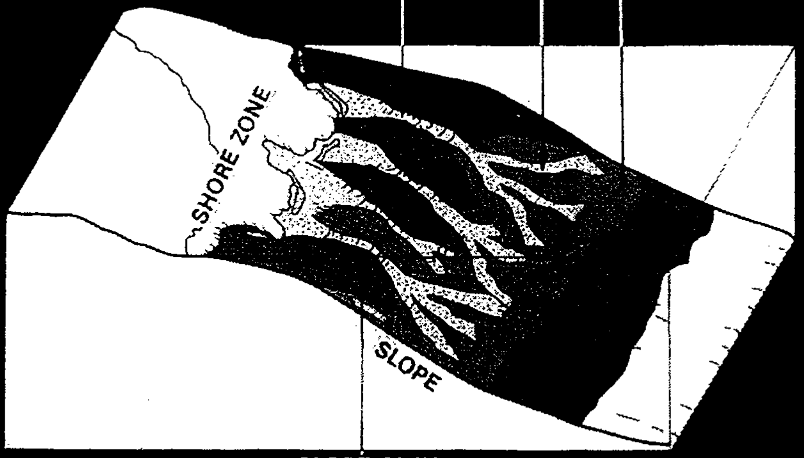
ROGER M. SLATT
AND
GRAHAM L. HOPKINS



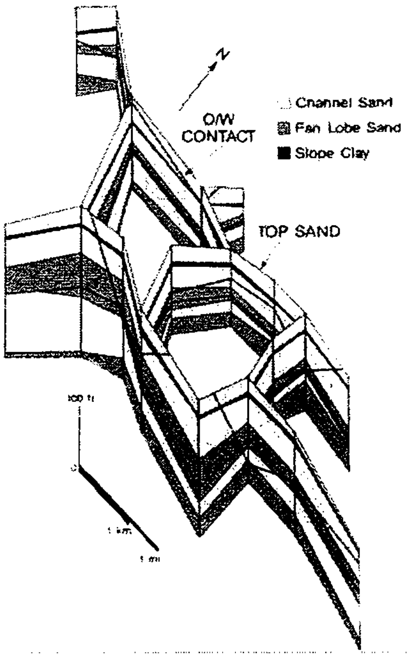


WELL LOCATIONS IN FIELD

DEPOSITIONAL MODEL



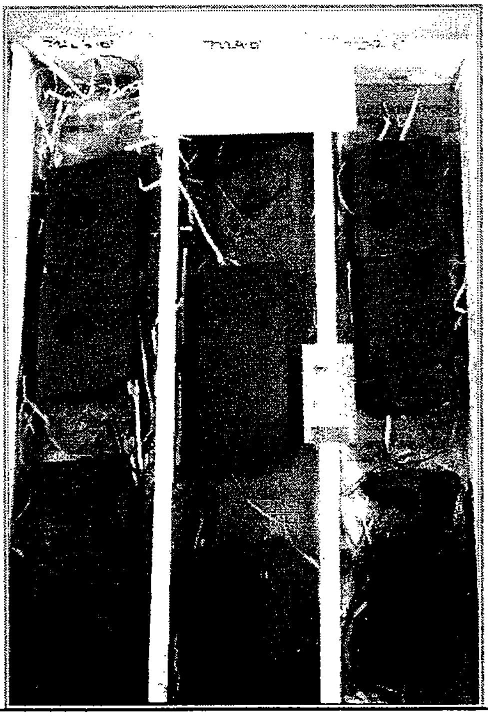
DISTRIBUTION OF FACIES

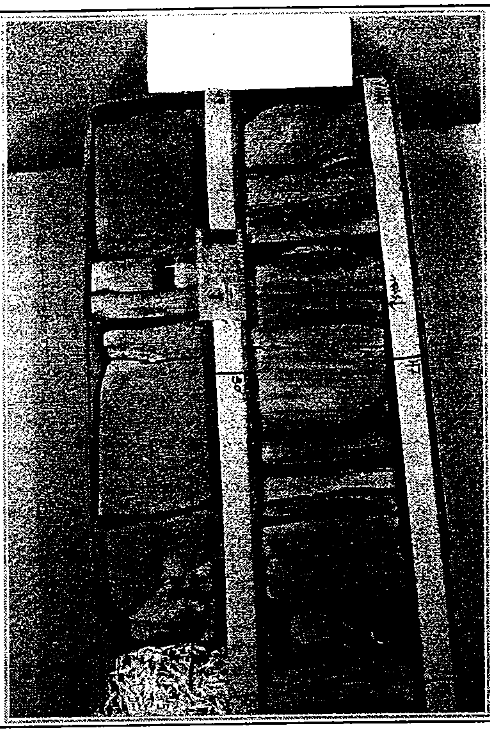


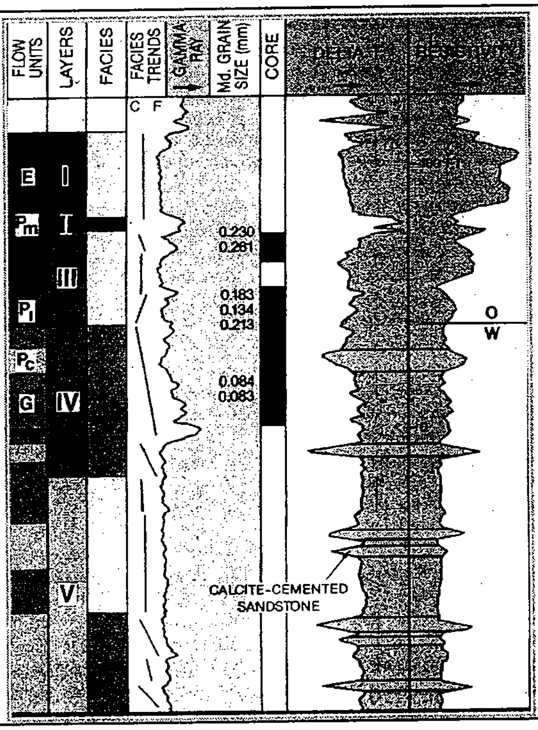
FLOW UNIT:

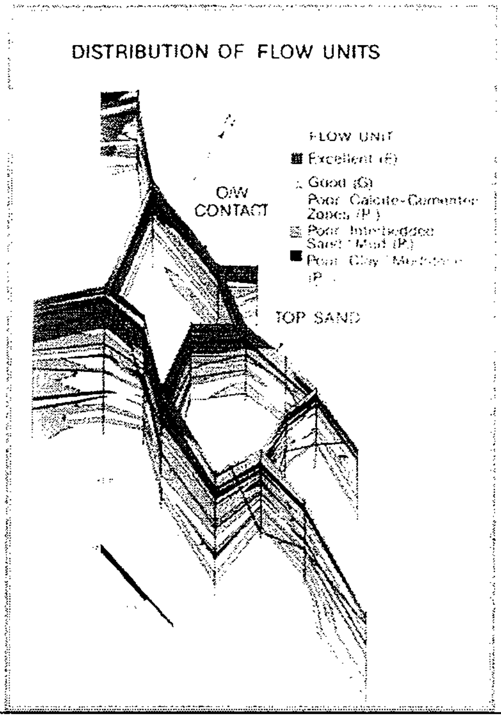
"VOLUME OF ROCK SUBDIVIDED ACCORDING TO GEOLOGICAL AND PETROPHYSICAL PROPERTIES THAT INFLUENCE THE FLOW OF FLUIDS THROUGH IT" (Ebanks, 1987)

FLOW FLOW	PERM. (md)	POR. (%)	Md. GRAIN SIZE (mm)	Md. PORE THROAT SIZE (mm)	S_B @ 200 psi (%)	CHARACTERISTICS
E	>1000	23-34	0.182-0.304	0.010-0.013	6-12	MASSIVE SAND. CHANNEL FACIES.
G	100-1000	20-34	0.083-0.242	0.007	11-24	MASSIVE SAND. CHANNEL / LOBE FACIES.
P_I	0.1->1000	7-32	0.100-0.230	0.002	31	INTERBEDDED SAND / MUD. CHANNEL / LOBE FACIES.
P_C	0.01->1000	4-28	0.113-0.245	0.002	30-37	MASSIVE SAND w/ CALCITE CEMENTED ZONES. CHANNEL / LOBE FACIES.
P_M	Imperm.	Non-porous	—	—	—	CLAY / MUDSTONE



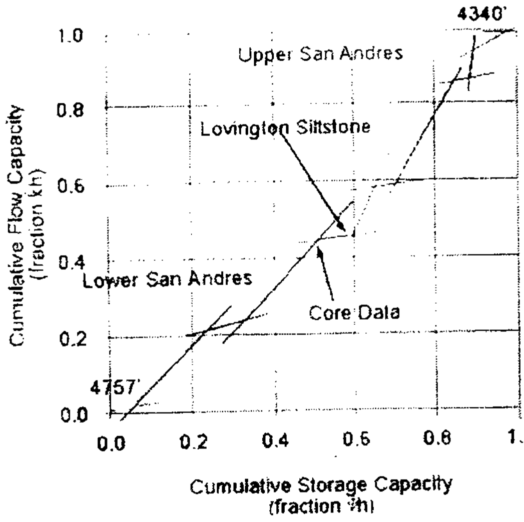



FLOW UNITS
LAYERS
FACIES
FACIES TRENDS
GAMMA RAY
Md. GRAIN SIZE (mm)
CORE
DELTA-T
RESISTIVITY
C
F
E
I
P_m
II
III
P_l
P_c
G
IV
V
0.230
0.261
0.183
0.134
0.213
0.084
0.083
O
W
CALCITE-CEMENTED SANDSTONE



GUNTER (1997) METHOD OF FLOW UNIT CHARACTERIZATION

- ***'STRATIGRAPHIC MODIFIED LORENZ PLOT'***(SML)
- ***'CUMULATIVE FLOW CAPACITY'*** **(PRODUCT OF AVER. PERM. AND INTERVAL THICKNESS)**
- ***'CUMULATIVE STORAGE CAPACIATY'*** **(PRODUCT OF AVER. POROSITY AND INTERVAL THICKNESS)**
- **CROSS PLOT THE TWO, WITH *CUM. STORAGE CAP.* ON HORIZONTAL AXIS AND *CUM. FLOW CAP.* ON VERTICAL AXIS.**
- **PLOT BEGINS (LOWER LEFT CORNER) AT STRATIGRAPHIC BASE**



(Pranter, 1999)

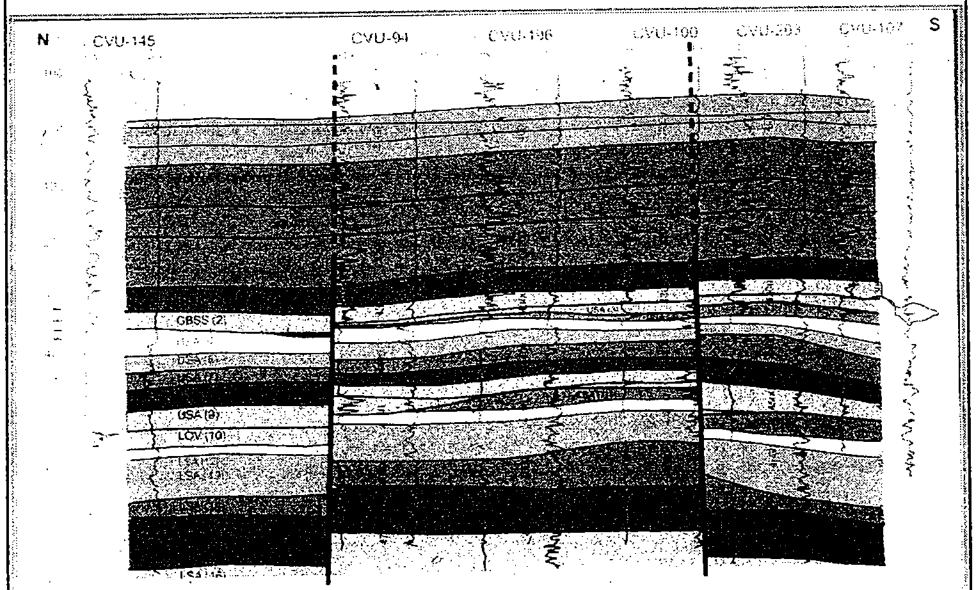
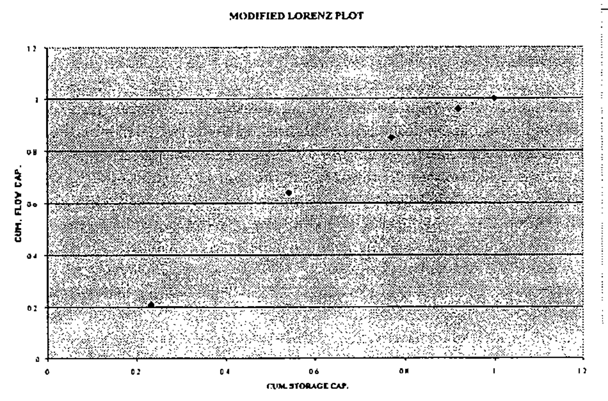


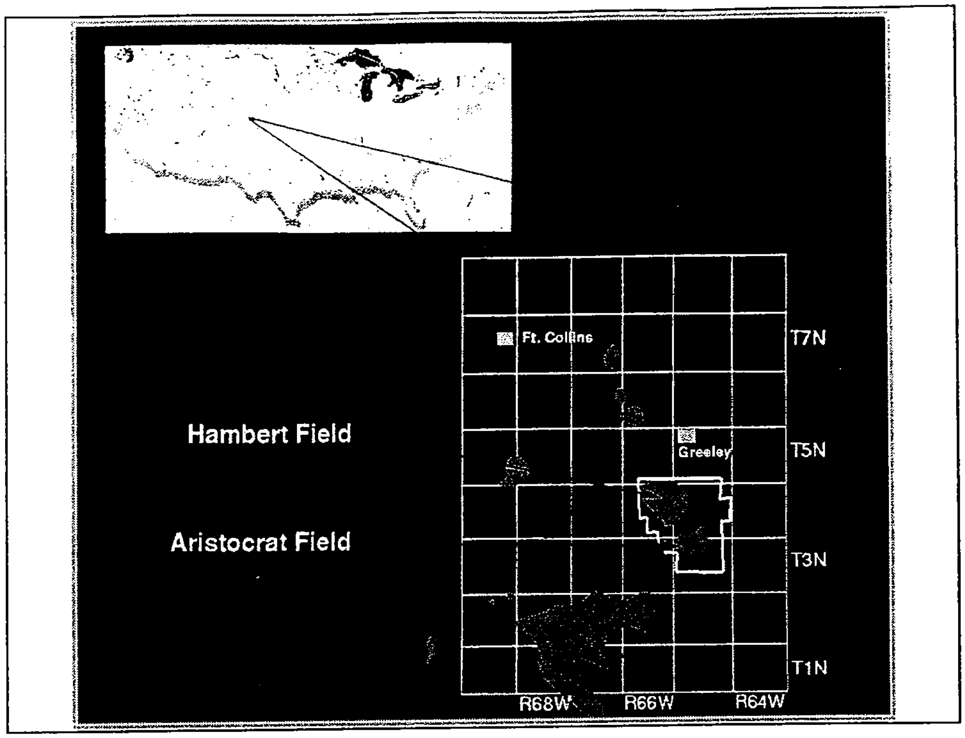
Figure 5.27 North-south structural cross section through study area with flow unit (different colors) correlations.

Depth(ft.)	Por.	(Por.) (H)	K	(K)(H)
1805	0.15	(0.15) (1)=0.15	10	(10) (1)=10
1804	0.20	(0.20) (1)=0.20	20	(20) (1)=20
1803	0.15	(0.15) (1)=0.15	10	(10) (1)=10
1802	0.10	(0.10) (1)=0.10	5	(5) (1)= 5
1801	0.05	(0.05) (1)=0.05	2	(2) (1)= 2
Summation=		=0.65		= 47

Depth(ft.)	Fract. (Por.) (H)=(X)/0.65	Fract. (K) (H) = (Y)/47
1805	(0.15)/0.65=0.23	(10)/47 = 0.21
1804	(0.20)/0.65=0.31	(20)/47 = 0.43
1803	(0.15)/0.65=0.23	(10)/47 = 0.21
1802	(0.10)/0.65=0.15	(5)/47 = 0.11
1801	(0.05)/0.65=0.08	(2)/47 = 0.04
Summation=	=1.00	= 1.00

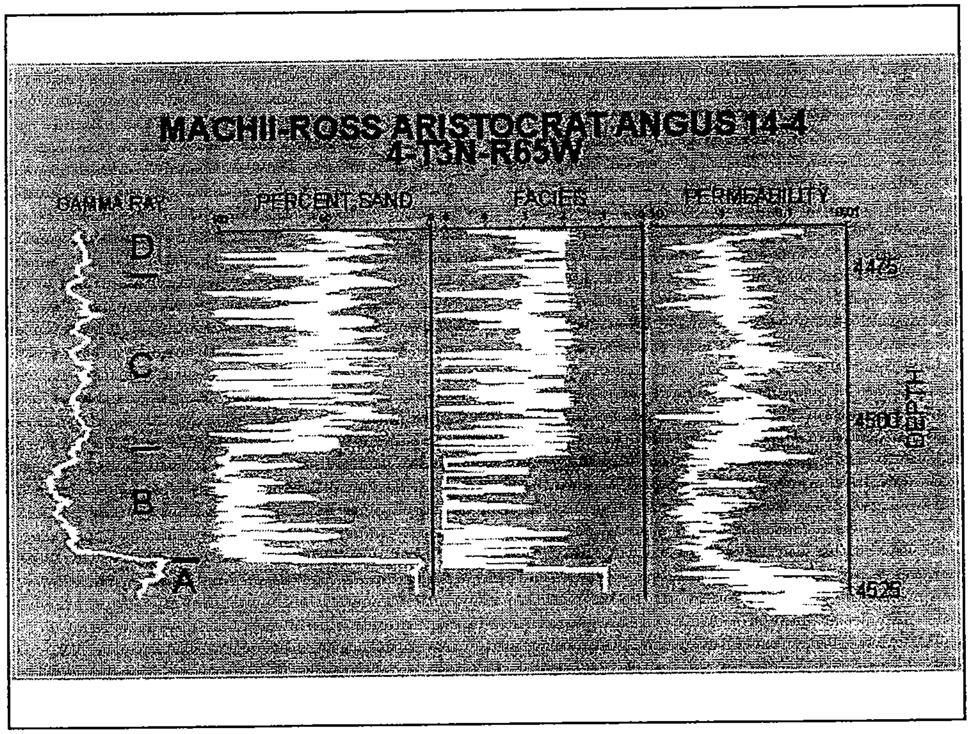
Depth	Cumulative (Por) (H) (Cum. Storage Capacity)	Cumulative (K) (H) (Cum. Flow Capacity)
1805	0.23	0.21
1804	0.54	0.64
1803	0.77	0.85
1802	0.92	0.96
1801	1.00	1.00



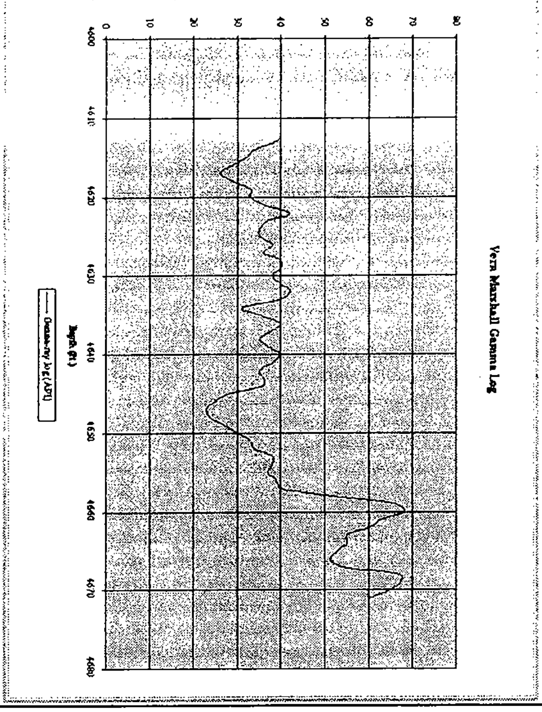


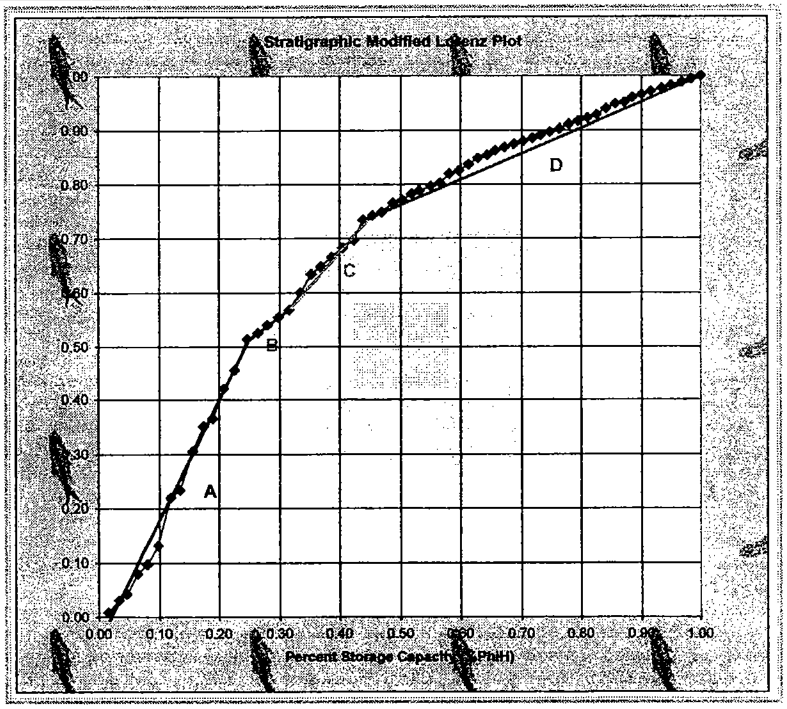
Hambert Field

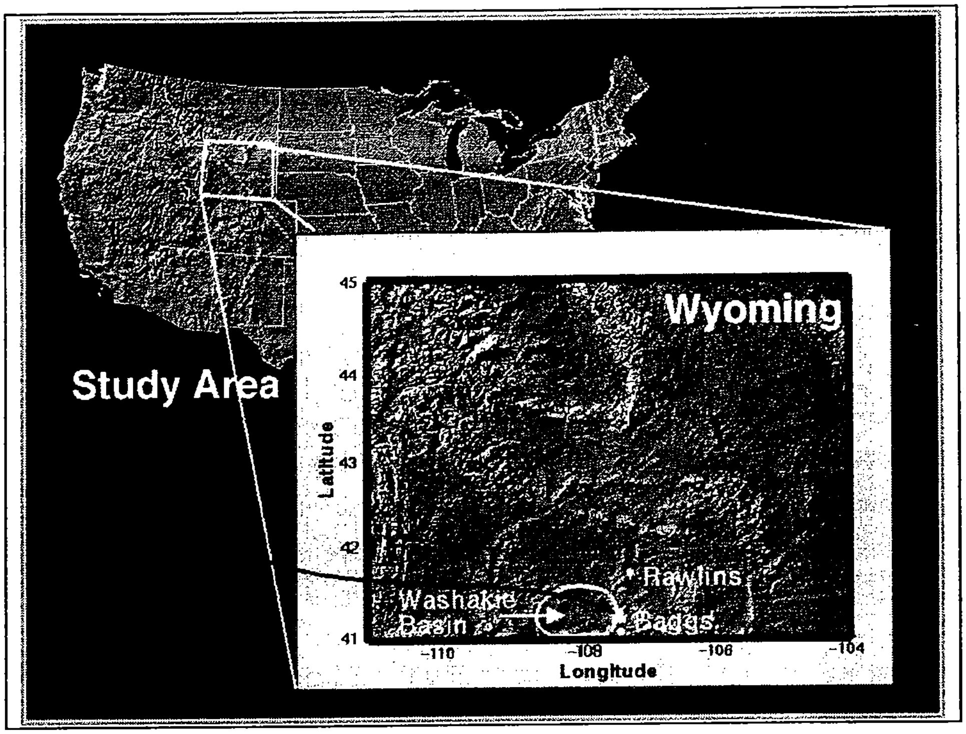
Aristocrat Field

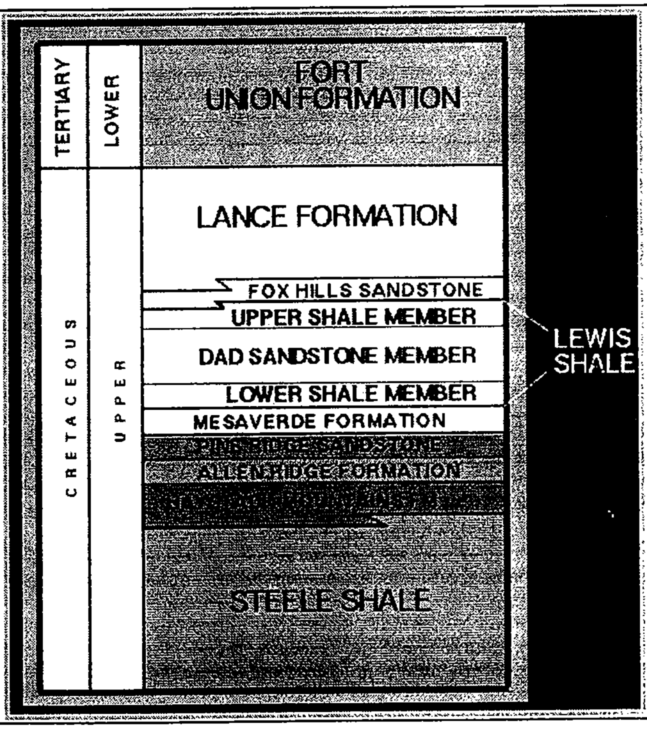


MACHII-ROSS ARISTOCRAT ANGUS 14-4 4-T3N-R65W


Vera Marshall Gamma Log
0
10
20
30
40
50
60
70
80
4600
4610
4620
4630
4640
4650
4660
4670
4680
Depth (ft.)
Gamma-ray log (API)


Stratigraphic Modified Lorenz Plot
1.00
0.90
0.80
0.70
0.60
0.50
0.40
0.30
0.20
0.10
0.00
0.00
0.10
0.20
0.30
0.40
0.50
0.60
0.70
0.80
0.90
1.00
A
B
C
D
Percent Storage Capacity (%PhiH)





FORT UNION FORMATION

LANCE FORMATION

FOX HILLS SANDSTONE

UPPER SHALE MEMBER

DAD SANDSTONE MEMBER

LOWER SHALE MEMBER

LEWIS SHALE

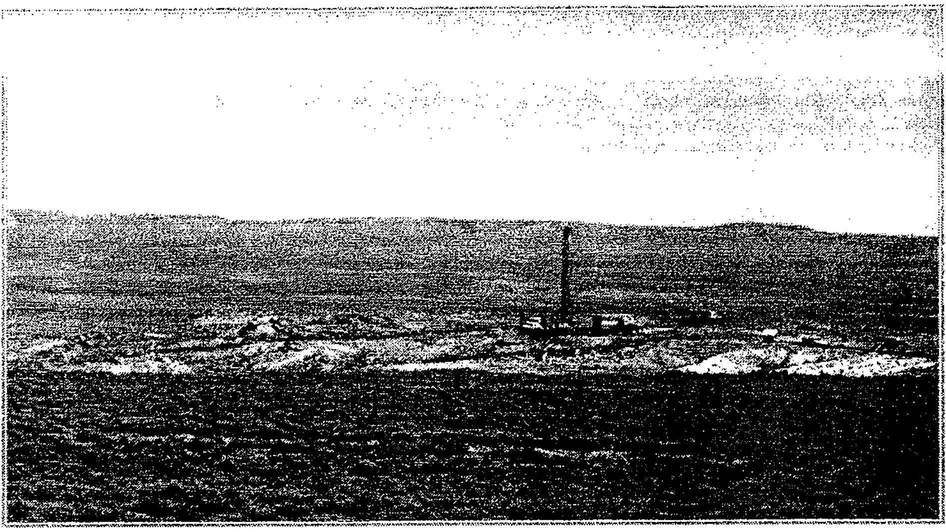
MESAVERDE FORMATION

PINE RIDGE SANDSTONE

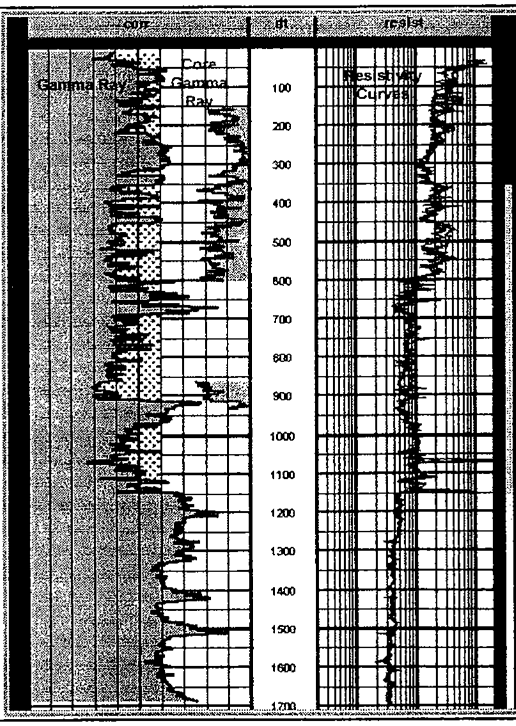
ALLEN RIDGE FORMATION

[illegible]

STEELE SHALE



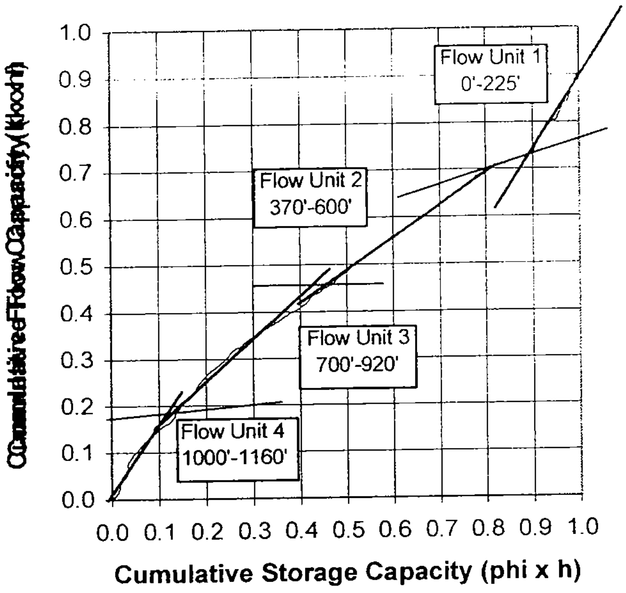
CSM Strat Test # 61



Basin Plain Facies

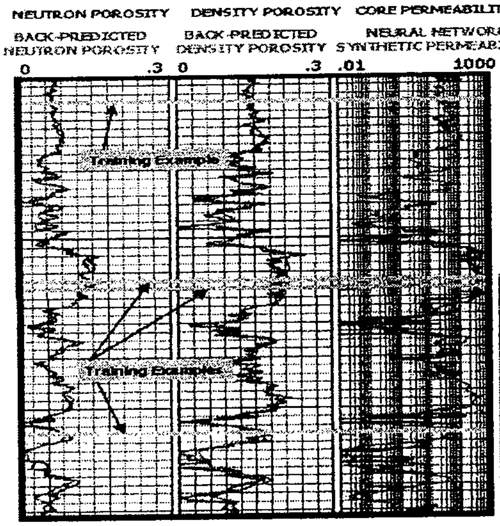
Lower Lewis Shale

← Asquith Source Rock



NNLAP™

Neural Network Core Permeability Example



TRAINING WELL

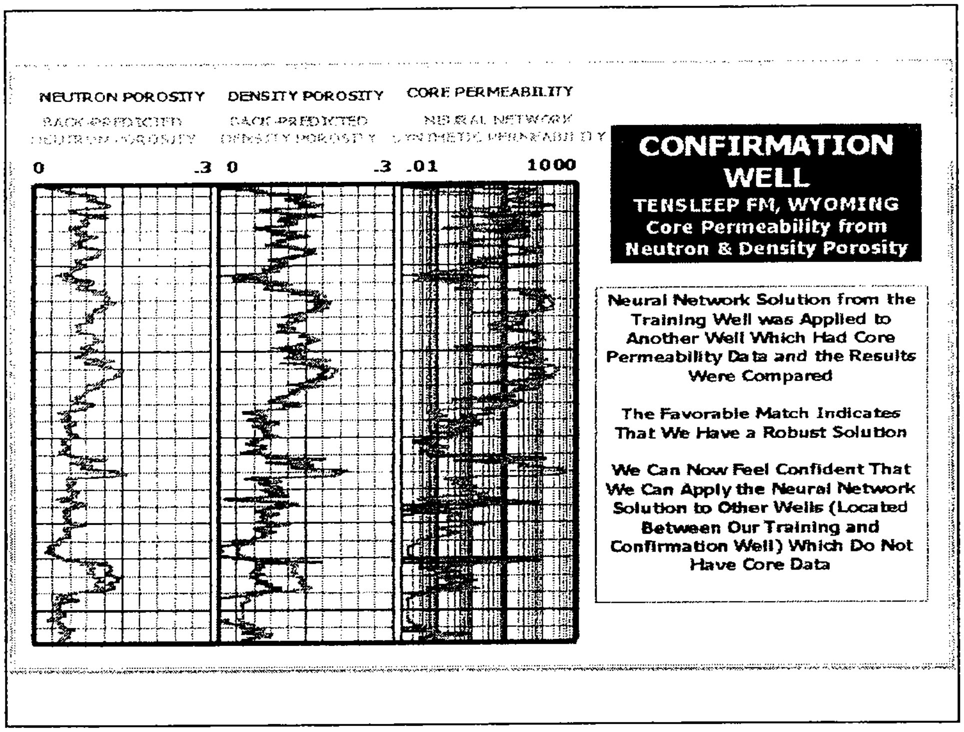
TENSLEEP FM, WYOMING
Core Permeability from
Neutron & Density Porosity

PERMEABILITY DATA WHERE NO CORE WAS RECOVERED

Difficult Problem in Cross-bedded Sandstone with Carbonate Cement

Core Permeability Ranges Over 5 Decades (0.01 to 500 md.)

Neural Network Predictions are Accurate to Within One Half of a Decade Using Only 4 Training Examples (Plus the Depth Interval Sample).



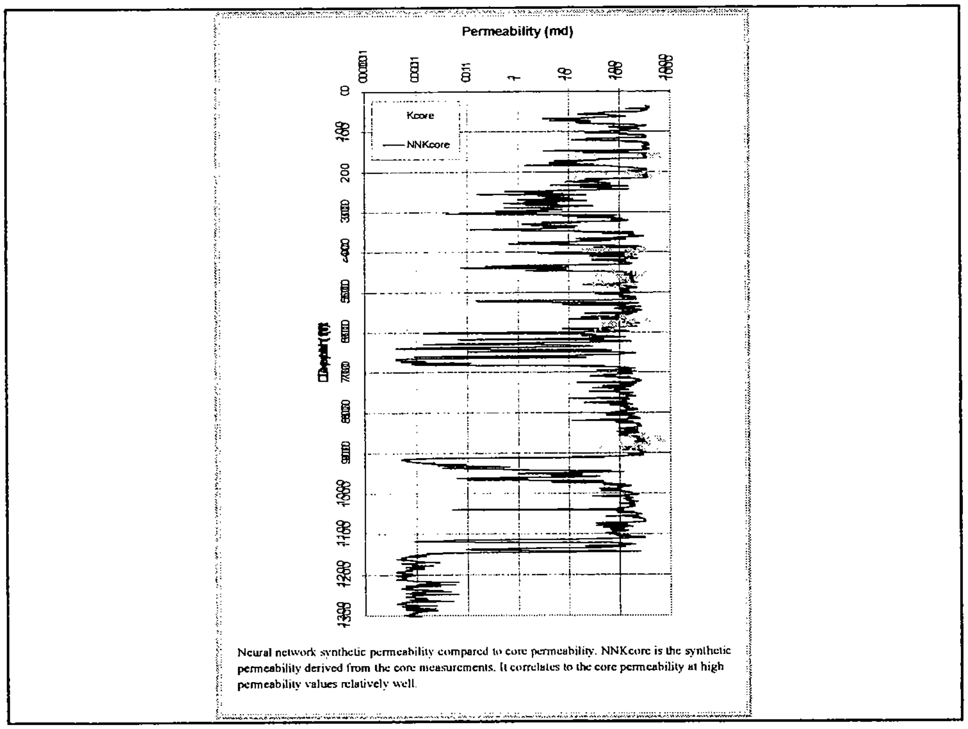
CONFIRMATION WELL

TENSLEEP FM, WYOMING
Core Permeability from Neutron & Density Porosity

Neural Network Solution from the Training Well was Applied to Another Well Which Had Core Permeability Data and the Results Were Compared

The Favorable Match Indicates That We Have a Robust Solution

We Can Now Feel Confident That We Can Apply the Neural Network Solution to Other Wells (Located Between Our Training and Confirmation Well) Which Do Not Have Core Data



Neural network synthetic permeability compared to core permeability. NNKcore is the synthetic permeability derived from the core measurements. It correlates to the core permeability at high permeability values relatively well.

LESSONS LEARNED

- RESERVOIRS CAN BE CHARACTERIZED BY A COMBINATION OF GEOLOGICAL AND PETROPHYSICAL PROPERTIES
- MODIFIED LORENZ PLOT REDUCES VARIABLES, AND QUANTIFIES ZONATION FOR SIMULATION
- NEURAL NET USEFUL FOR DEVELOPING PERMEABILITY LOG FOR FLOW UNIT ZONATION. CORE IS REQUIRED FOR CALIBRATION.

APPLIED RESERVOIR CHARACTERIZATION FOR THE INDEPENDENT OPERATOR: WITH EMPHASIS ON COMPARTMENTALIZED RESERVOIRS AND ROUTINE TECHNIQUES FOR DETECTING COMPARTMENTS

UNIT 1: INTRODUCTION TO RESERVOIR CHARACTERIZATION

UNIT 2: EXAMPLES OF COMPARTMENTALIZED RESERVOIRS

UNIT 3: GEOLOGIC CONTROLS ON POROSITY AND PERMEABILITY

UNIT 3A: SEISMIC POROSITY DETECTION IN A CARBONATE RESERVOIR

UNIT 4: FLOW UNIT DETERMINATION & CHARACTERIZATION

***UNIT 5: BASICS OF SEQUENCE STRATIGRAPHY**

UNIT 6: FLUVIAL DEPOSITS AND RESERVOIRS

UNIT 7: EOLIAN DEPOSITS AND RESERVOIRS

UNIT 8: SHOREFACE DEPOSITS AND RESERVOIRS

UNIT 9: DELTAIC DEPOSITS AND RESERVOIRS

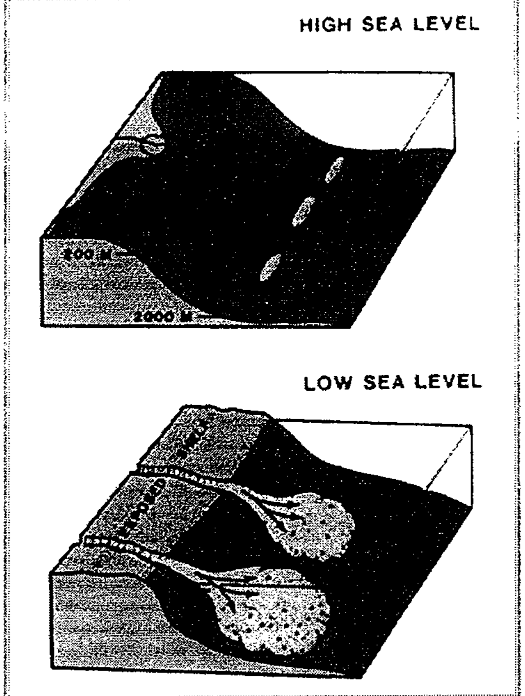
UNIT 10: DEEP-WATER (TURBIDITE) DEPOSITS AND RESERVOIRS

UNIT 11: BOREHOLE IMAGE LOGS AND APPLICATIONS

UNIT 12: DIPMETER LOGS AND APPLICATIONS

UNIT 13: STRUCTURALLY COMPARTMENTALIZED RESERVOIRS

KEY REFERENCES TO INDIVIDUAL UNITS



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

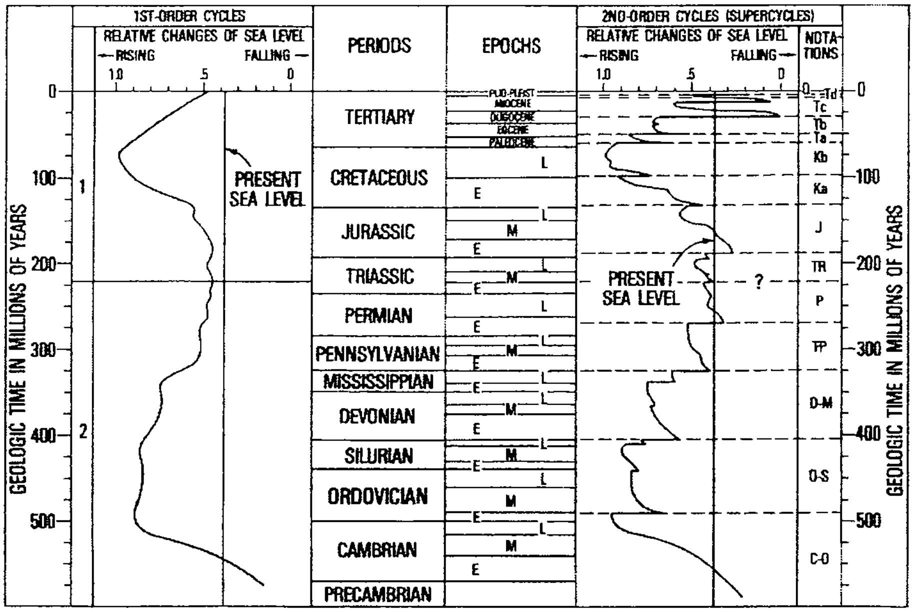
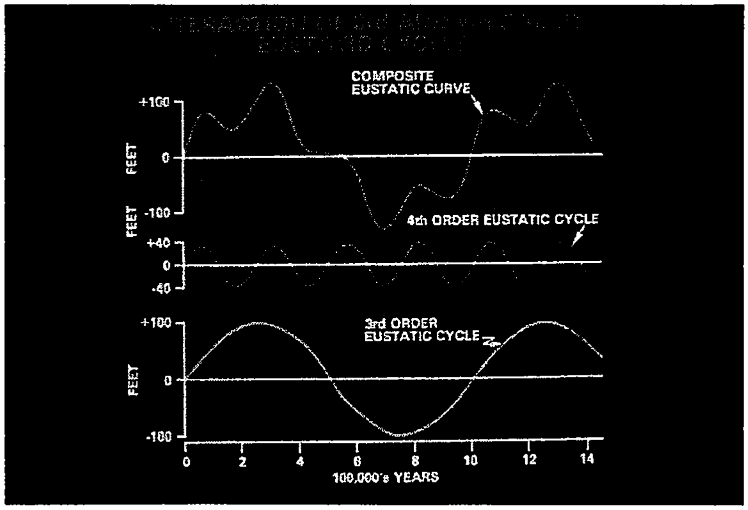
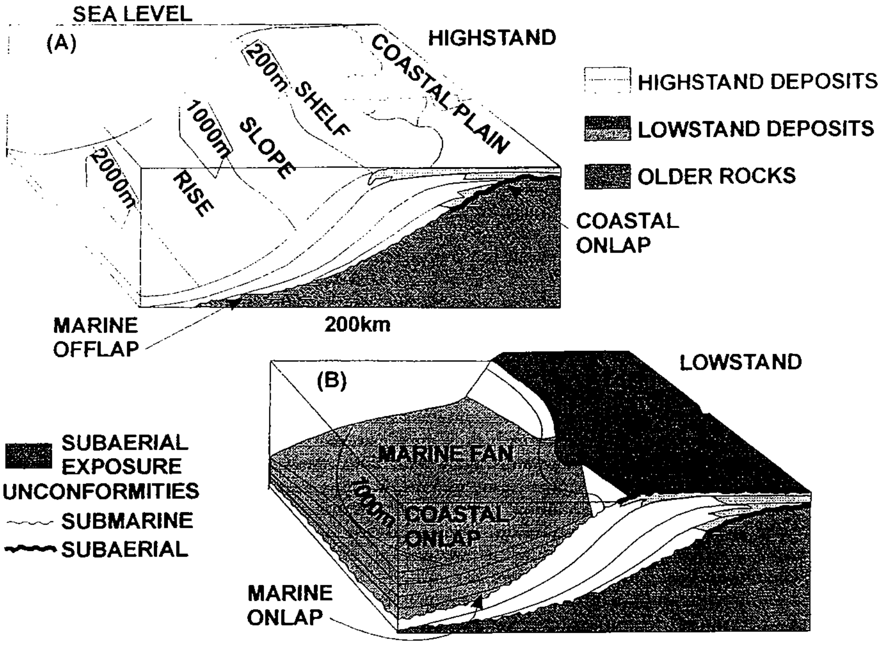


FIG. 1—First- and second-order global cycles of relative change of sea level during Phanerozoic time.





Vail et al., 1977

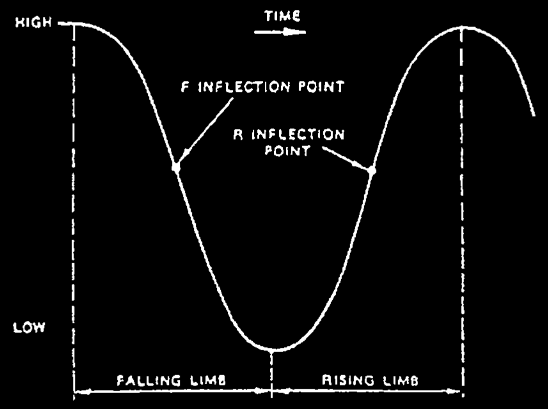


Figure 1. Elements of eustatic change. Maximum rates of rise and fall coincide with R- and F-inflection points. From Posamentier and others, 1988.
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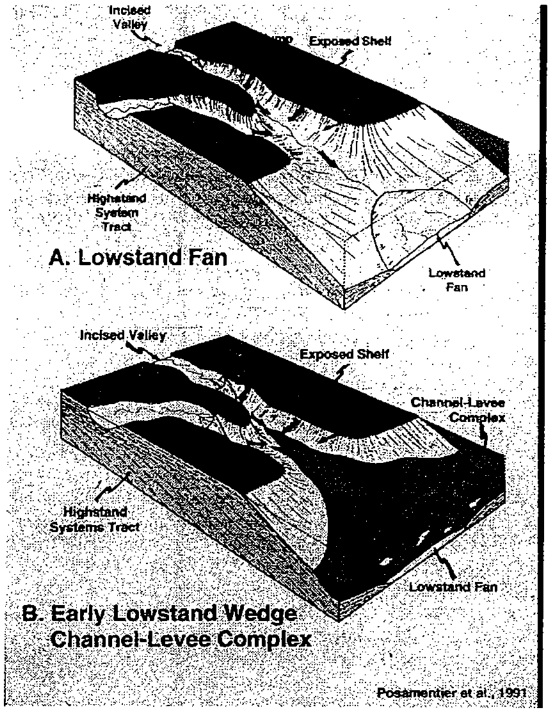
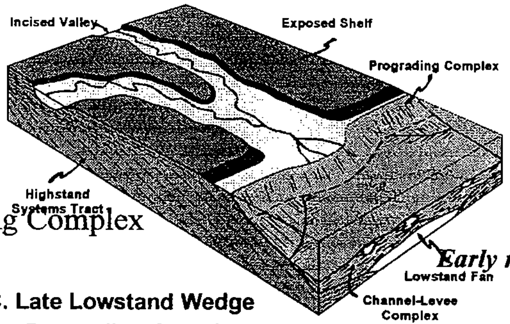
Falling sea level

Turnaround in sea level

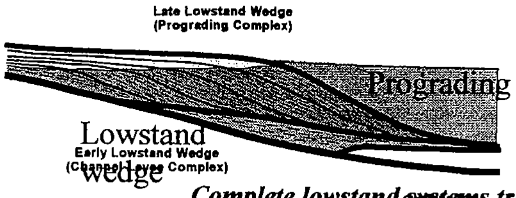




Prograding Complex

Early rise in sea level

C. Late Lowstand Wedge Prograding Complex



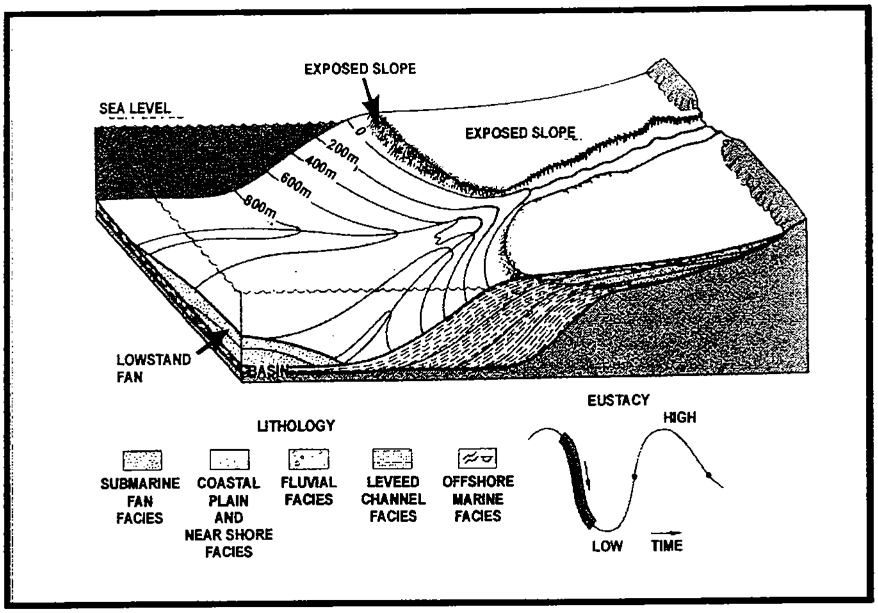
Prograding complex

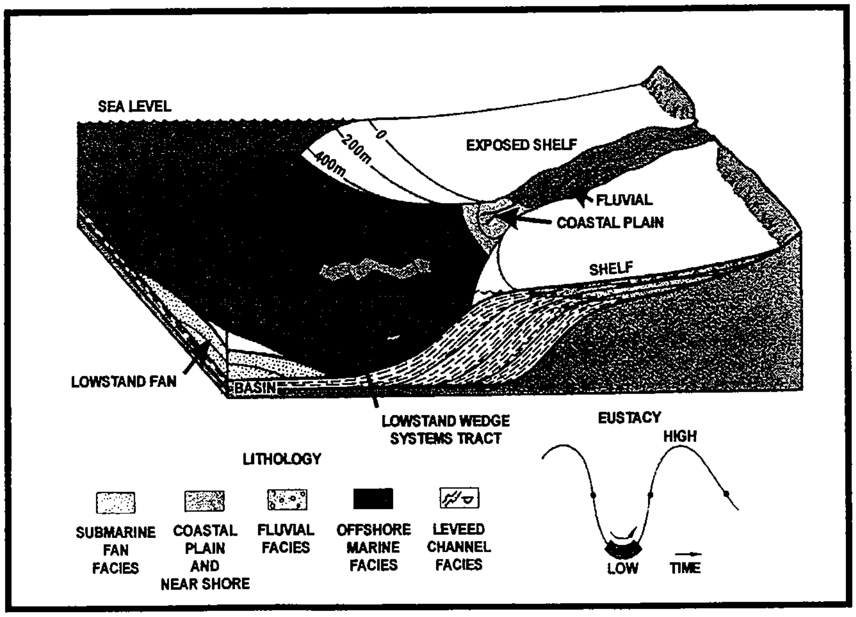
Lowstand Fan

Lowstand wedge

Complete lowstand systems tract

D. Axial Section through Canyon and Slope


EXPOSED SLOPE
SEA LEVEL
EXPOSED SLOPE
0
200m
400m
600m
800m
LOWSTAND FAN
BASIN
EUSTACY
HIGH
LOW
TIME
LITHOLOGY
SUBMARINE FAN FACIES
COASTAL PLAIN AND NEAR SHORE FACIES
FLUVIAL FACIES
LEVEED CHANNEL FACIES
OFFSHORE MARINE FACIES


SEA LEVEL
0
200m
400m
EXPOSED SHELF
FLUVIAL
COASTAL PLAIN
SHELF
LOWSTAND FAN
BASIN
LOWSTAND WEDGE SYSTEMS TRACT
EUSTACY
HIGH
LOW
TIME
LITHOLOGY
SUBMARINE FAN FACIES
COASTAL PLAIN AND NEAR SHORE
FLUVIAL FACIES
OFFSHORE MARINE FACIES
LEVEED CHANNEL FACIES

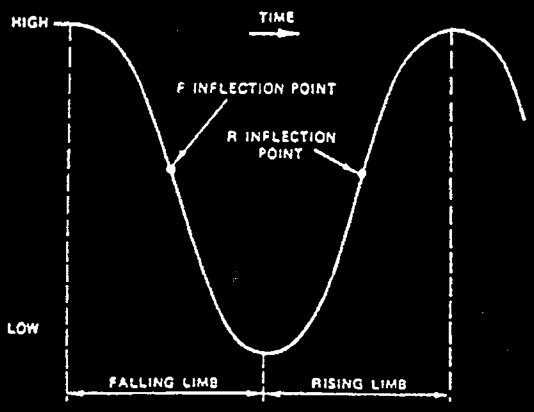


Figure 1. Elements of eustatic change. Maximum rates of rise and fall coincide with R- and F-inflection points. From Posamentier and others, 1988.
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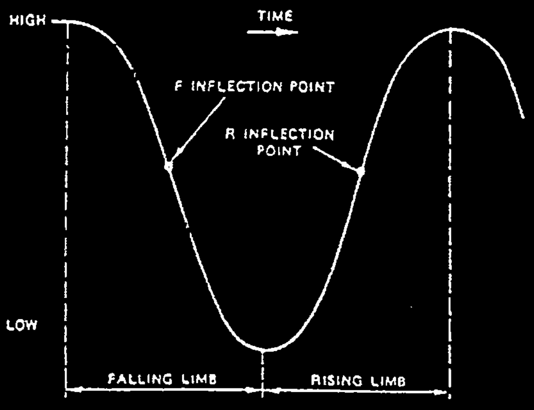

Figure 1. Elements of eustatic change. Maximum rates of rise and fall coincide with R- and F-inflection points. From Posamentier and others, 1988.
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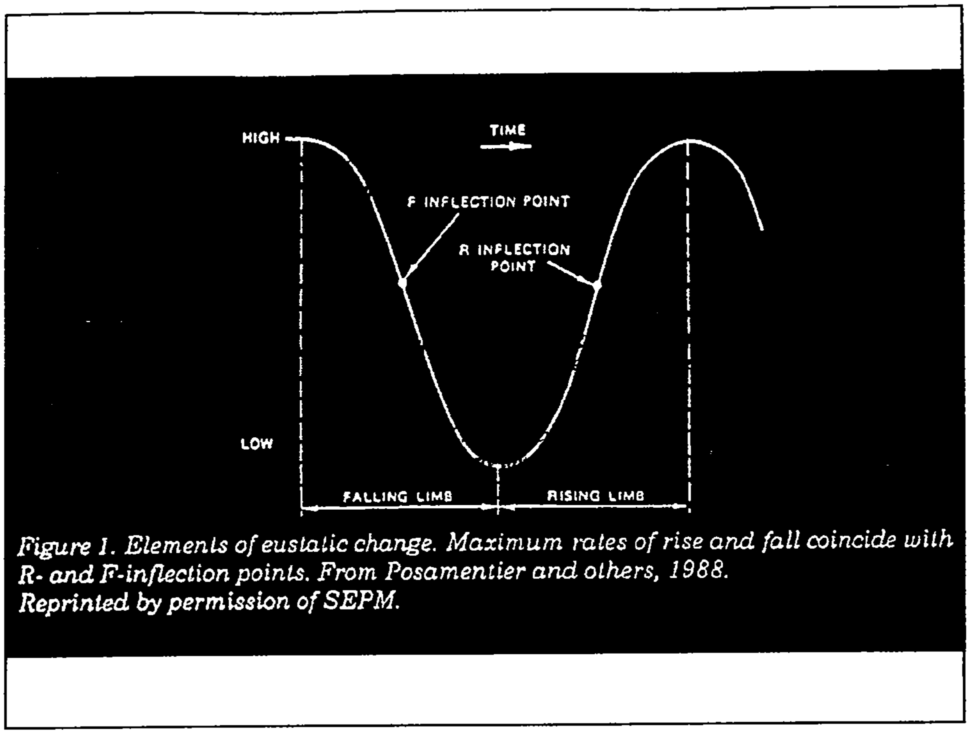


Figure 1. Elements of eustatic change. Maximum rates of rise and fall coincide with R- and F-inflection points. From Posamentier and others, 1988. Reprinted by permission of SEPM.

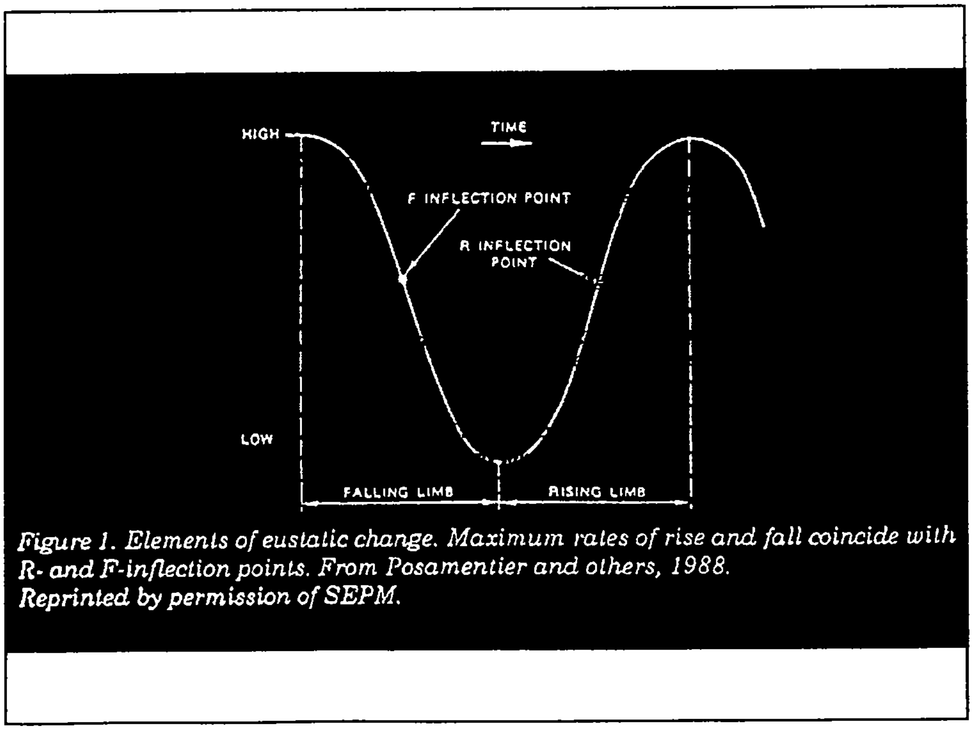


Figure 1. Elements of eustatic change. Maximum rates of rise and fall coincide with R- and F-inflection points. From Posamentier and others, 1988. Reprinted by permission of SEPM.

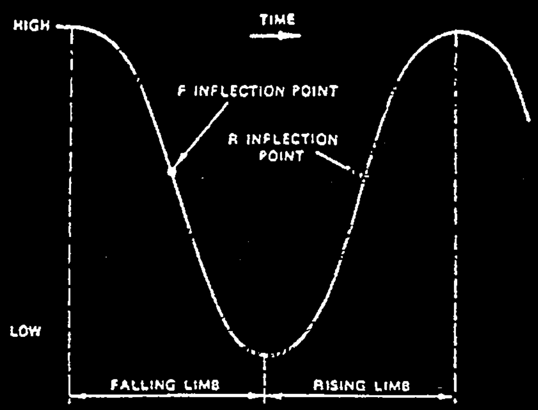
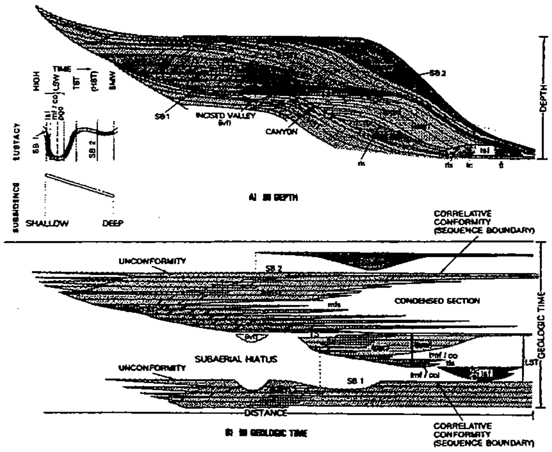


Figure 1. Elements of eustatic change. Maximum rates of rise and fall coincide with R- and F-inflection points. From Posamentier and others, 1988. Reprinted by permission of SEPM.

SEQUENCE STRATIGRAPHY DEPOSITIONAL MODEL
SHOWING SURFACES AND SYSTEMS TRACTS



LEGEND

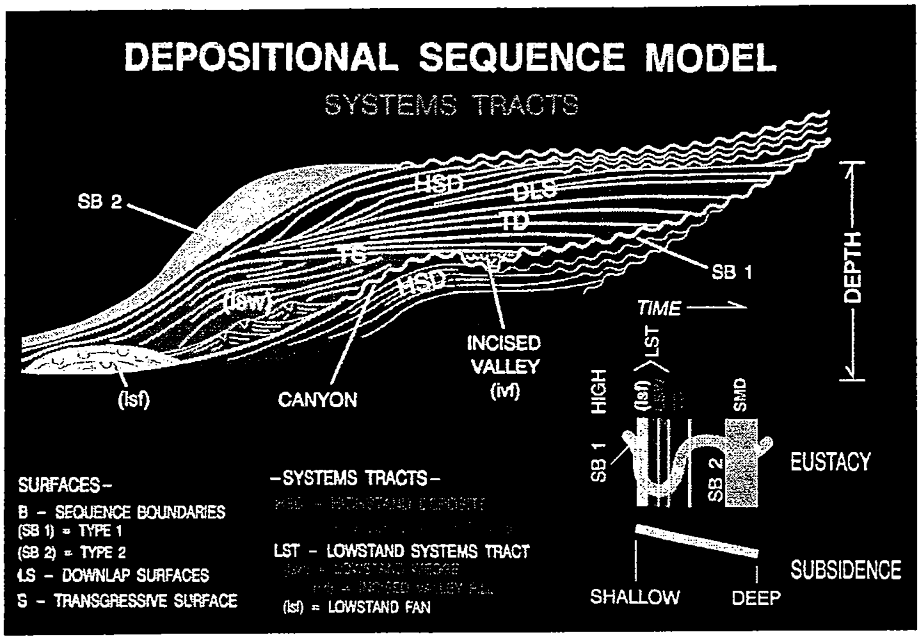
SURFACES

(SB) SEQUENCE BOUNDARIES
  (SB 1) = TYPE 1
  (SB 2) = TYPE 2
(DLS) DOWNLAP SURFACES
  (mfs) = maximum flooding surface
  (tfs) = top fan surface
  (tmf / co) = top mass flow / channel overbank
(TS) TRANSGRESSIVE SURFACE
  (First flooding surface above maximum regression)

SYSTEMS TRACTS

HST = HIGHSTAND SYSTEMS TRACT
TST = TRANSGRESSIVE-SYSTEMS TRACT
  ivf = incised-valley fill
LST = LOWSTAND SYSTEMS TRACT
  ivf = incised-valley fill
  lsw = lowstand wedge
  pgc = prograding complex
  mf / co = mass flow / channel overbank deposits
  lsf = lowstand fan
    fc = fan channels
    fl = fan lobes
SMW = SHELF MARGIN WEDGE SYSTEMS TRACT

Figure 1



DEPOSITIONAL SEQUENCE MODEL

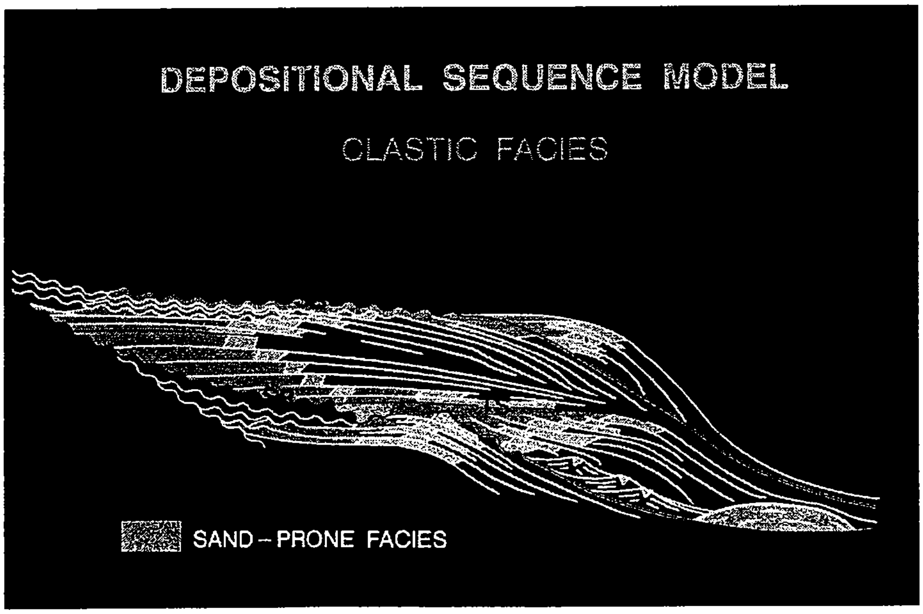
SYSTEMS TRACTS

SURFACES-

B - SEQUENCE BOUNDARIES
(SB 1) = TYPE 1
(SB 2) = TYPE 2
LS - DOWNLAP SURFACES
S - TRANSGRESSIVE SURFACE

-SYSTEMS TRACTS-

HSD - HIGHSTAND DEPOSITE
[illegible]
LST - LOWSTAND SYSTEMS TRACT
(lsw) = LOWSTAND WEDGE
(ivf) = INCISED VALLEY FILL
(lsf) = LOWSTAND FAN



DEPOSITIONAL SEQUENCE MODEL

CLASTIC FACIES

▨ SAND-PRONE FACIES

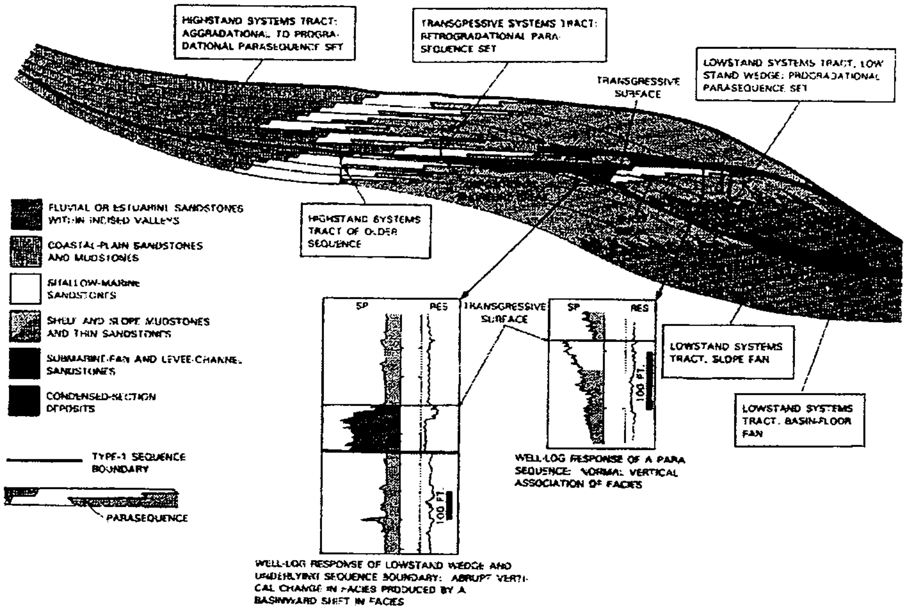


Figure 19—Stratal patterns in a type-1 sequence deposited in a basin with a shelf break.

STACKING PATTERNS

- **A COMPLETE VERTICAL SEQUENCE CONSISTS OF:**

Con

Sequence Boundary

-Highstand systems tract (thin sh. in deep water; deltas)

-Transgressive systems tract, including condensed section (thin, organic rich sh. in deep water; shoreface sands)

-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

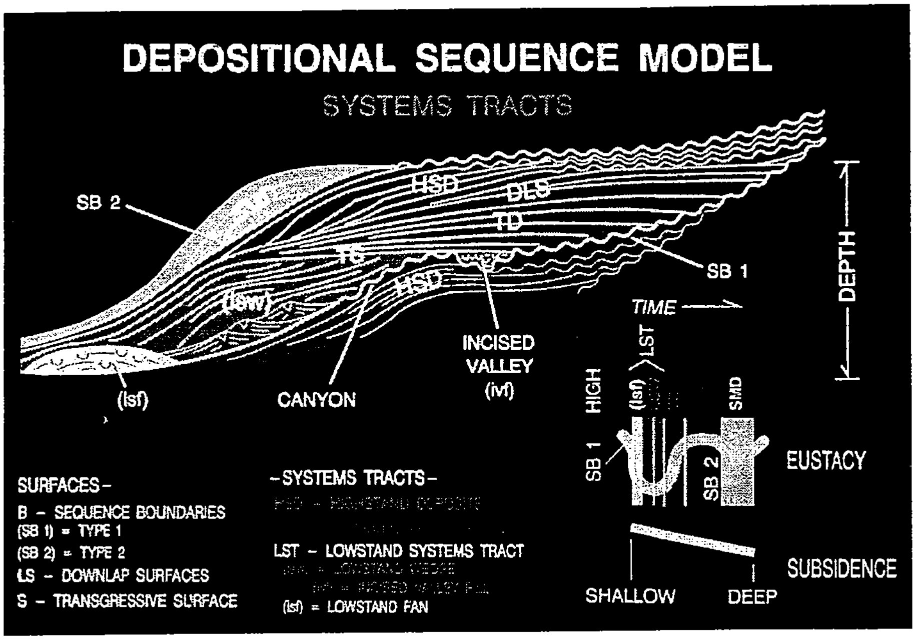
-Mass transport complex

Sequence Boundary

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

DEPOSITIONAL SEQUENCE MODEL

SYSTEMS TRACTS



SURFACES-

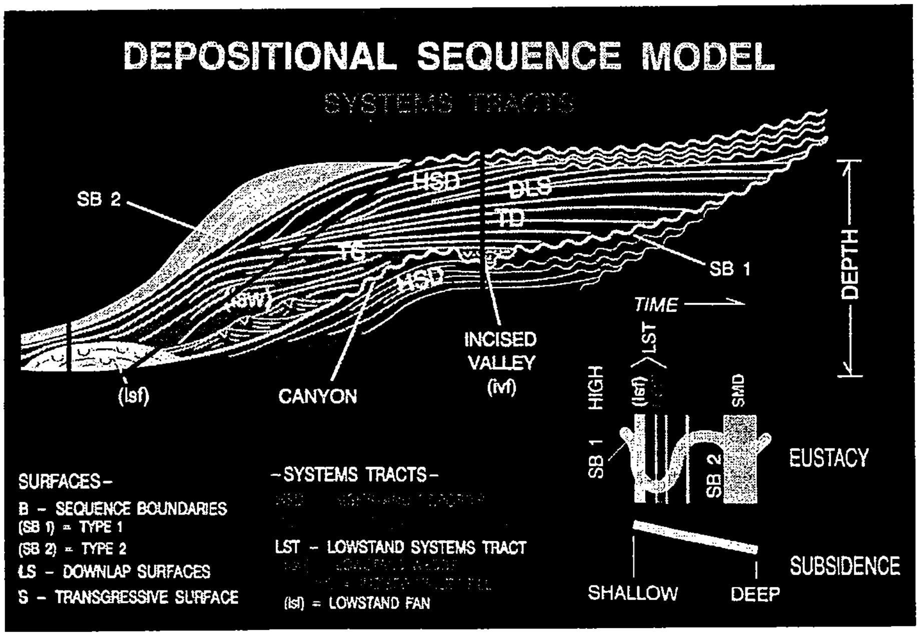
B - SEQUENCE BOUNDARIES
(SB 1) = TYPE 1
(SB 2) = TYPE 2
LS - DOWNLAP SURFACES
S - TRANSGRESSIVE SURFACE

-SYSTEMS TRACTS-

HSD - HIGHSTAND DEPOSITS
[illegible]
LST - LOWSTAND SYSTEMS TRACT
(lsw) = LOWSTAND WEDGE
(ivf) = INCISED VALLEY FILL
(lsf) = LOWSTAND FAN

DEPOSITIONAL SEQUENCE MODEL

SYSTEMS TRACTS



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-SYSTEMS TRACTS-

HSD - HIGHSTAND DEPOSITS
[illegible]
LST - LOWSTAND SYSTEMS TRACT
(lsw) = LOWSTAND WEDGE
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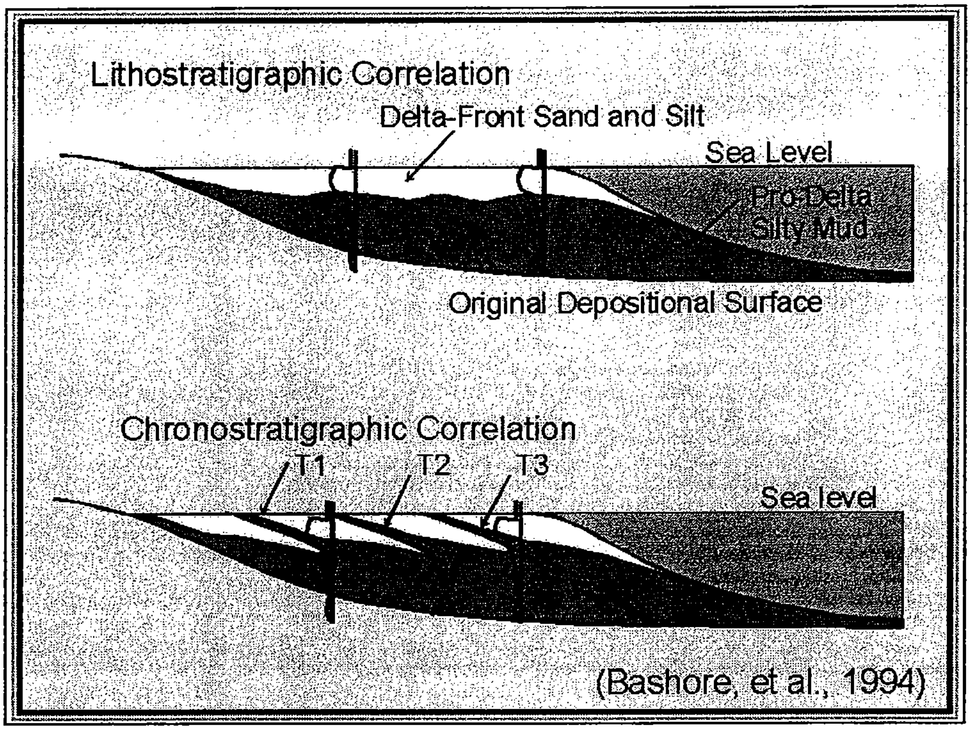
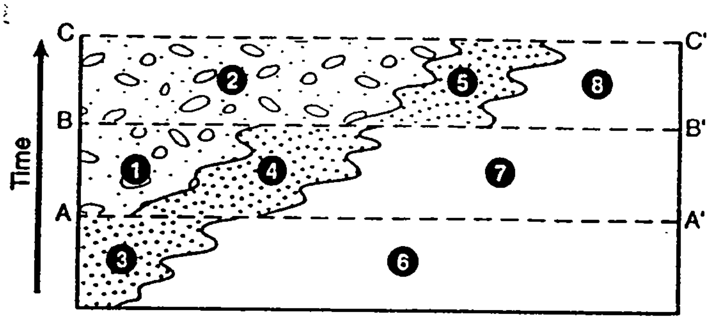
(lsf) = LOWSTAND FAN



(Bashore, et al., 1994)

ROCK vs. TIME STRATIGRAPHY

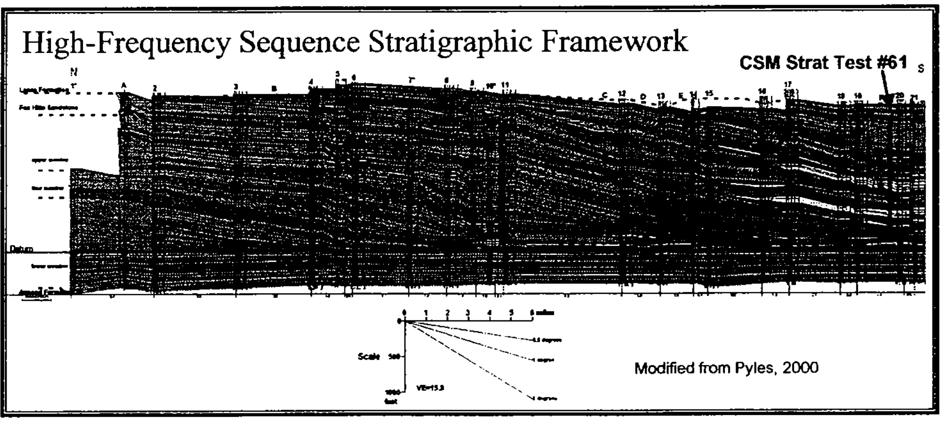
- *LITHOSTRATIGRAPHY*: **CORRELATION OF ROCK UNITS ON THE BASIS OF CHARACTERISTICS;**
- *SEQUENCE STRATIGRAPHY*: **CORRELATION OF UNITS ON THE BASIS OF TIME-EQUIVALENT SURFACES;**
- **OWING TO TIME-TRANSGRESSIVE NATURE OF STRATA, TIME-EQUIVALENT SURFACES CROSS-CUT LITHOSTRATIGRAPHIC BOUNDARIES**



Emery and Myers, 1996

Figure 2.1. The difference between sequence stratigraphy, which has a geological time significance and lithostratigraphy, which correlates rocks of similar type. A lithostratigraphic correlation would correlate conglomerate units 1 and 2, sandstone units 3, 4 and 5 and mudstone units 6, 7 and 8. A sequence stratigraphic correlation would correlate time lines A-A', B-B' and C-C'. Used with permission of Blackwell Science.

High-Frequency Sequence Stratigraphic Framework



Modified from Pyles, 2000

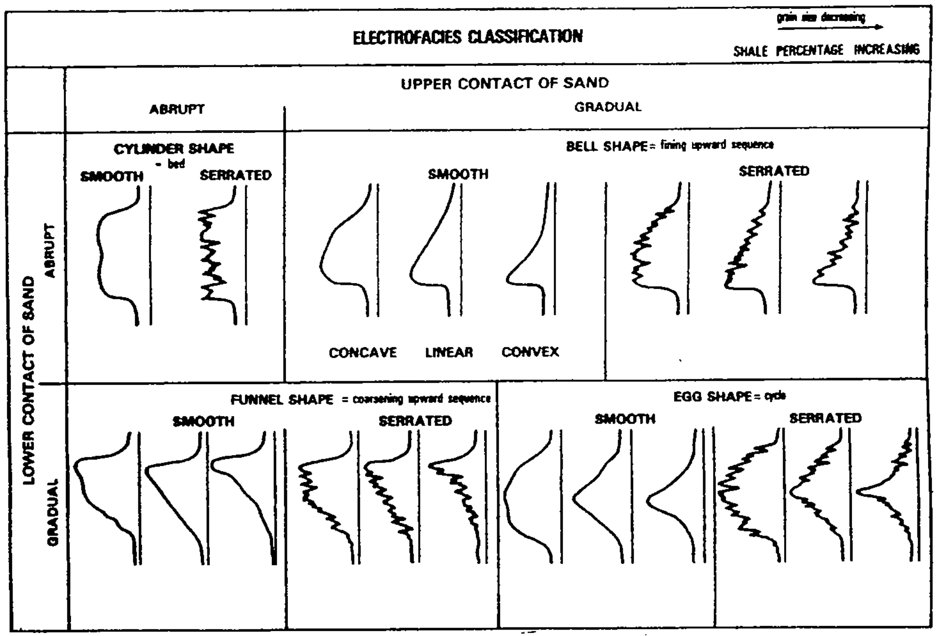
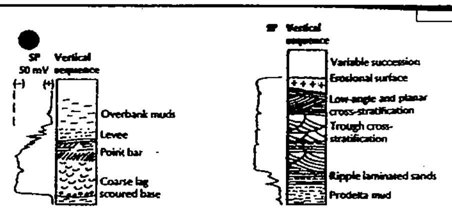
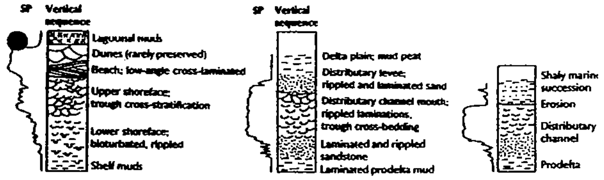


Fig. 3-21. - Relationship between SP curve shape and grain size or shaliness (adapted from SHELL's documents).



Common thickness: 8–35 ft (2–10 m)
Geometry: multistory sheet or shoestring
Width and length: extremely variable
Trend: roughly perpendicular to depositional strike
A

Common thickness: 10–40 ft (3–13 m)
Geometry: sheet or shoestring
Length: up to tens of kilometers
Width: variable
Trend: parallel to depositional strike
B



Common thickness: 20–60 ft (7–20 m), but may exceed 80 ft (25m)
Geometry: elongate
Length: up to 60 km
Width: 1–20 km (depending on preservation)
Trend: parallel to depositional strike
C

Common thickness: 10–40 ft (2–13 m)
Geometry: podiform to elongate
Length and width: variable
Trend: associated with delta lobes
D

Real example of preserved distributary channel mouth: Wilcox Group, Gulf Coast

Figure 17.6

Idealized examples of stratigraphic motifs and self-potential (SP) logs for (A) a fluvial meander, (B) a coastal barrier, (C) a barrier island, and (D) a distributary channel mouth. Note that the log shape is an approximation of the grain size and sand content. For example, the fining-upward fluvial sequence also tapers upward on the SP curve; the coarsening-upward barrier island sequence also widens upward. (After Galloway, 1978.)

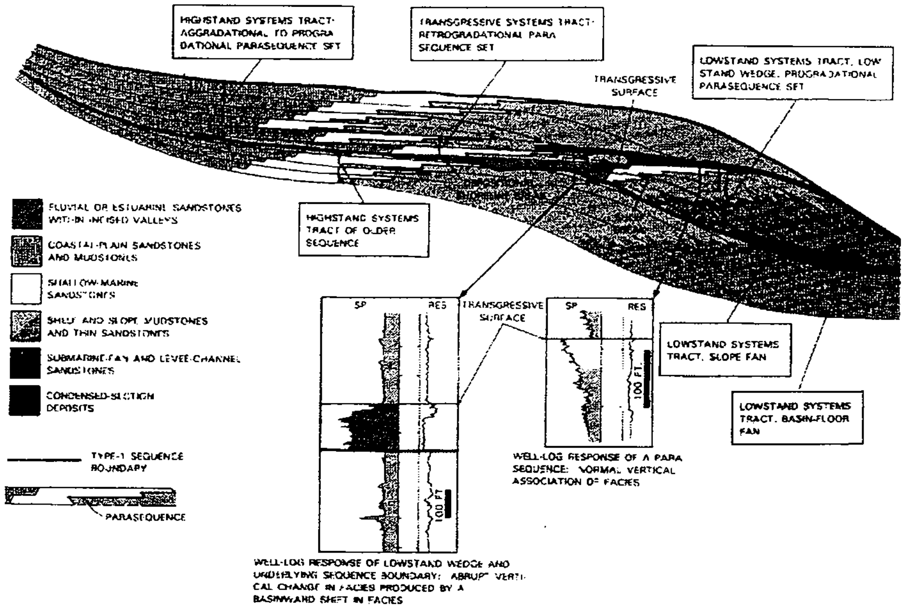


Figure 19—Stratal patterns in a type-1 sequence deposited in a basin with a shelf break.

APPLIED RESERVOIR CHARACTERIZATION FOR THE INDEPENDENT OPERATOR: WITH EMPHASIS ON COMPARTMENTALIZED RESERVOIRS AND ROUTINE TECHNIQUES FOR DETECTING COMPARTMENTS

UNIT 1: INTRODUCTION TO RESERVOIR CHARACTERIZATION

UNIT 2: EXAMPLES OF COMPARTMENTALIZED RESERVOIRS

UNIT 3: GEOLOGIC CONTROLS ON POROSITY AND PERMEABILITY

UNIT 3A: SEISMIC POROSITY DETECTION IN A CARBONATE RESERVOIR

UNIT 4: FLOW UNIT DETERMINATION & CHARACTERIZATION

UNIT 5: BASICS OF SEQUENCE STRATIGRAPHY

*UNIT 6: FLUVIAL DEPOSITS AND RESERVOIRS

UNIT 7: EOLIAN DEPOSITS AND RESERVOIRS

UNIT 8: SHOREFACE DEPOSITS AND RESERVOIRS

UNIT 9: DELTAIC DEPOSITS AND RESERVOIRS

UNIT 10: DEEP-WATER (TURBIDITE) DEPOSITS AND RESERVOIRS

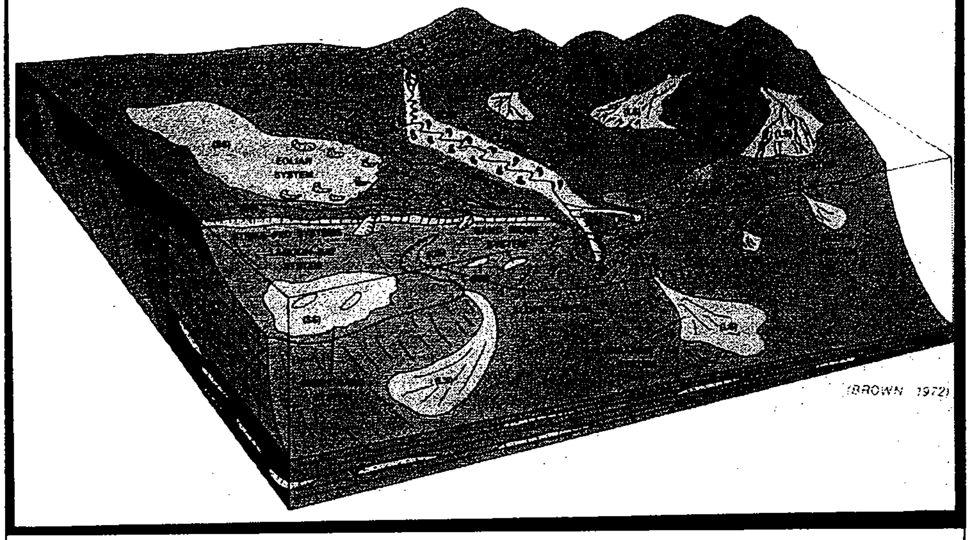
UNIT 11: BOREHOLE IMAGE LOGS AND APPLICATIONS

UNIT 12: DIPMETER LOGS AND APPLICATIONS

UNIT 13: STRUCTURALLY COMPARTMENTALIZED RESERVOIRS

KEY REFERENCES TO INDIVIDUAL UNITS

ENVIRONMENTAL SETTING OF CLASTIC STRATIGRAPHIC TRAPS



(BROWN 1972)

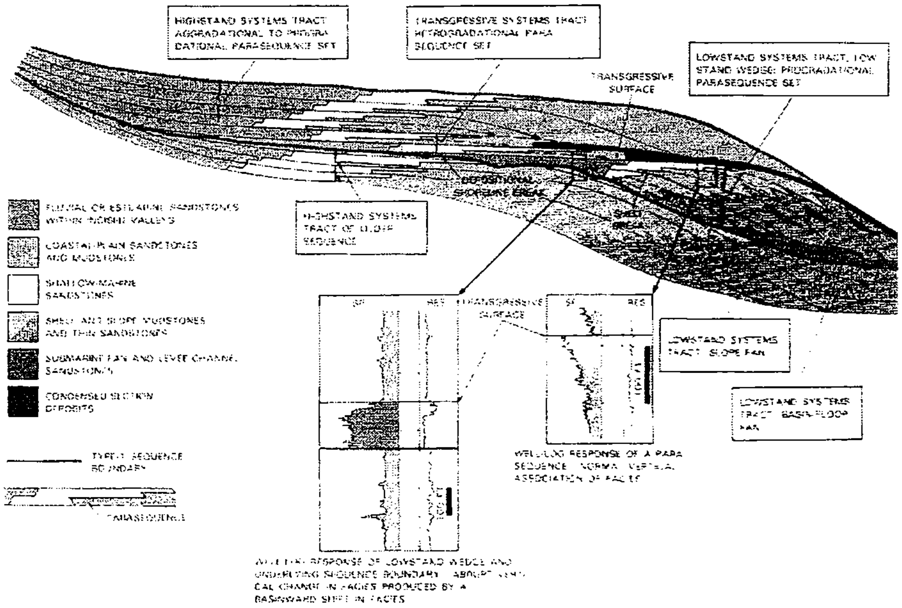


Figure 19—Stratal patterns in a type-1 sequence deposited in a basin with a shelf break.

FLUVIAL (RIVER) DEPOSITS

-ORIGIN

-TYPES

  -Point Bar (Meandering)
  -Braided
  -Alluvial fan
  -Incised valley fill

-CHARACTERISTICS

-RESERVOIR EXAMPLES

FLUVIAL (RIVER) DEPOSITS

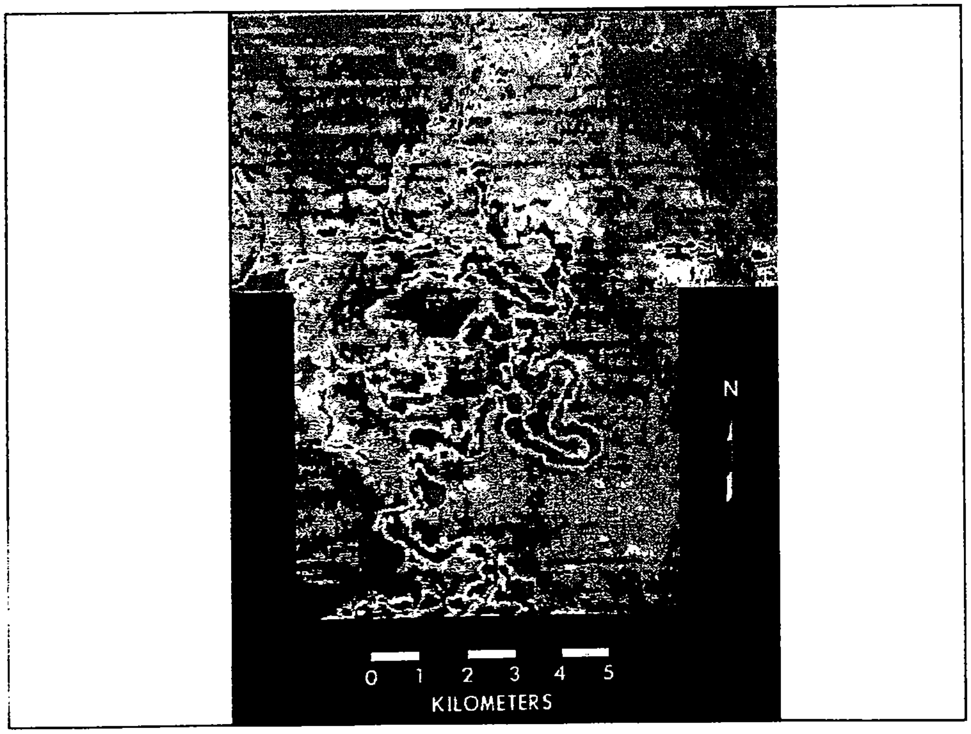
-ORIGIN

-TYPES

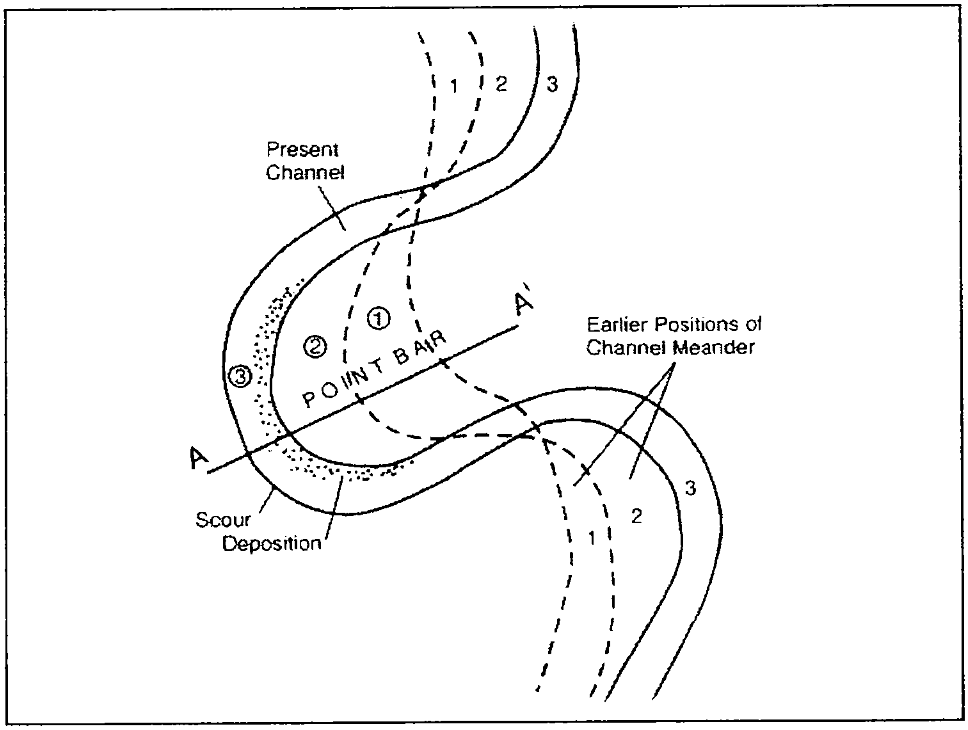
  -Point Bar (Meandering)
  -Braided
  -Alluvial fan
  -Incised valley fill

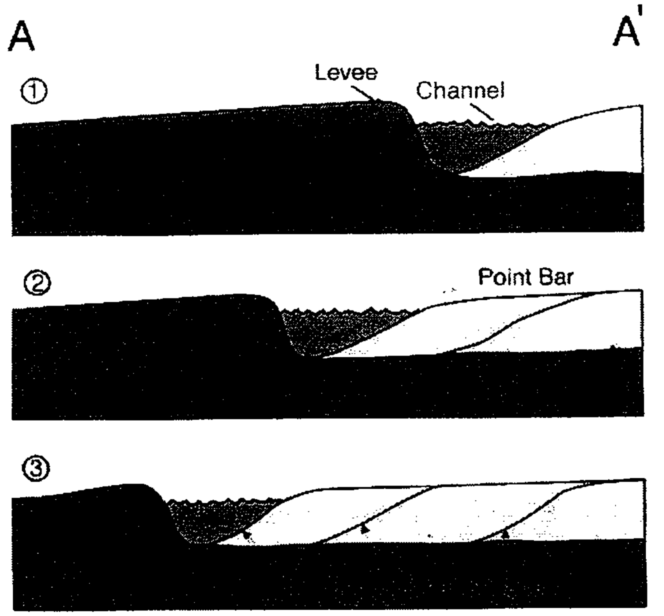
-CHARACTERISTICS

-RESERVOIR EXAMPLES

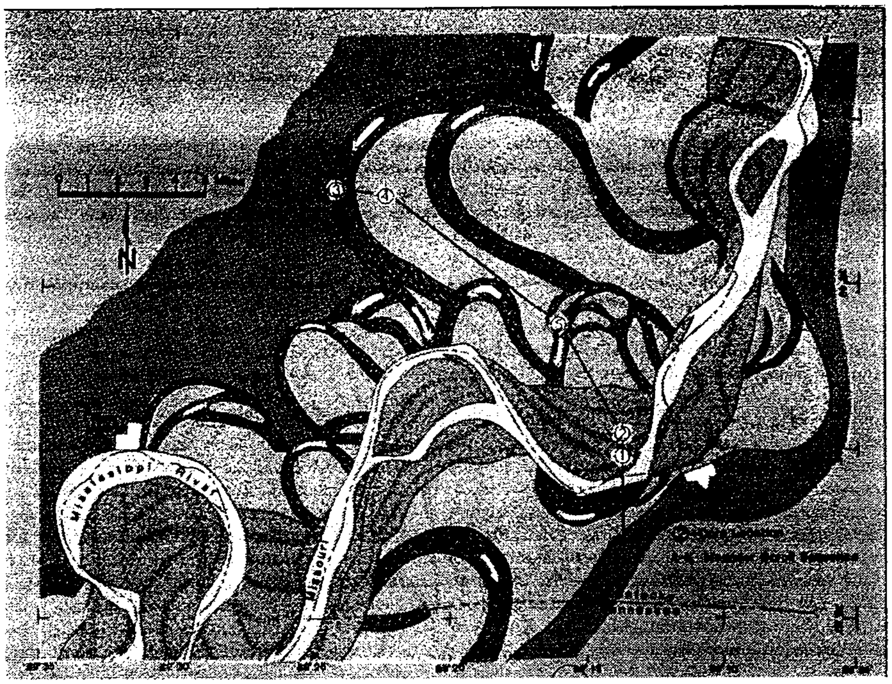

N
0 1 2 3 4 5
KILOMETERS

Meander bend in river, showing ripples and cutbank and point bar

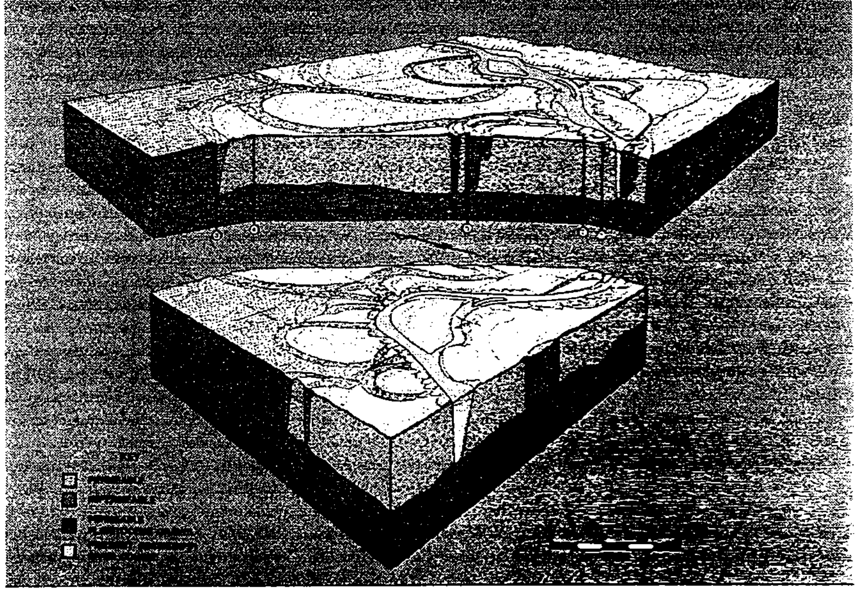


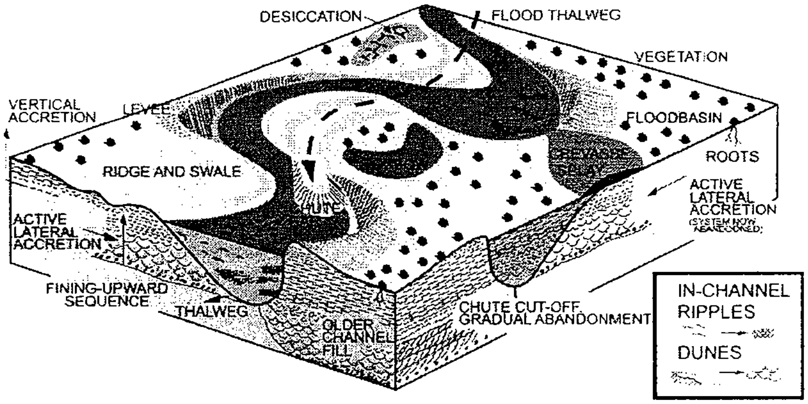


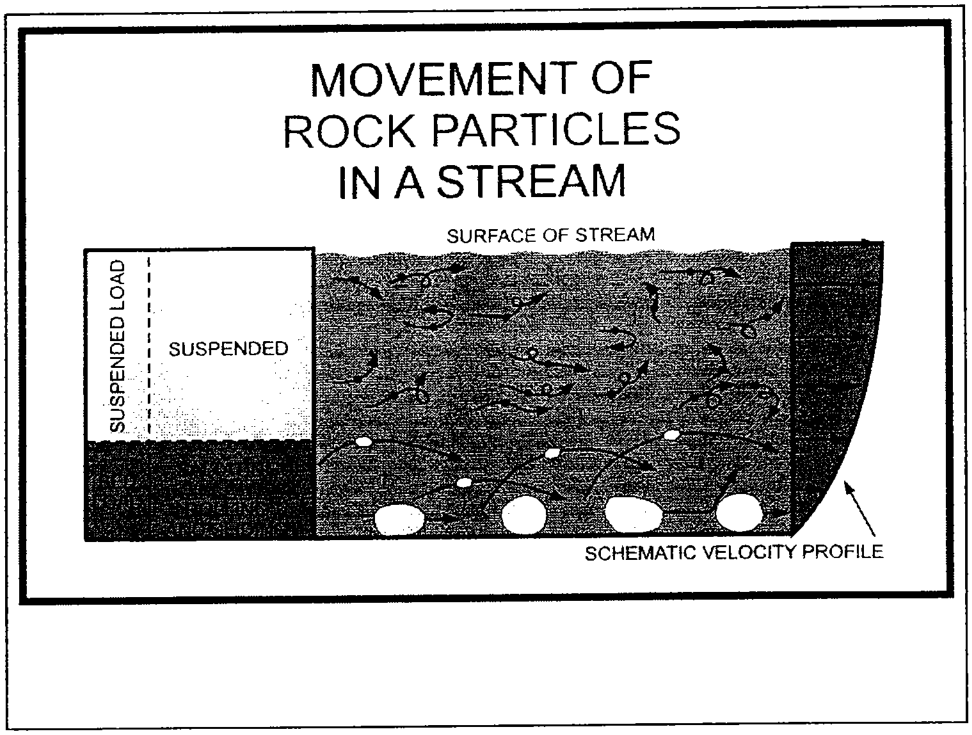
(LeBlanc, 1972)



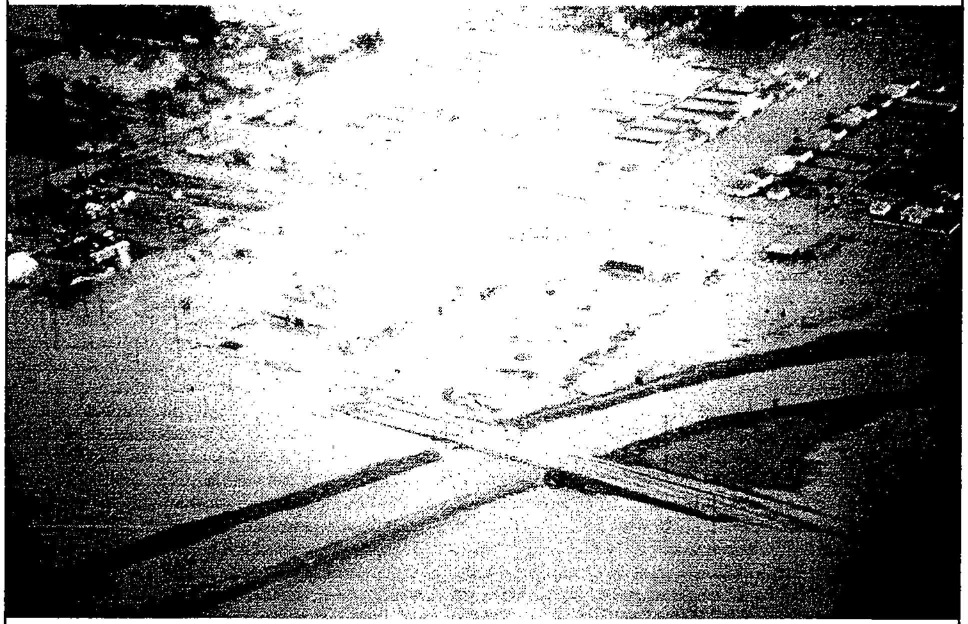
LEVEL 1 HETEROGENEITY
MISSISSIPPI RIVER MEANDER BELT
SOUTHEASTERN MISSOURI

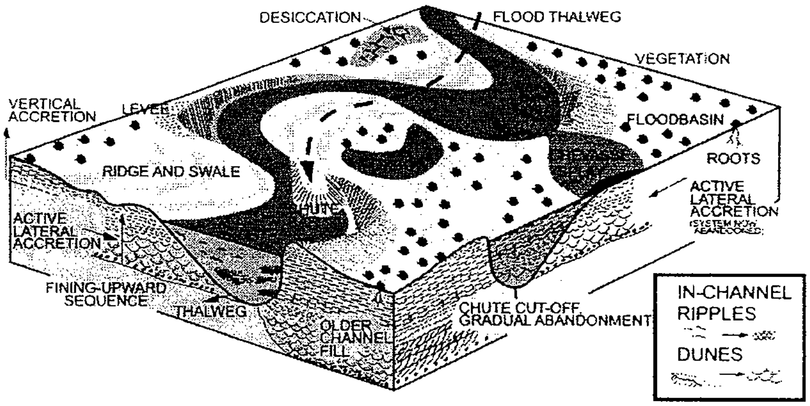



DESICCATION
FLOOD THALWEG
VEGETATION
VERTICAL ACCRETION
LEVEE
FLOODBASIN
ROOTS
RIDGE AND SWALE
CHUTE
ACTIVE LATERAL ACCRETION
ACTIVE LATERAL ACCRETION (SYSTEM NOW ABANDONED)
FINING-UPWARD SEQUENCE
THALWEG
OLDER CHANNEL FILL
CHUTE CUT-OFF
GRADUAL ABANDONMENT
IN-CHANNEL
RIPPLES
DUNES



MOVEMENT OF ROCK PARTICLES IN A STREAM





DESICCATION
FLOOD THALWEG
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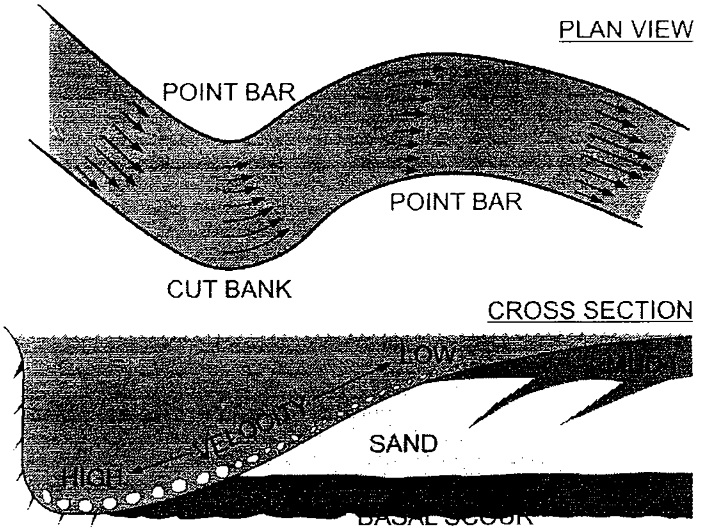
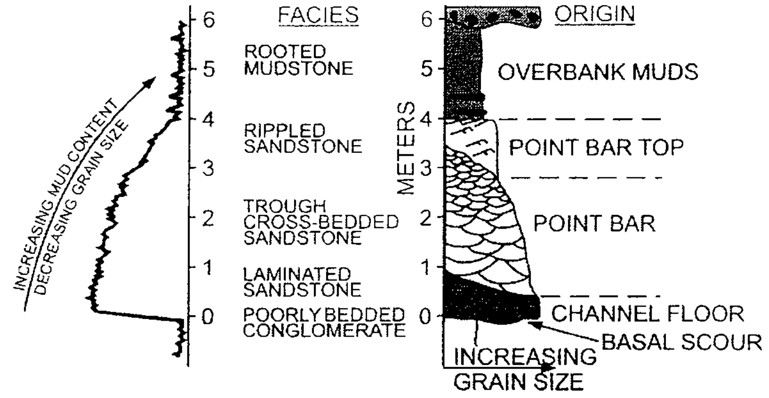
THALWEG
OLDER CHANNEL FILL
CHUTE CUT-OFF GRADUAL ABANDONMENT
IN-CHANNEL
RIPPLES
DUNES

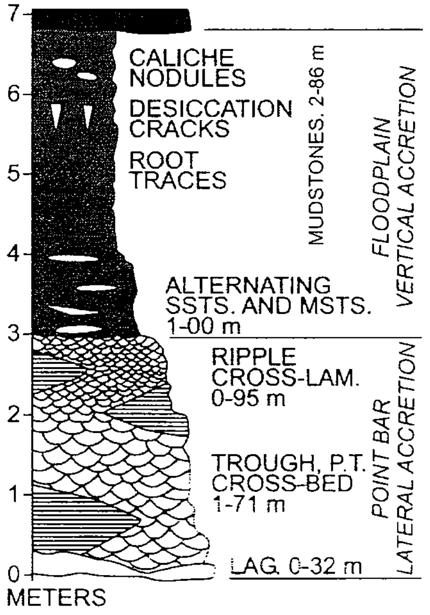
FLOW AND SEDIMENT TRANSPORT IN A MEANDERING RIVER



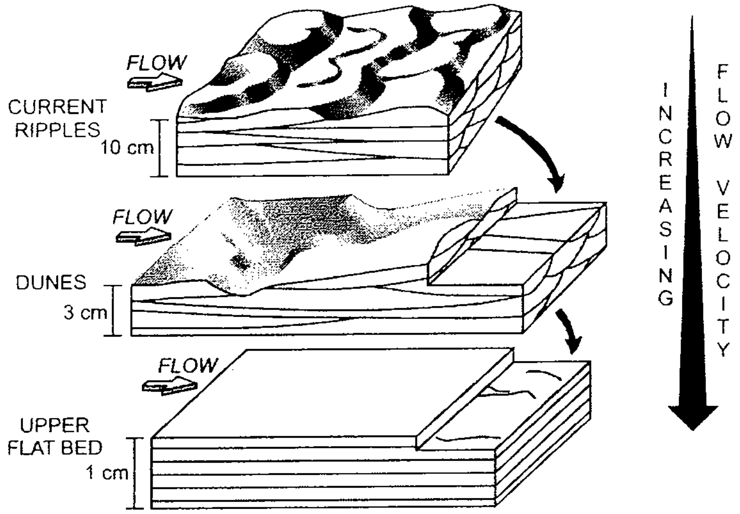
MEANDERING RIVER FACIES MODEL

GAMMA RAY/SP LOG RESPONSE LIGHOLOGIC VERTICAL SEQUENCE





BED FORM SEQUENCE WITH INCREASING FLOW VELOCITY



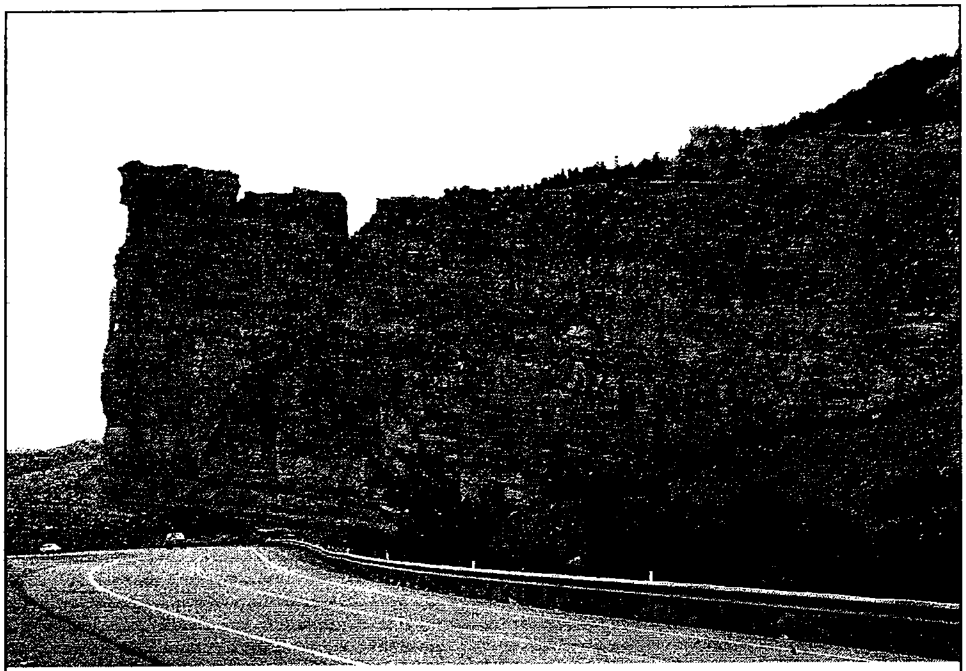
FLUVIAL (RIVER) DEPOSITS

-ORIGIN

-TYPES
 - ***-Point Bar***
 - ***-Braided***
 - ***-Alluvial fan***
 - ***-Incised valley fill***

-CHARACTERISTICS

-RESERVOIR EXAMPLES



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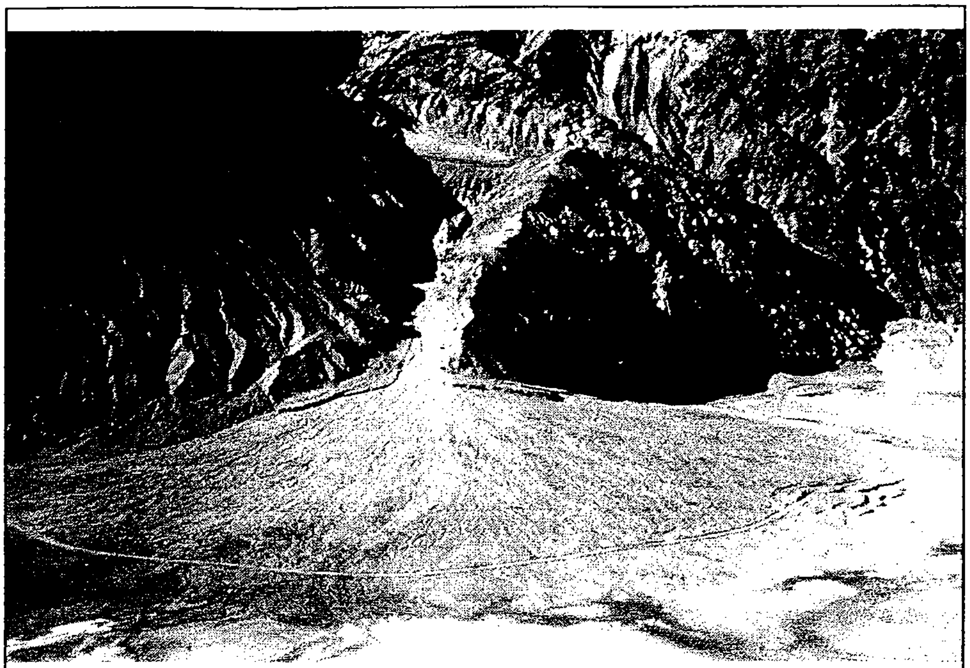
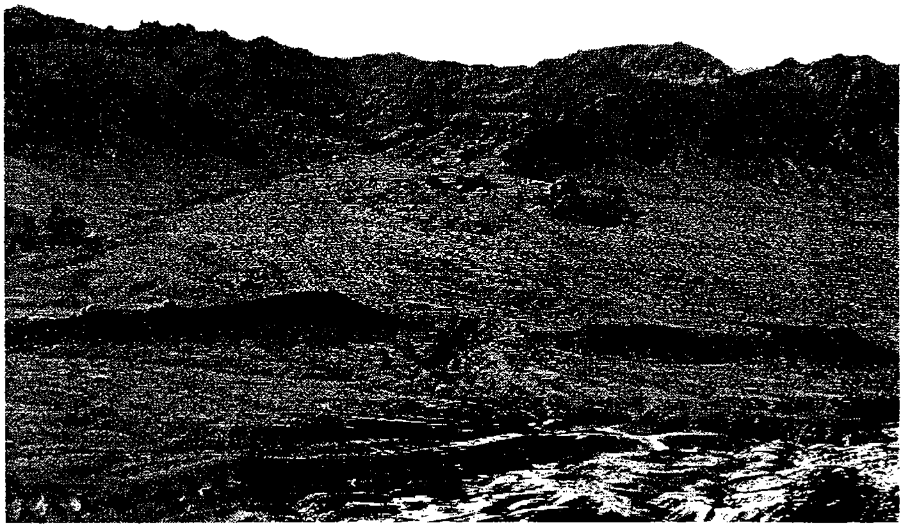
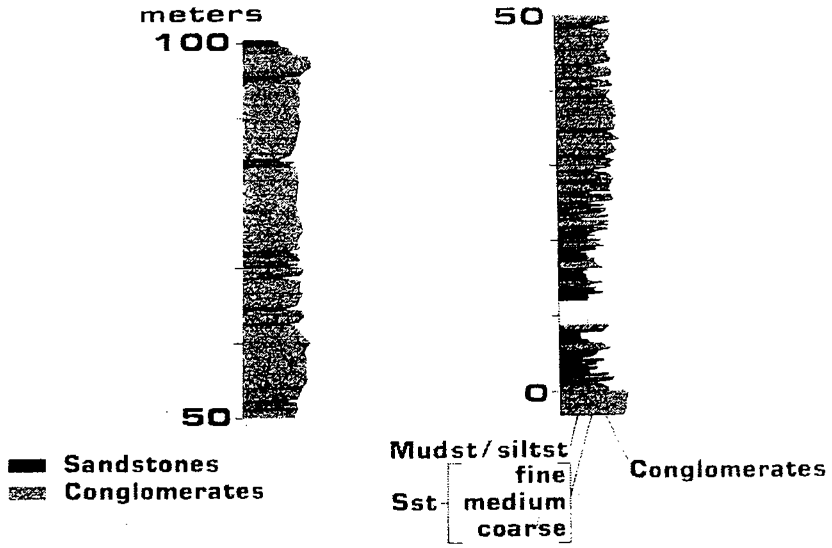




COARSENING-UPWARDS ALLUVIAL FAN SEQUENCES



FLUVIAL (RIVER) DEPOSITS

-ORIGIN

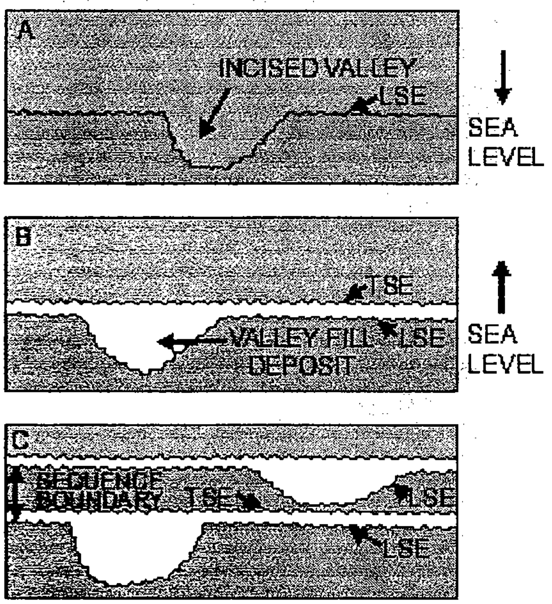
-TYPES
  - *-Point Bar*
  - *-Braided*
  - *-Alluvial fan*
  - *-Incised valley fill*

-CHARACTERISTICS

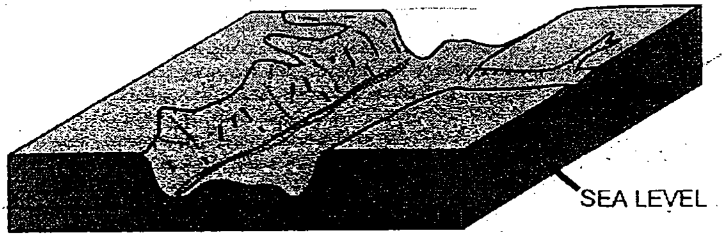
-RESERVOIR EXAMPLES

INCISED VALLEY FILL RESERVOIRS

- VALLEY IS INCISED DURING FALL IN SEA (BASE) LEVEL
- VALLEY IS FILLED DURING TURNAROUND AND RISE IN SEA (BASE) LEVEL
- IDEAL VERTICAL SEQUENCE:
  - -BASAL FLUVIAL LAG
  - -ESTUARINE STRATA
  - -OPEN MARINE STRATA
- LATERAL SEQUENCE: ESTUARINE TO FLUVIAL IN THE PALEO-LANDWARD DIRECTION
- ENCASED IN MARINE SHALE, SO GOOD STRAT. TRAP

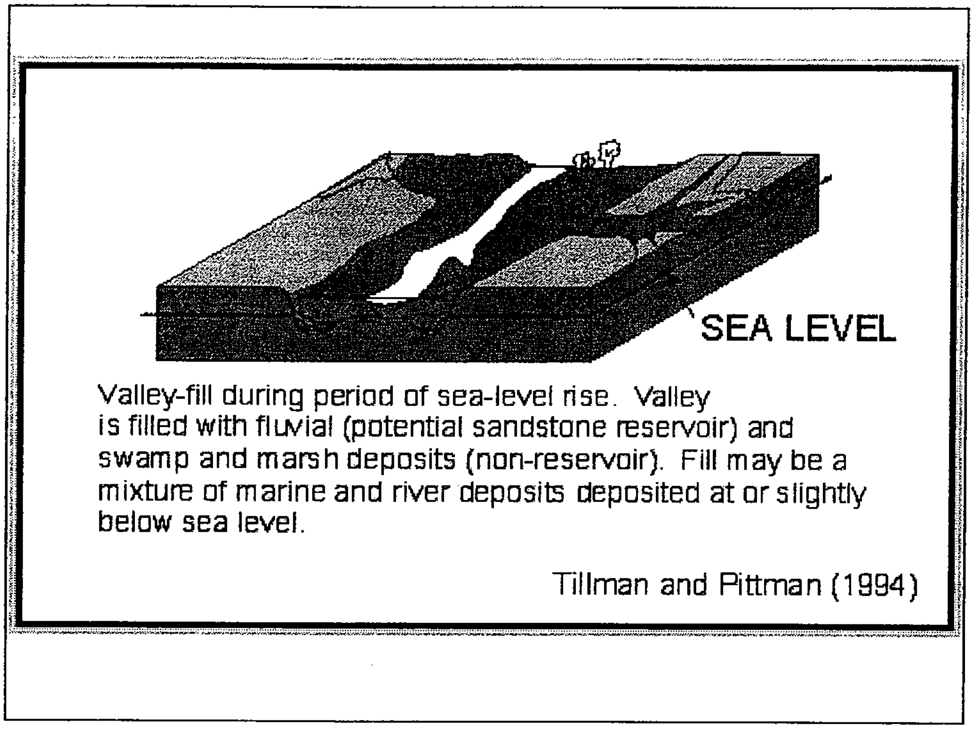


(Weimer, 1994)



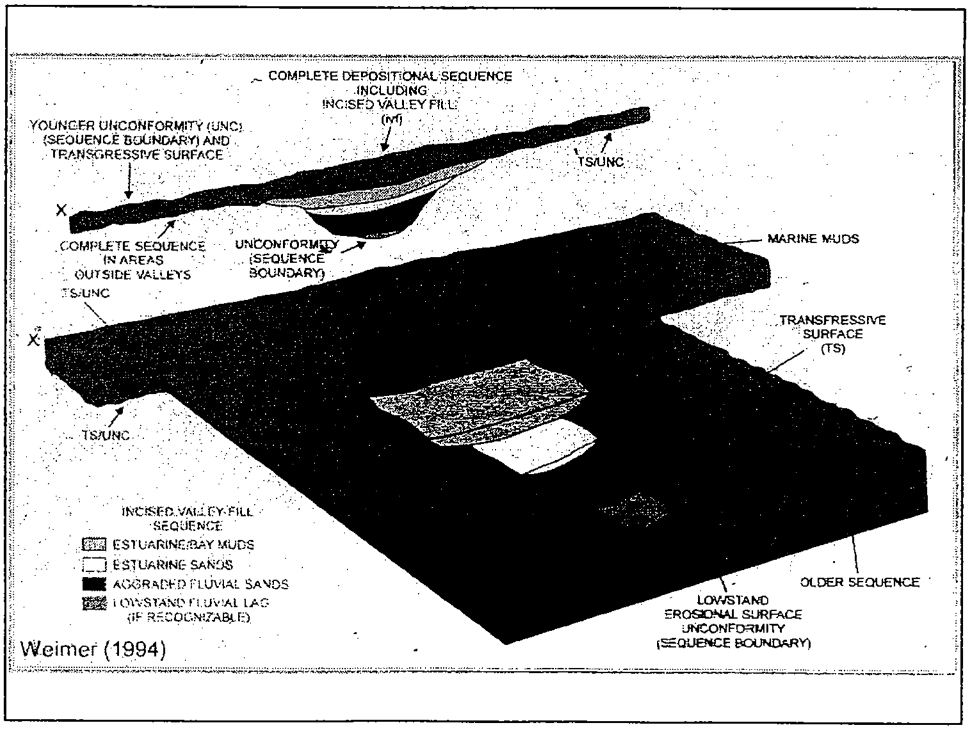
Valley cut into sediment during sea-level drop. At this time the valley is an open conduit in which no sediment is accumulated.

Tillman and Pittman (1994)



Valley-fill during period of sea-level rise. Valley is filled with fluvial (potential sandstone reservoir) and swamp and marsh deposits (non-reservoir). Fill may be a mixture of marine and river deposits deposited at or slightly below sea level.

Tillman and Pittman (1994)



Weimer (1994)

FLUVIAL (RIVER) DEPOSITS

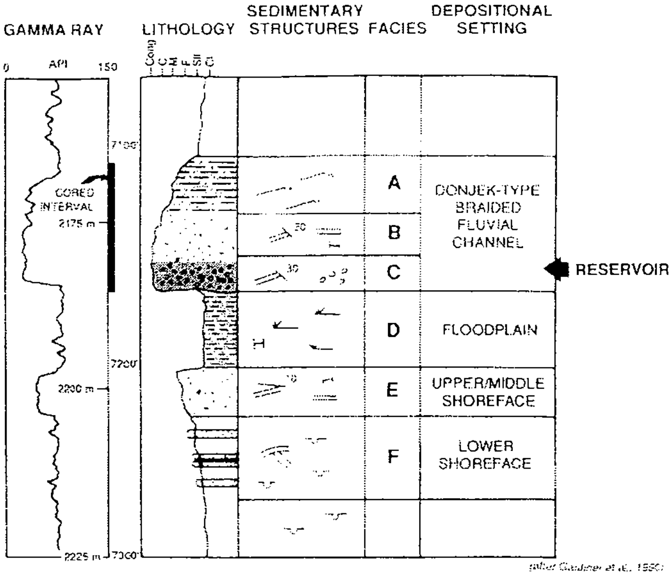
-ORIGIN

-TYPES
  - *-Point Bar*
  - *-Braided*
  - *-Alluvial fan*
  - *-Incised valley fill*

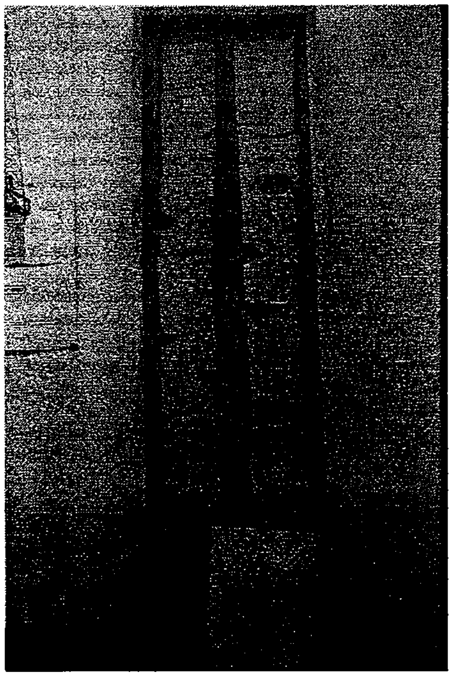
-CHARACTERISTICS

-RESERVOIR EXAMPLES
  - *-Peco Field, Alberta*
  - *-Murdoch Field, North Sea*

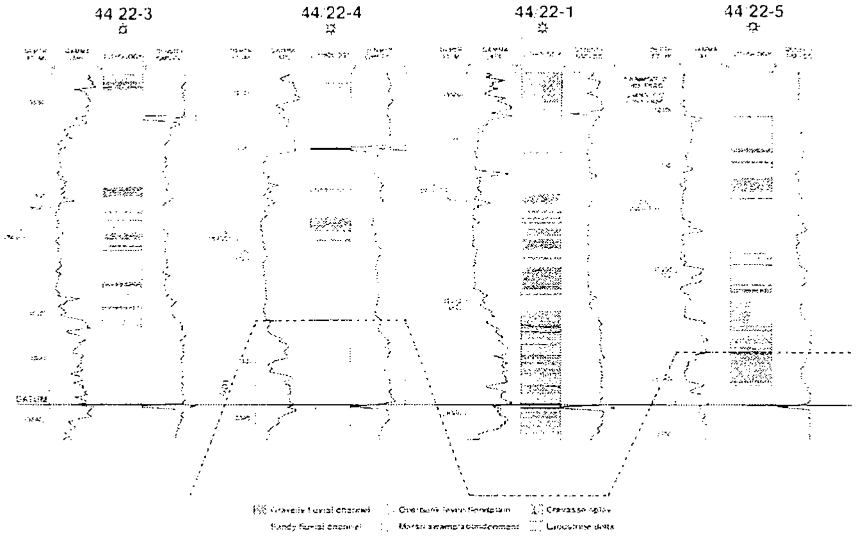
PECO FIELD, ALBERTA

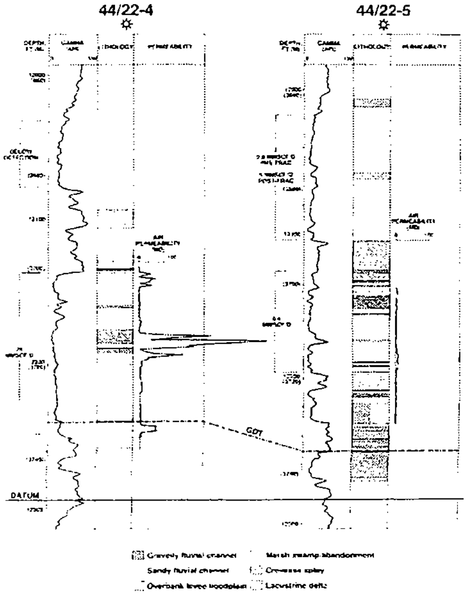


(after Gardner et al., 1990)

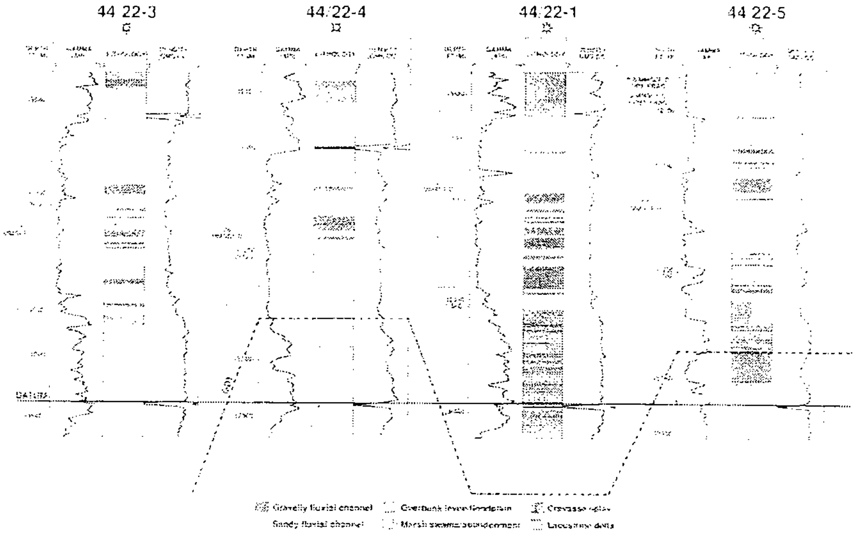


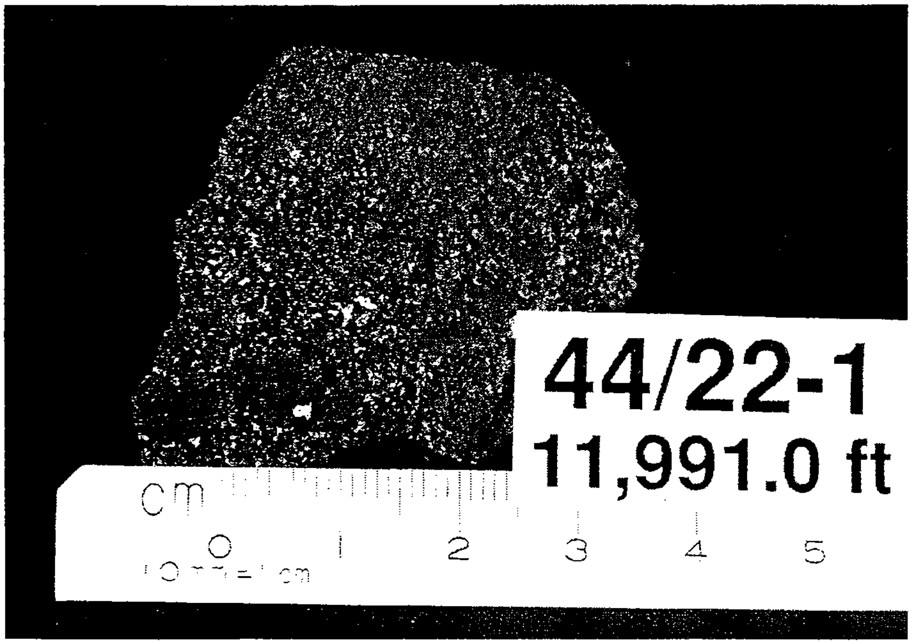
MURDOCH FIELD





MURDOCH FIELD





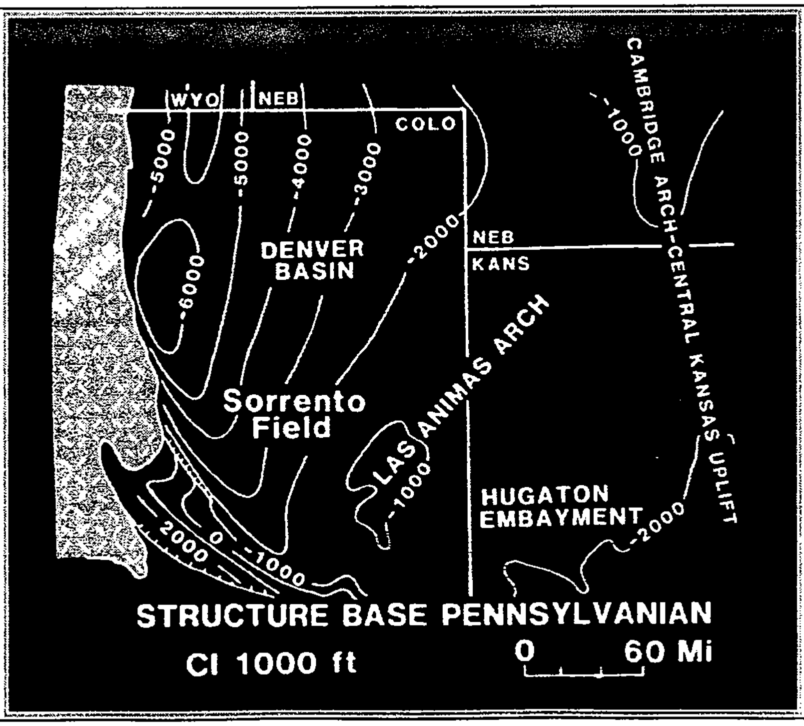
FLUVIAL (RIVER) DEPOSITS

-ORIGIN

-TYPES
- *-Point Bar*
- *-Braided*
- *-Alluvial fan*
- *-Incised valley fill*

-CHARACTERISTICS

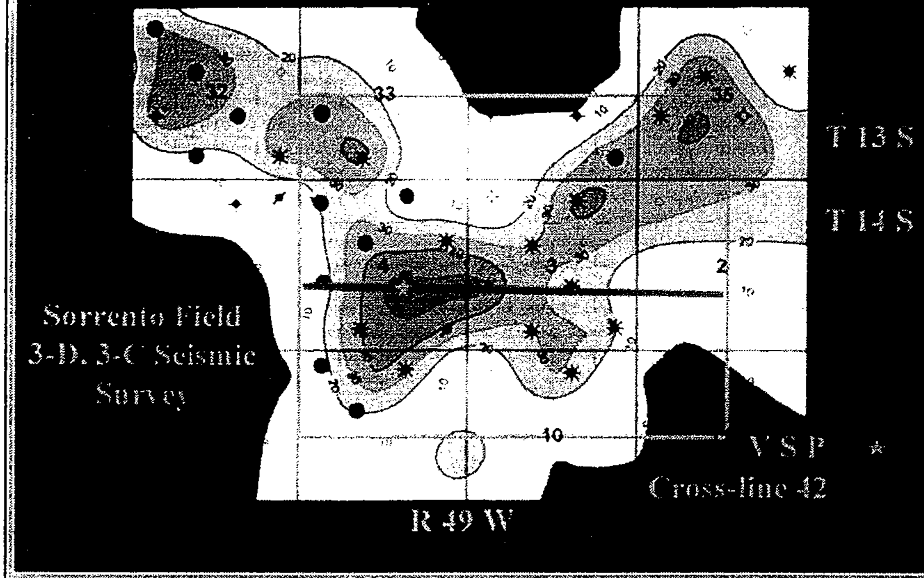
-RESERVOIR EXAMPLES
- *-Sorrento Field*
- *-Stockholm Field*



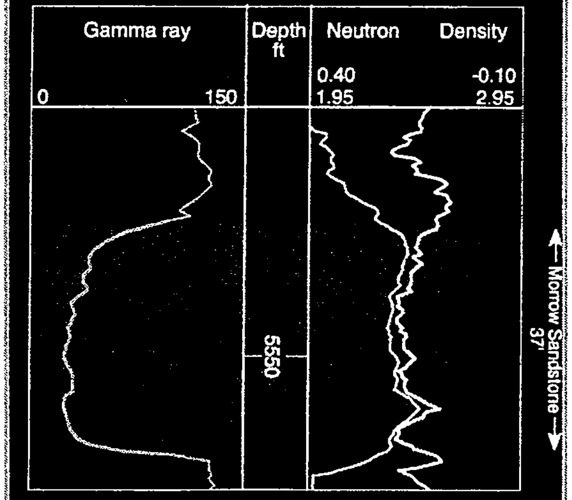
STRUCTURE BASE PENNSYLVANIAN

CI 1000 ft

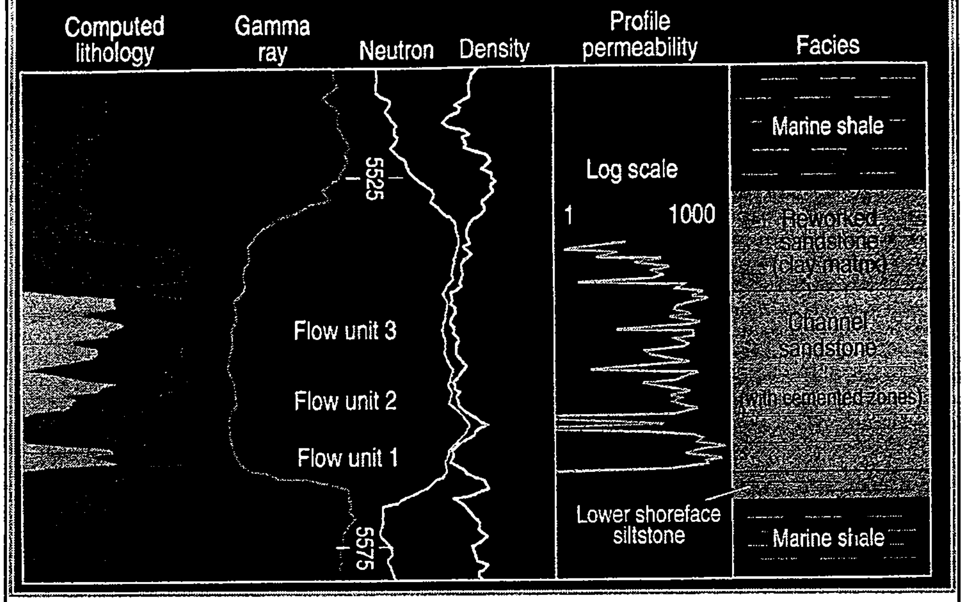
Sandstone Thickness - GR < 75

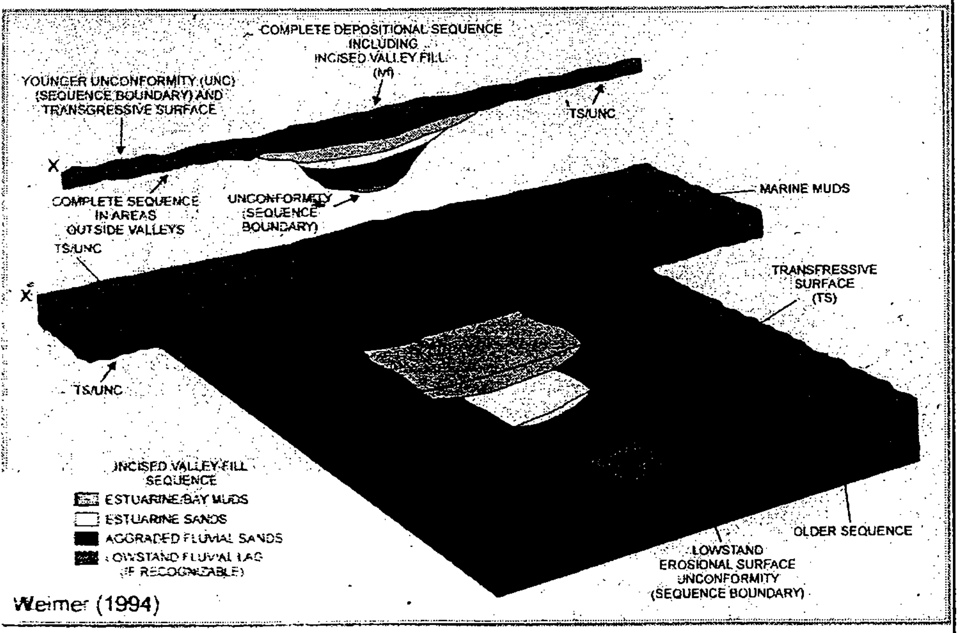


#7 McCormick
Sec 33 T13S / R49W



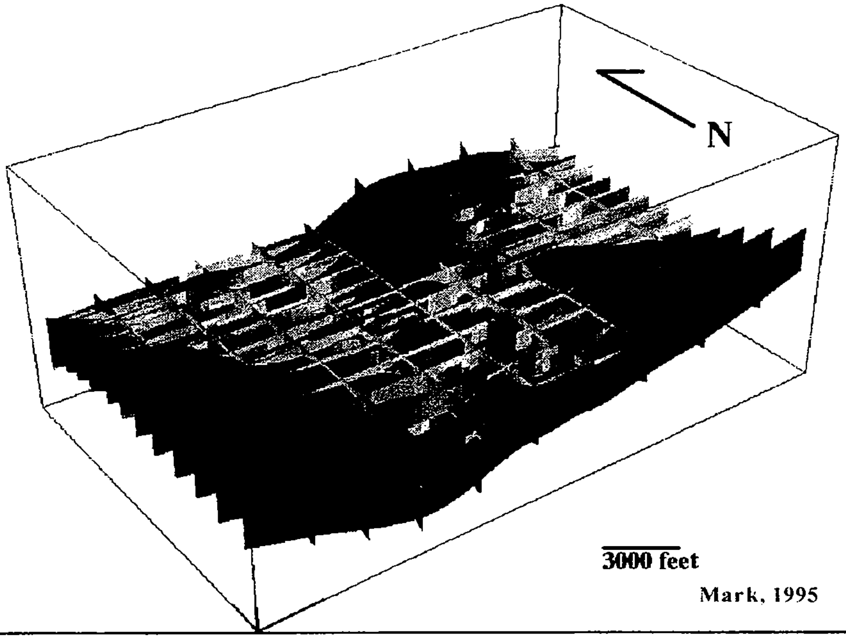
#7 McCormick Log Display





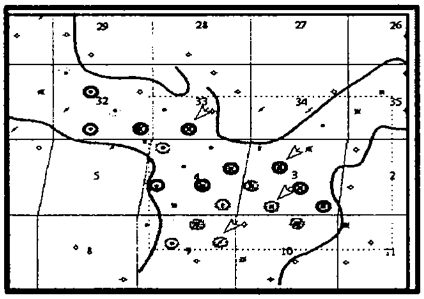
Weimer (1994)

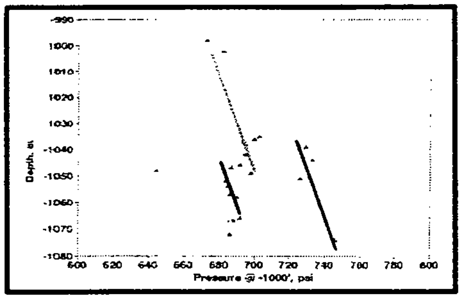
Incised Valley Topography and Valley Fill Facies



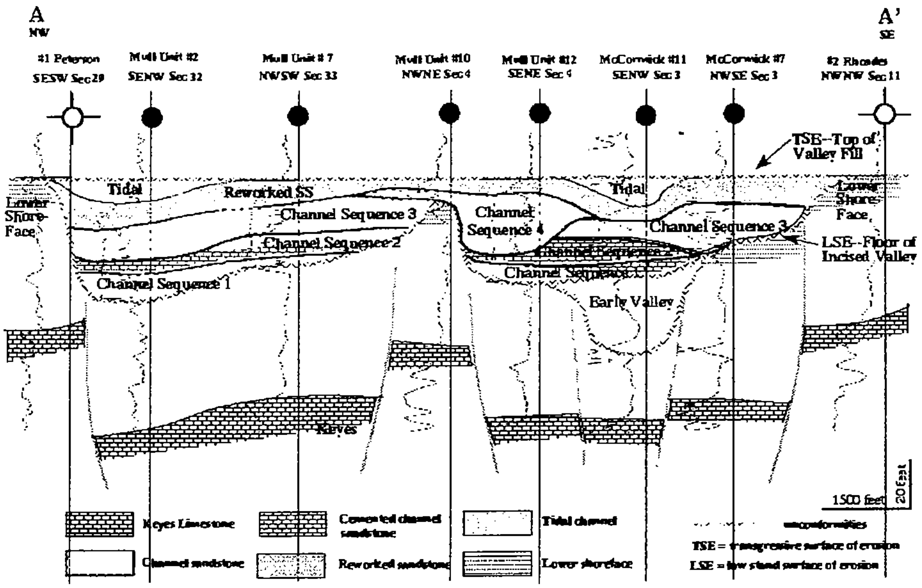
Mark, 1995

Static Pressure Test Results

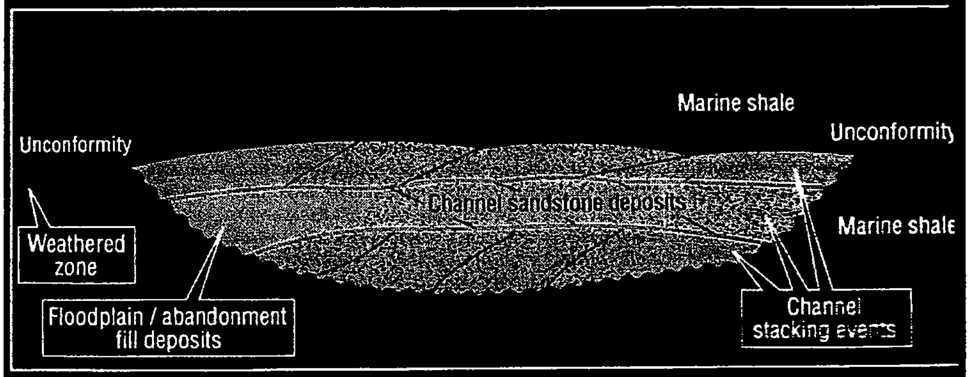




Mark, 1995

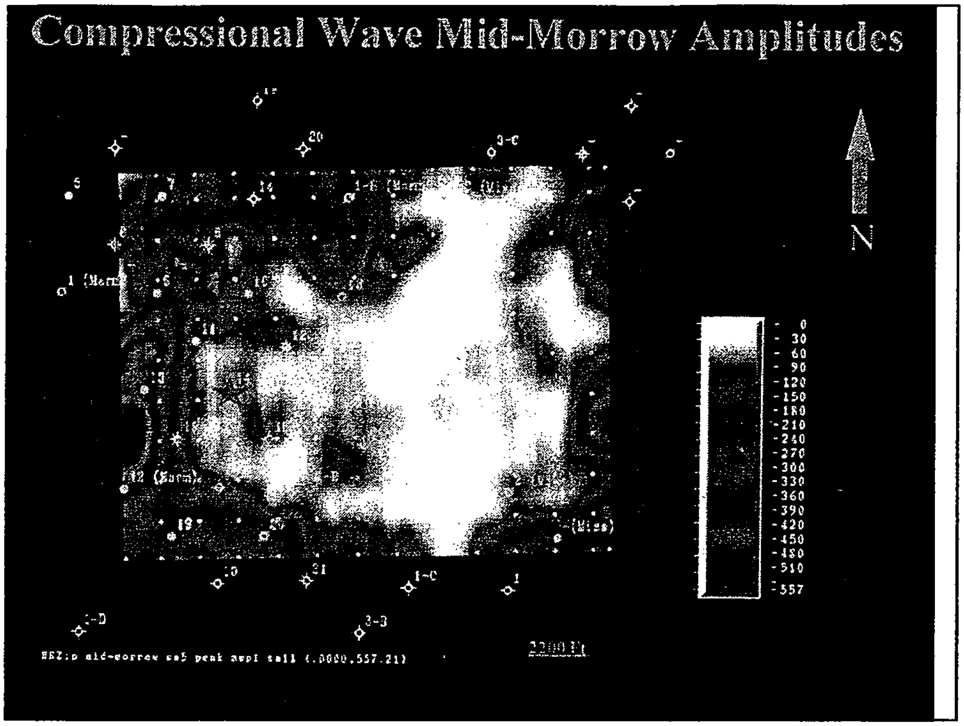


Vertical Units of Flow-Units May Represent Cycles of Channel Stacking Events

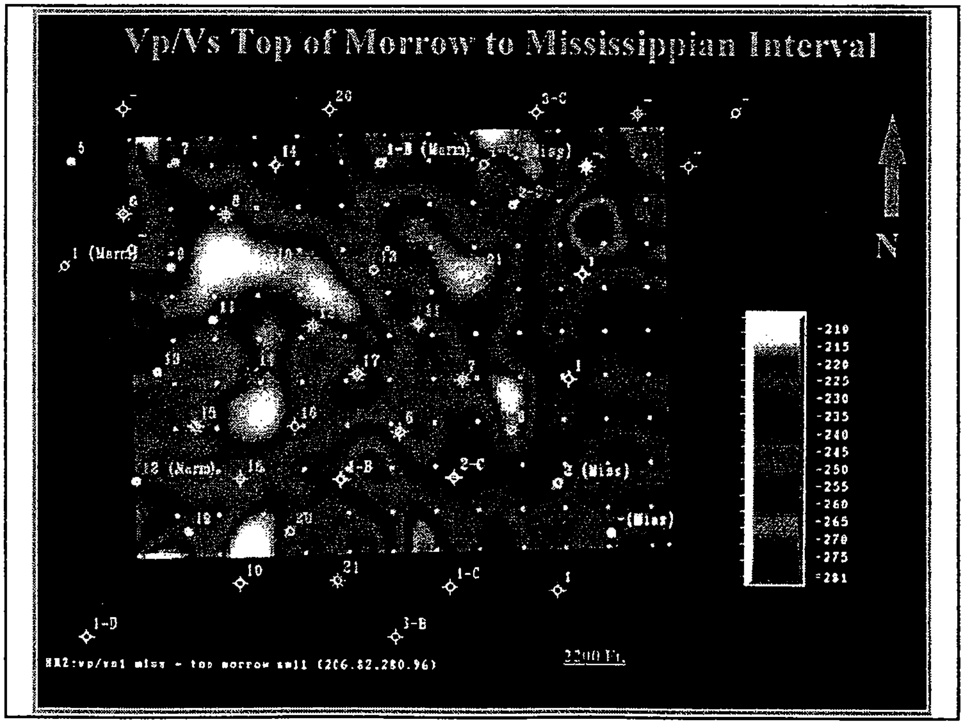


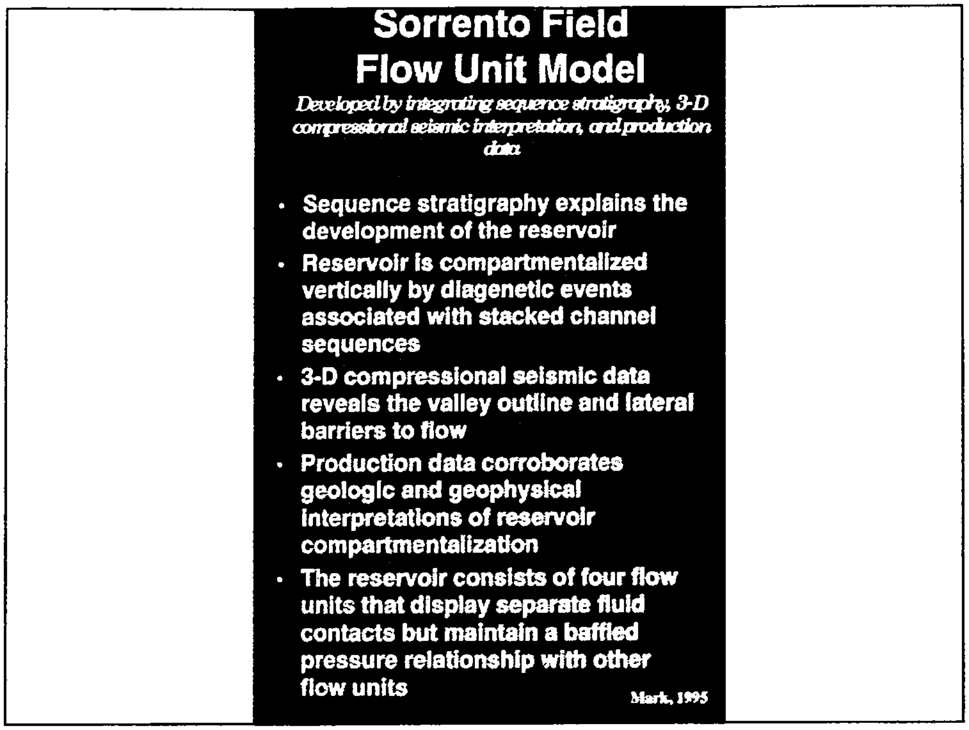
After Bowen et.al.,1990

Compressional Wave Mid-Morrow Amplitudes



Vp/Vs Top of Morrow to Mississippian Interval



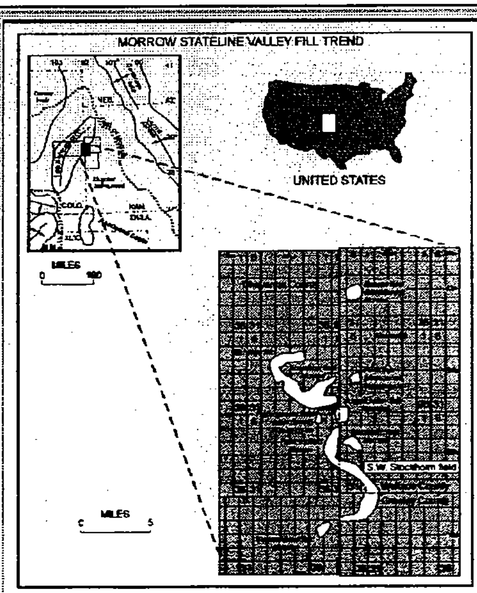


Sorrento Field
Flow Unit Model

Developed by integrating sequence stratigraphy, 3-D compressional seismic interpretation, and production data

- **Sequence stratigraphy explains the development of the reservoir**
- **Reservoir is compartmentalized vertically by diagenetic events associated with stacked channel sequences**
- **3-D compressional seismic data reveals the valley outline and lateral barriers to flow**
- **Production data corroborates geologic and geophysical interpretations of reservoir compartmentalization**
- **The reservoir consists of four flow units that display separate fluid contacts but maintain a baffled pressure relationship with other flow units**

Mark, 1995

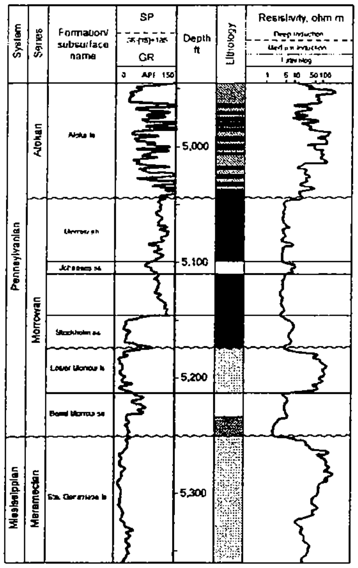


Location of 20-mile-long "Stateline Trend" Morrow Sandstone fields, which produce from valley-fill sandstone reservoirs. Southwest Stockholm field, Kansas, is located in Greeley and Wallace counties, Kansas.

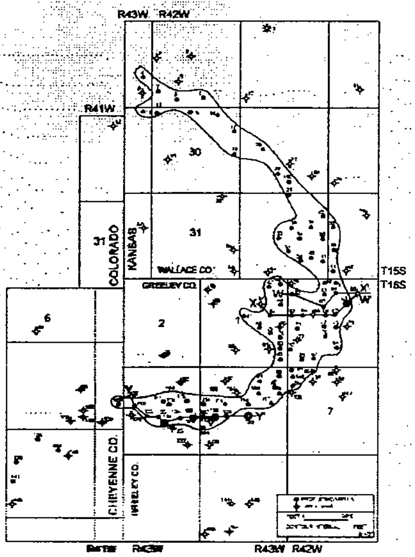
(Tillmand and Pittman, 1993)

TYPE LOG

Texas Oil and Gas 4 Evans E, NW NE SE 11-16s-43w

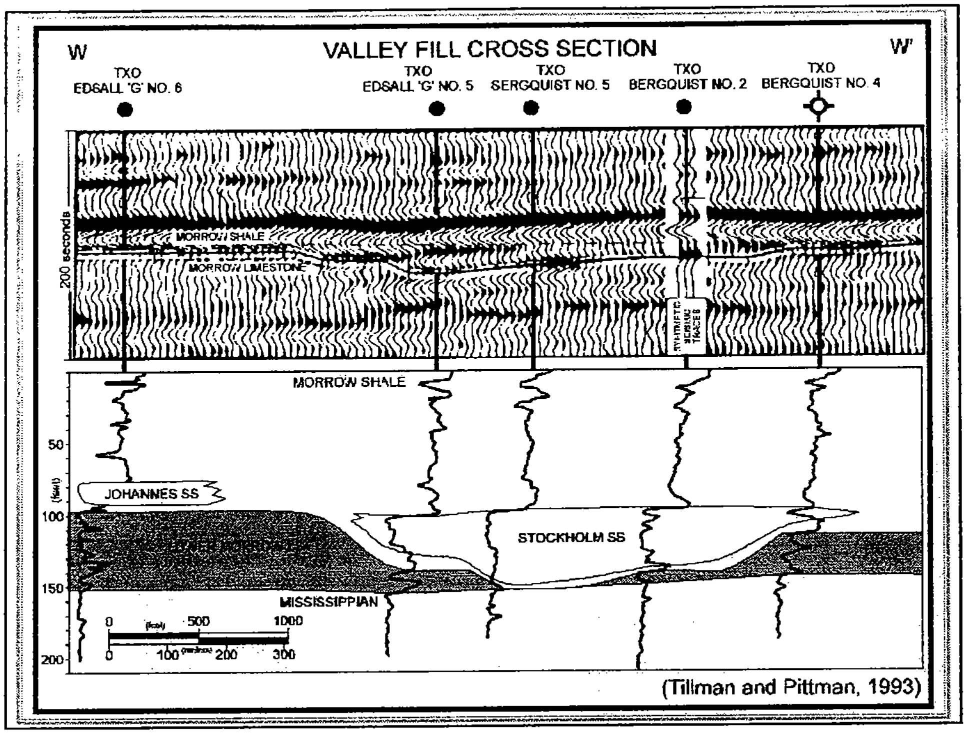


Tillman and Pittman (1994)

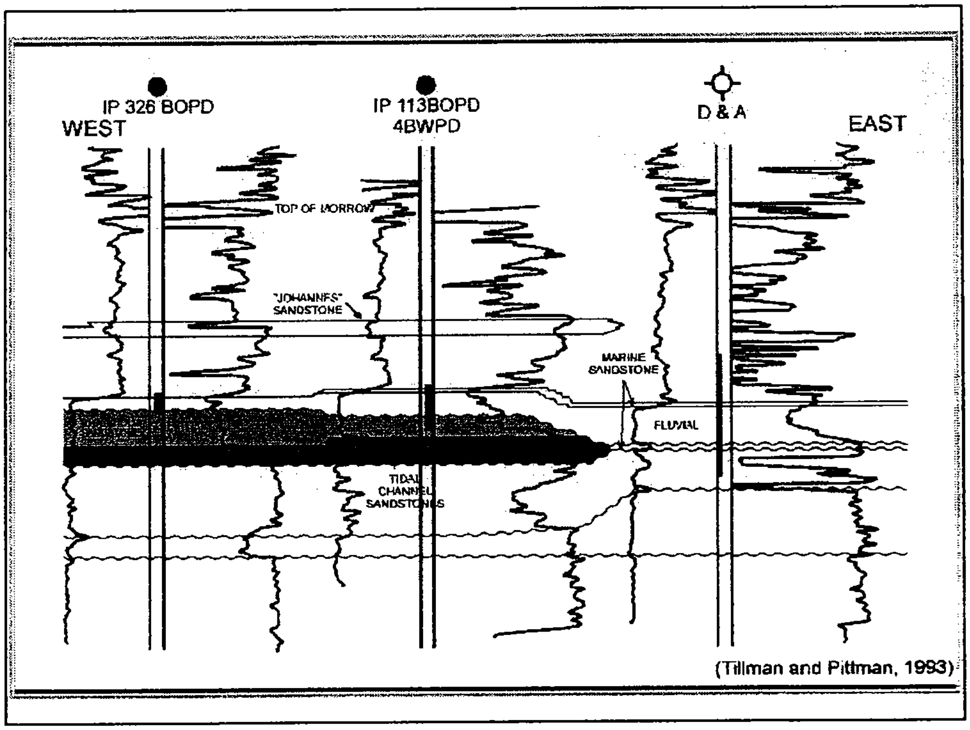


Base map, outlining borders of Southwest Stockholm field, Kansas. Location of stratigraphic cross sections X-X', Y-Y' and W-W' is indicated. Cored wells described in this study are indicated by circles. Type log well (Fig. 5) is indicated by a triangle. A list of all numbered wells on this map is available from the senior author.

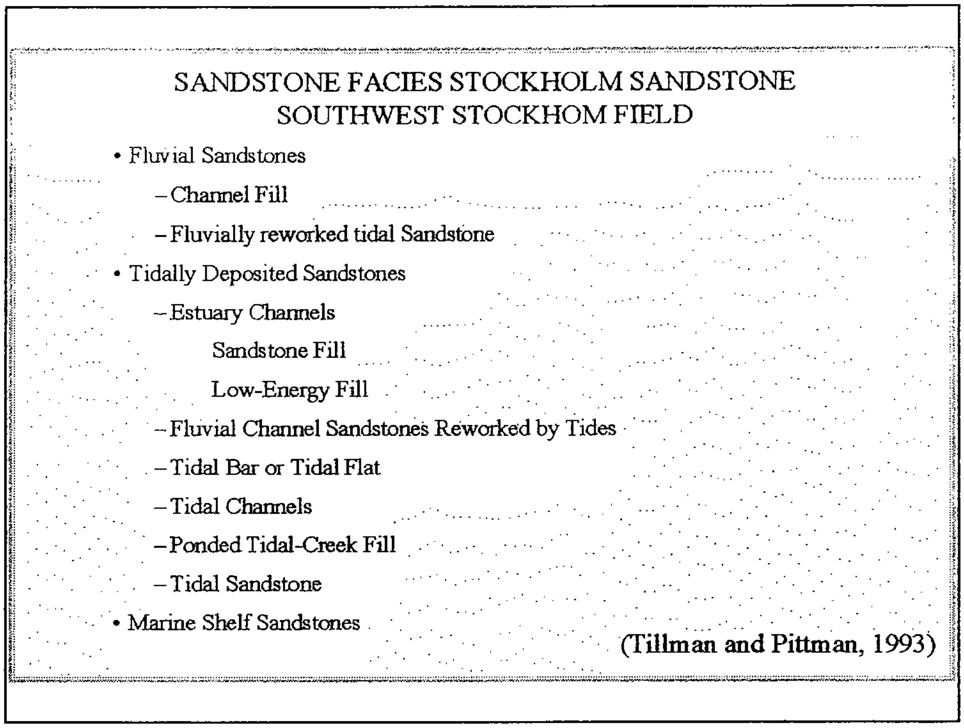
(Tillman and Pittman, 1993)



(Tillman and Pittman, 1993)



(Tillman and Pittman, 1993)



SANDSTONE FACIES STOCKHOLM SANDSTONE SOUTHWEST STOCKHOM FIELD

- Fluvial Sandstones
  - –Channel Fill
  - –Fluvially reworked tidal Sandstone
- Tidally Deposited Sandstones
  - –Estuary Channels
    - Sandstone Fill
    - Low-Energy Fill
  - –Fluvial Channel Sandstones Reworked by Tides
  - –Tidal Bar or Tidal Flat
  - –Tidal Channels
  - –Ponded Tidal-Creek Fill
  - –Tidal Sandstone
- Marine Shelf Sandstones

(Tillman and Pittman, 1993)

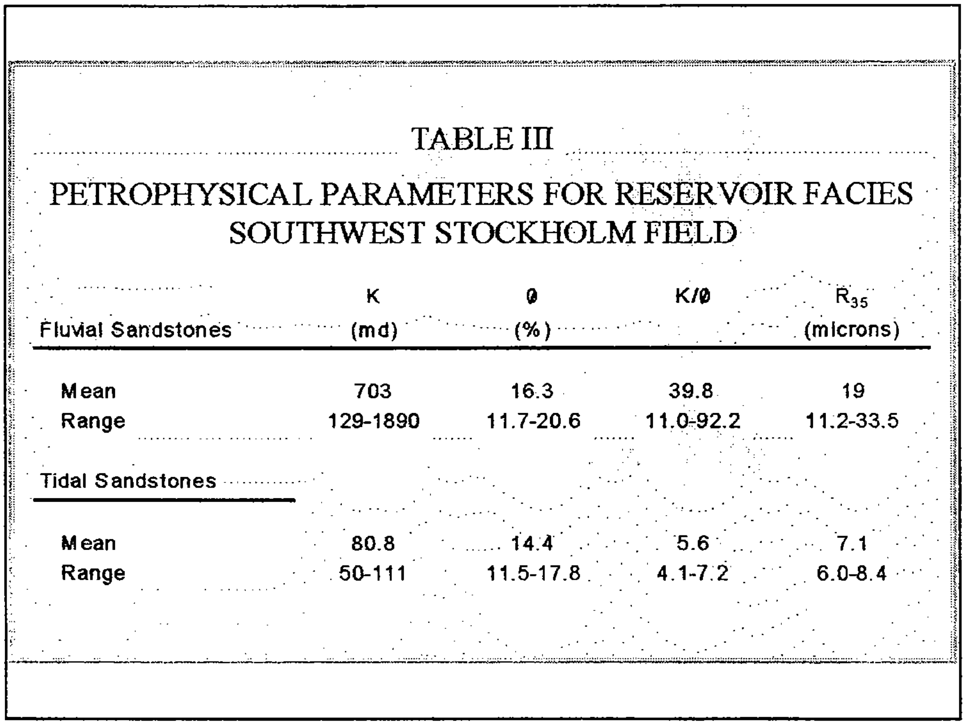


TABLE III

PETROPHYSICAL PARAMETERS FOR RESERVOIR FACIES SOUTHWEST STOCKHOLM FIELD

Fluvial Sandstones	K (md)	ϕ (%)	K/ϕ	R_{35} (microns)
Mean	703	16.3	39.8	19
Range	129-1890	11.7-20.6	11.0-92.2	11.2-33.5
Tidal Sandstones				
Mean	80.8	14.4	5.6	7.1
Range	50-111	11.5-17.8	4.1-7.2	6.0-8.4

FLUVIAL (RIVER) DEPOSITS

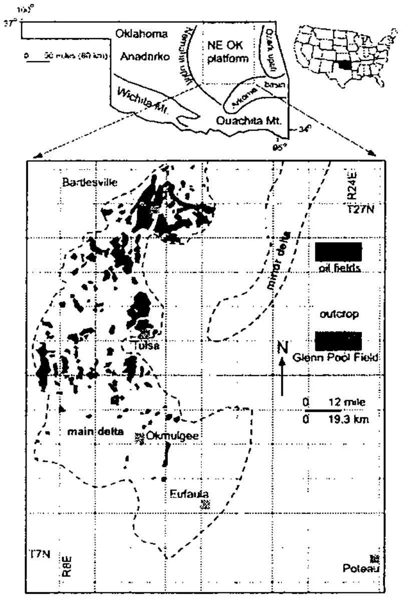
-ORIGIN

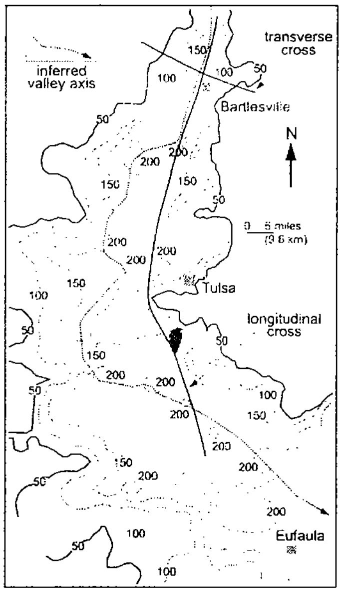
-TYPES
- ***-Point Bar***
- ***-Braided***
- ***-Alluvial fan***
- ***-Incised valley fill***

-CHARACTERISTICS

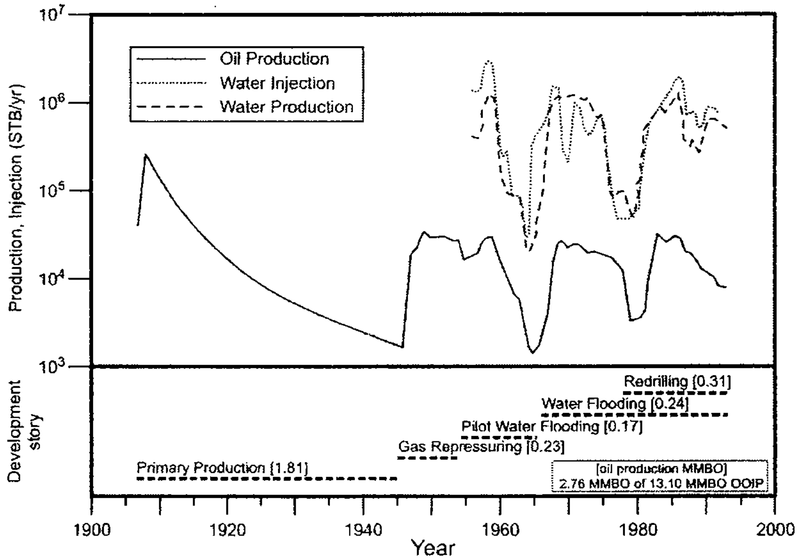
-RESERVOIR EXAMPLES
- ***-Glen Pool Field***

Location of Glenn Pool Field

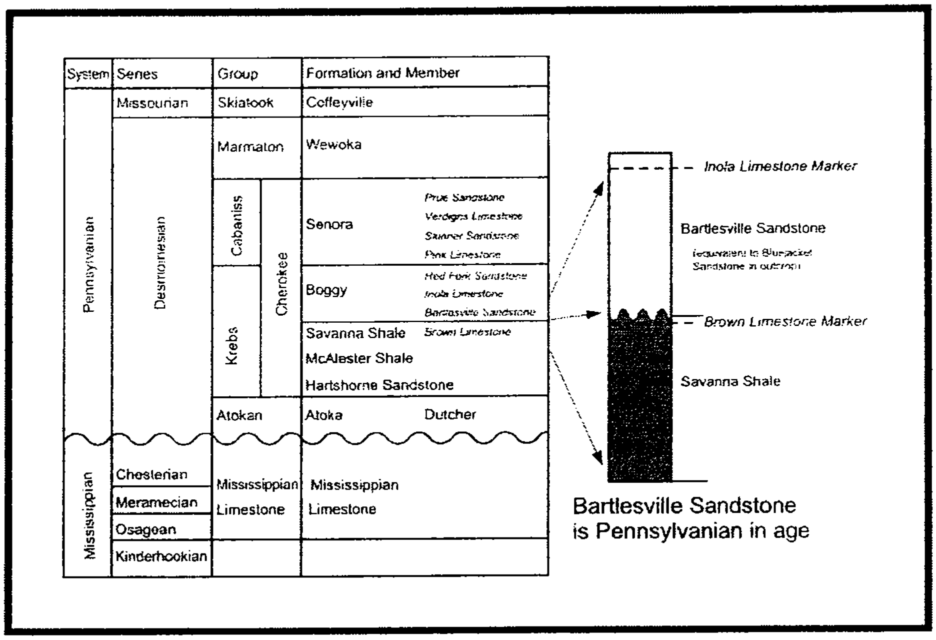




Isopach map of Bartlesville Sandstone near Glenn Pool Field (contour interval is 50ft.)

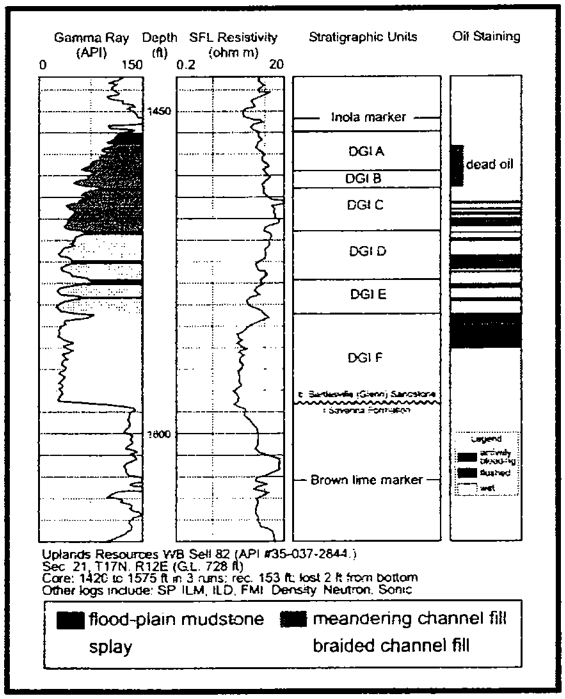


Production History of the Self Unit Glenn Pool Field, Oklahoma
Note changes in prodution as new Recovery techniques are begun in field



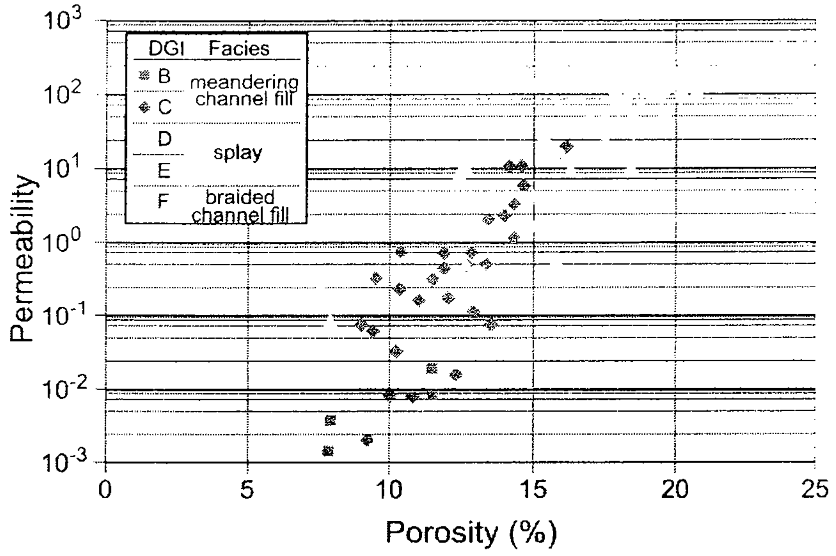
System	Series	Group		Formation and Member	
Pennsylvanian	Missourian	Skiatook		Coffeyville	
	Desmoinesian	Marmaton		Wewoka	
		Cabaniss	Cherokee	Senora	Prue Sandstone Verdigris Limestone Skinner Sandstone Pink Limestone
		Krebs		Boggy	Red Fork Sandstone Inola Limestone Bartlesville Sandstone
				Savanna Shale	Brown Limestone
				McAlester Shale	
				Hartshorne Sandstone	
		Atokan		Atoka	Dutcher
Mississippian	Chesterian	Mississippian Limestone		Mississippian Limestone	
	Meramecian				
	Osagean				
	Kinderhookian				

Bartlesville Sandstone is Pennsylvanian in age

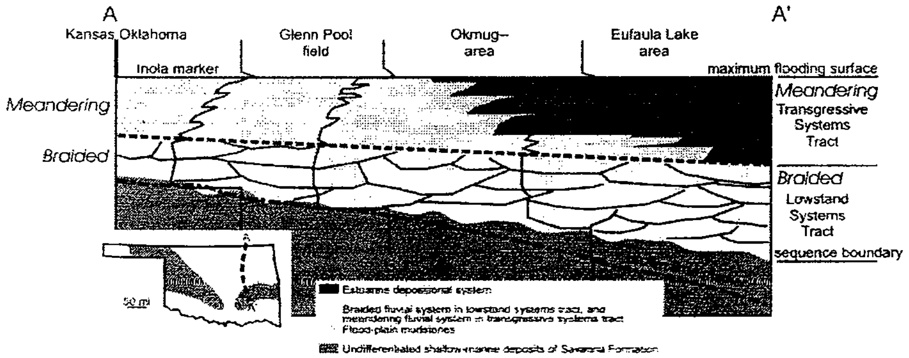


Uplands Resources WB Sell 82 (API #35-037-2844.)
Sec 21, T17N, R12E (G.L. 728 ft)
Core: 1420 to 1575 ft in 3 runs; rec. 153 ft; lost 2 ft from bottom
Other logs include: SP ILM, ILD, FMI Density Neutron, Sonic

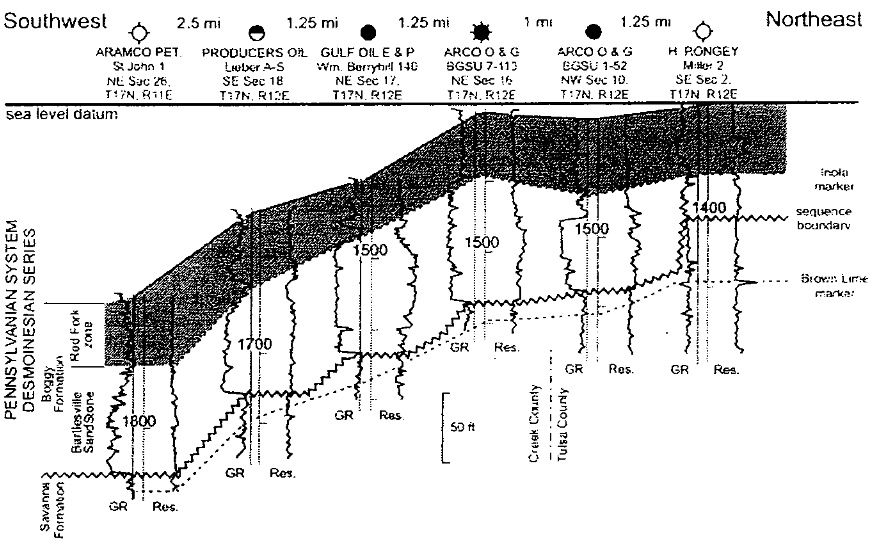
■ flood-plain mudstone ■ meandering channel fill
splay braided channel fill



DGI Facies
B
C
meandering channel fill
D
E
splay
F
braided channel fill
Permeability
10^3
10^2
10^1
10^0
10^{-1}
10^{-2}
10^{-3}
0
5
10
15
20
25
Porosity (%)



A
A'
Kansas Oklahoma
Glenn Pool field
Okmug– area
Eufaula Lake area
Inola marker
maximum flooding surface
Meandering
Braided
Meandering
Transgressive Systems Tract
Braided
Lowstand Systems Tract
sequence boundary
50 mi
Estuarine depositional system
Braided fluvial system in lowstand systems tract, and meandering fluvial system in transgressive systems tract
Flood-plain mudstones
Undifferentiated shallow-marine deposits of Savanna Formation



Structural cross section. Note that 'updip' is to the northeast.
Oil will migrate in the updip direction, and be more abundant there.

CONCLUSIONS

- **INCISED VALLEY FILL DEPOSITS ARE INTERNALLY COMPLEX AND CAN BE STRATIGRAPHICALLY COMPARTMENTALIZED BY CHANNEL INCISEMENT AND/OR CEMENTATION**

- **FLUVIAL AND ESTUARINE/MARINE FACIES WILL EXHIBIT DIFFERENT PORO./PERM. VALUES, RESULTING IN VARIABLE RESERVOIR VOLUMETRICS AND PERFORMANCE**

- **COMPLEXITIES CAN BE IMAGED SEISMICALLY AND DETERMINED BY CORE ANALYSIS AND PRESSURE TESTS**

APPLIED RESERVOIR CHARACTERIZATION FOR THE INDEPENDENT OPERATOR: WITH EMPHASIS ON COMPARTMENTALIZED RESERVOIRS AND ROUTINE TECHNIQUES FOR DETECTING COMPARTMENTS

UNIT 1: INTRODUCTION TO RESERVOIR CHARACTERIZATION

UNIT 2: EXAMPLES OF COMPARTMENTALIZED RESERVOIRS

UNIT 3: GEOLOGIC CONTROLS ON POROSITY AND PERMEABILITY

UNIT 3A: SEISMIC POROSITY DETECTION IN A CARBONATE RESERVOIR

UNIT 4: FLOW UNIT DETERMINATION & CHARACTERIZATION

UNIT 5: BASICS OF SEQUENCE STRATIGRAPHY

UNIT 6: FLUVIAL DEPOSITS AND RESERVOIRS

***UNIT 7: EOLIAN DEPOSITS AND RESERVOIRS**

UNIT 8: SHOREFACE DEPOSITS AND RESERVOIRS

UNIT 9: DELTAIC DEPOSITS AND RESERVOIRS

UNIT 10: DEEP-WATER (TURBIDITE) DEPOSITS AND RESERVOIRS

UNIT 11: BOREHOLE IMAGE LOGS AND APPLICATIONS

UNIT 12: DIPMETER LOGS AND APPLICATIONS

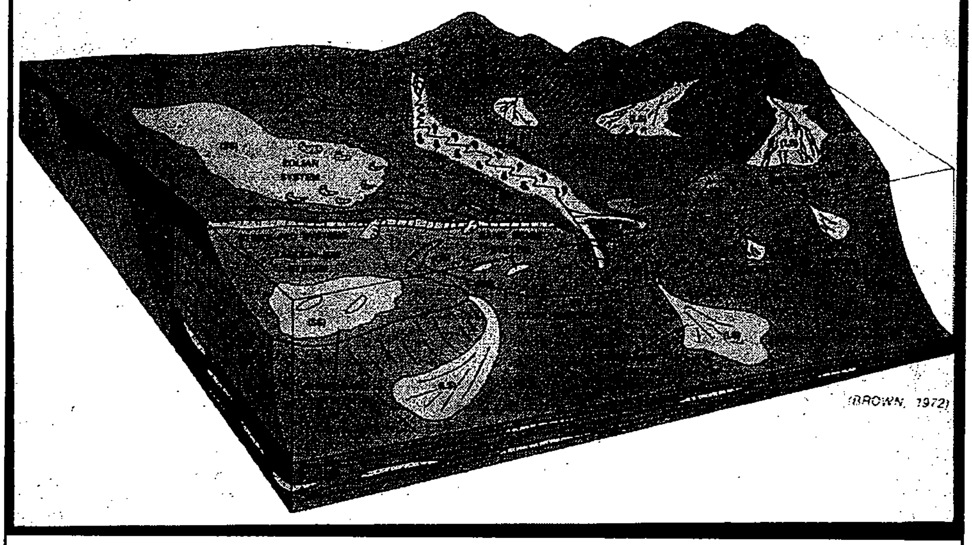
UNIT 13: STRUCTURALLY COMPARTMENTALIZED RESERVOIRS

KEY REFERENCES TO INDIVIDUAL UNITS

EOLIAN (WIND-BLOWN, SAND SEA) DEPOSITS AND RESERVOIRS

EOLIAN DEPOSITS & RESERVOIRS

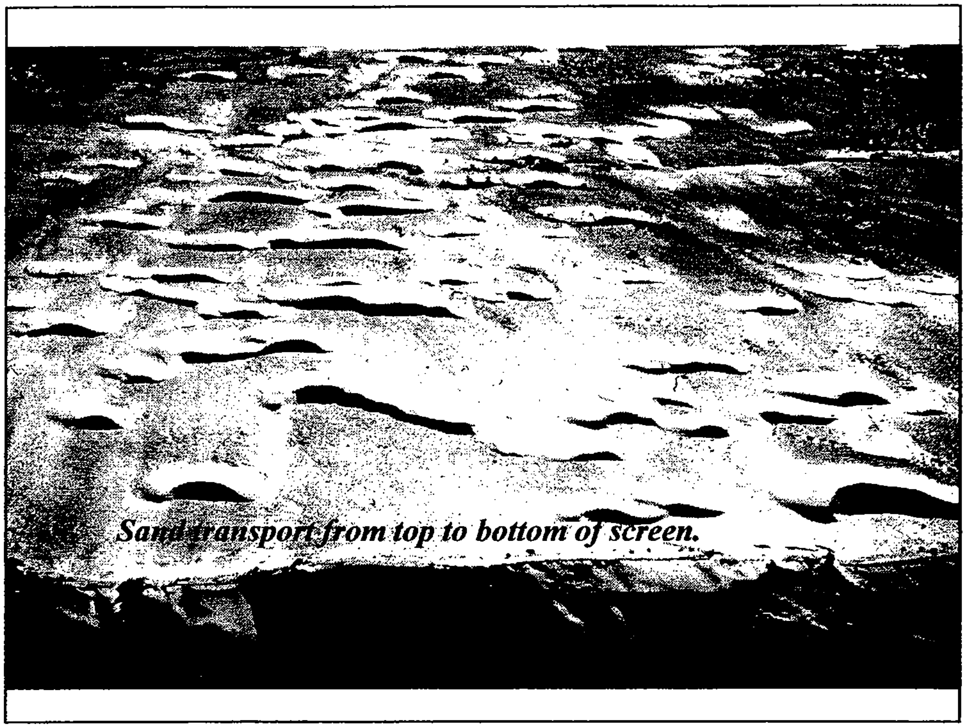
ENVIRONMENTAL SETTING OF CLASTIC STRATIGRAPHIC TRAPS



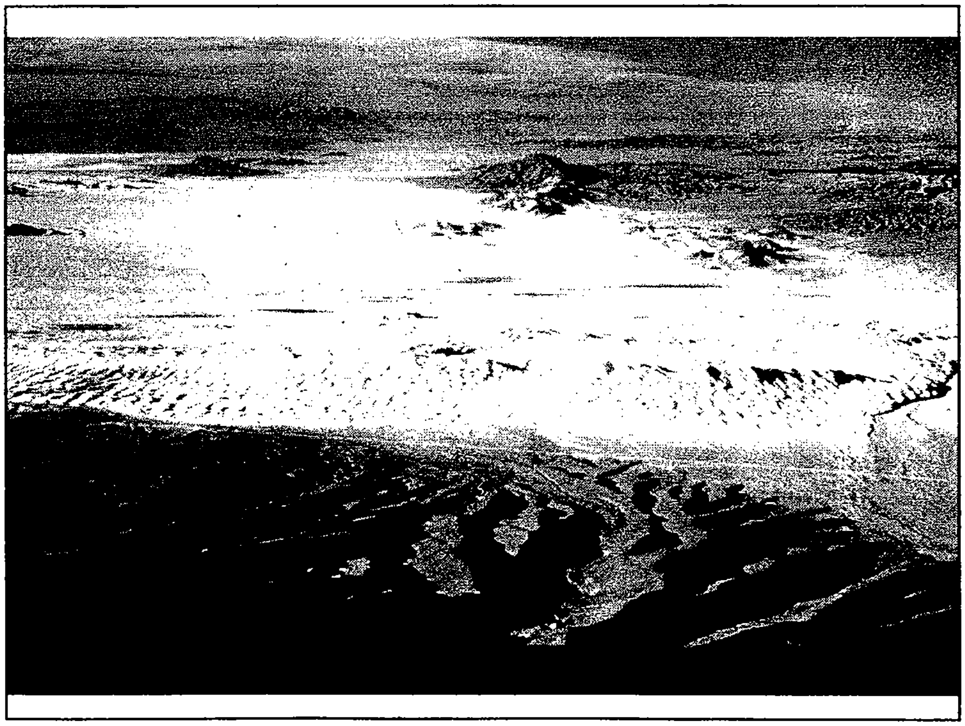
(BROWN, 1972)

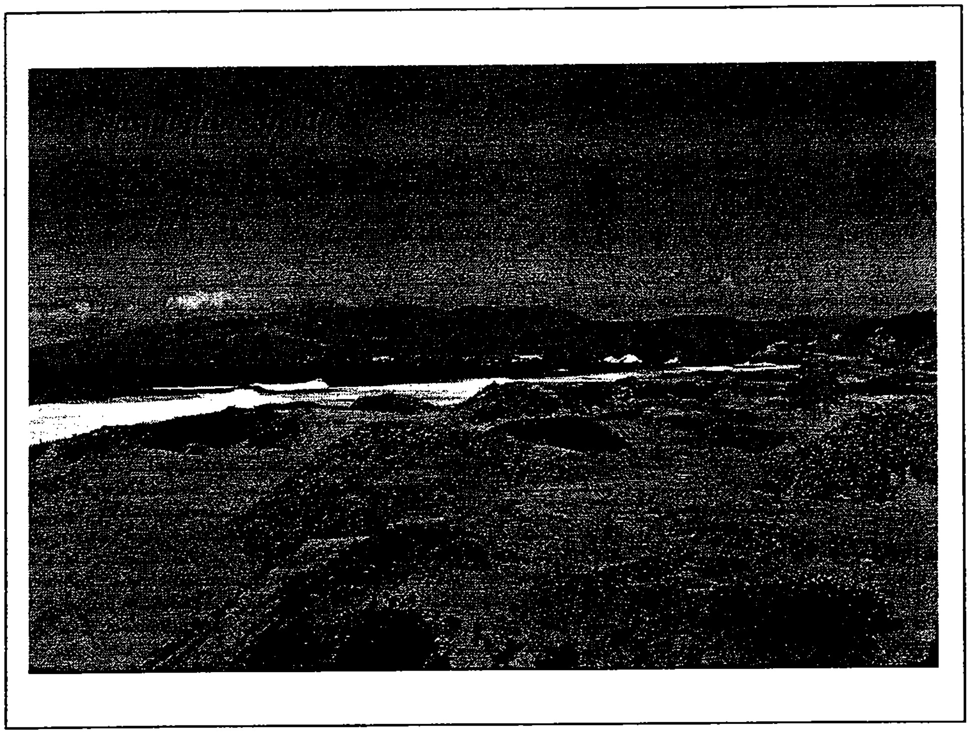
Dust devil entraining sediment into atmosphere.

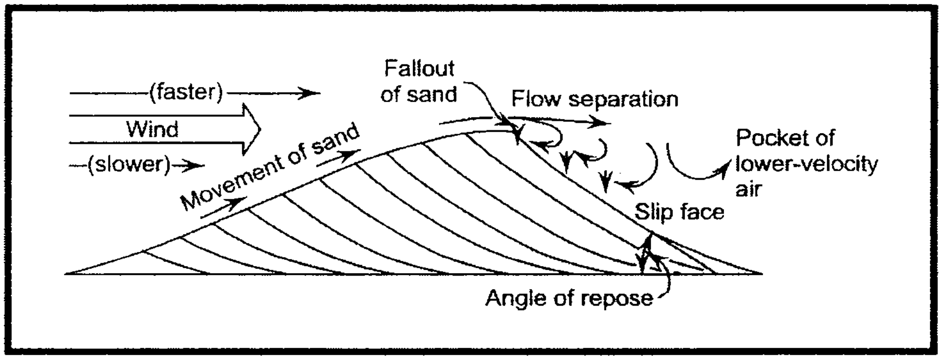
Dust storm descending on Phoenix, Arizona



Sand transport from top to bottom of screen.

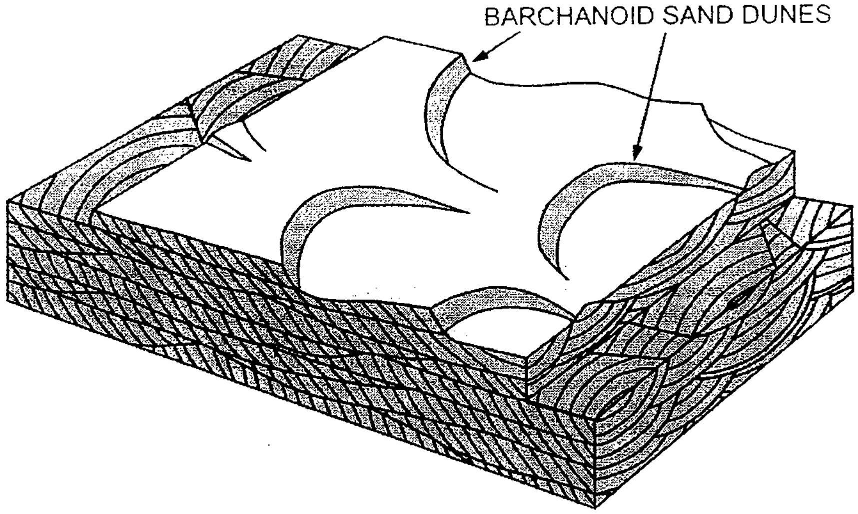


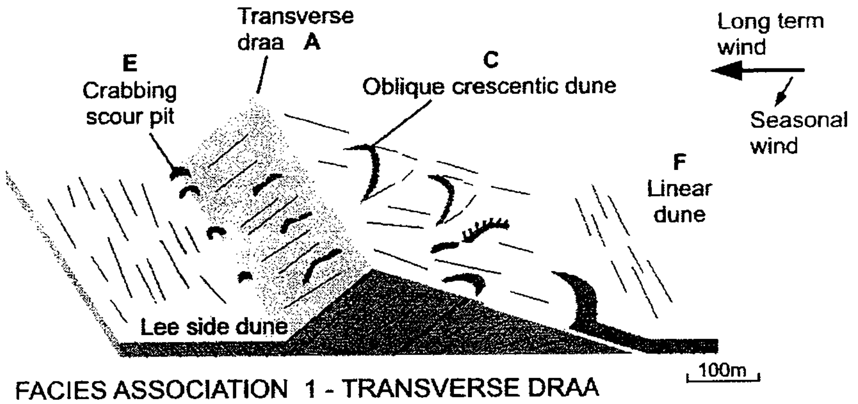




PROCESS OF DUNE MIGRATION

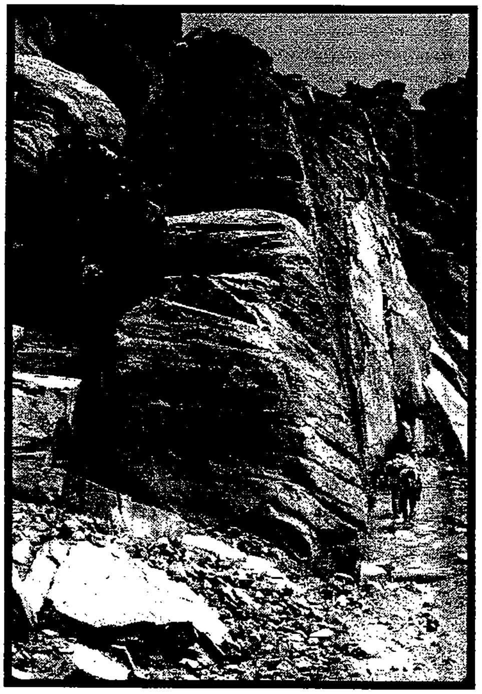
IDEALIZED BARCHANOID SAND DUNES

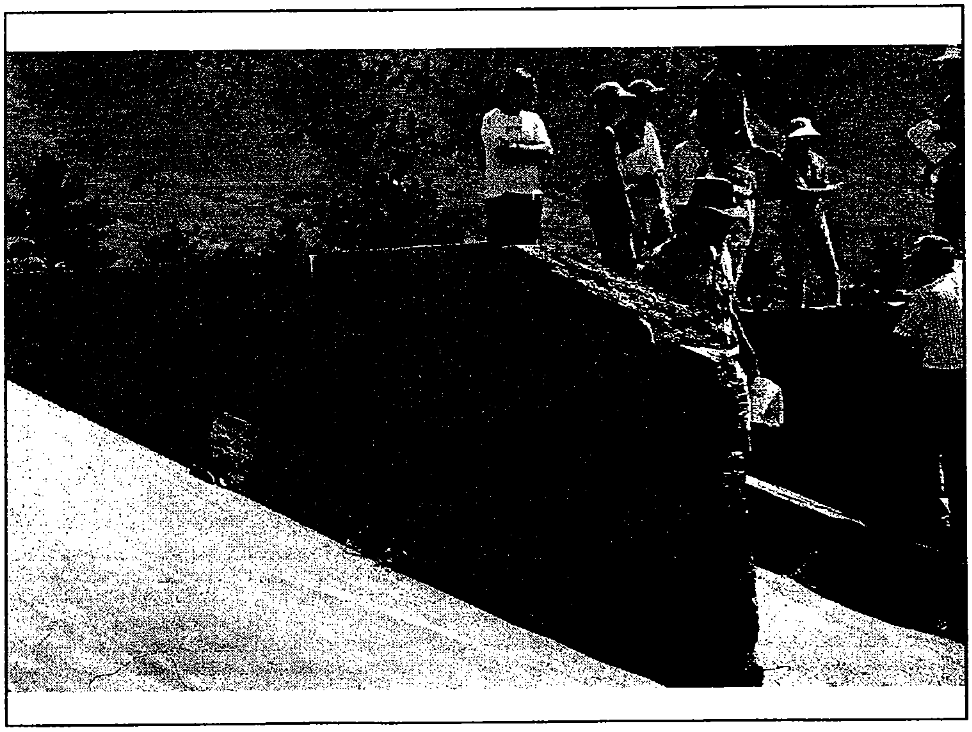




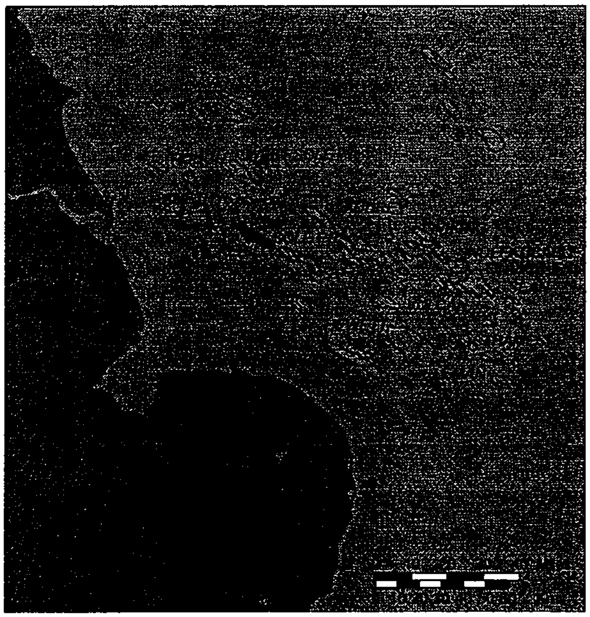
FACIES ASSOCIATION 1 - TRANSVERSE DRAA

Dune cross bedding due to fluctuating wind direction

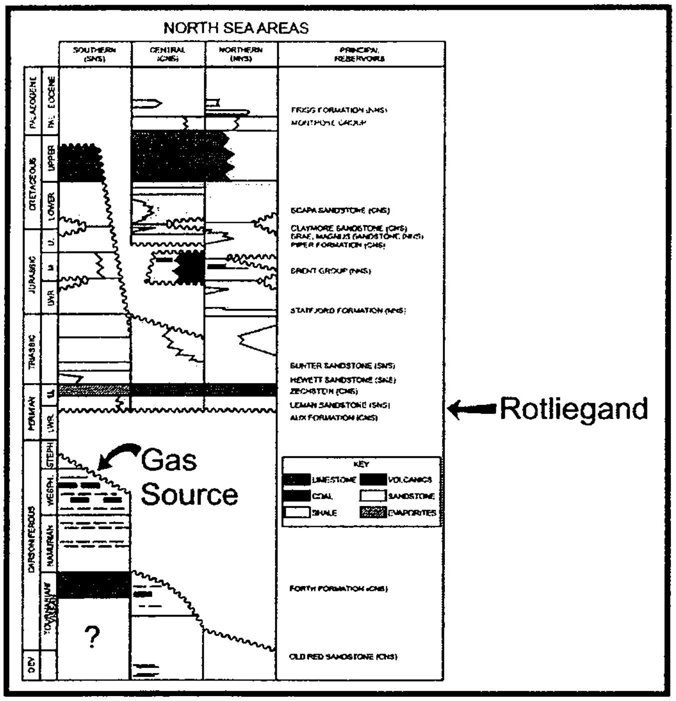


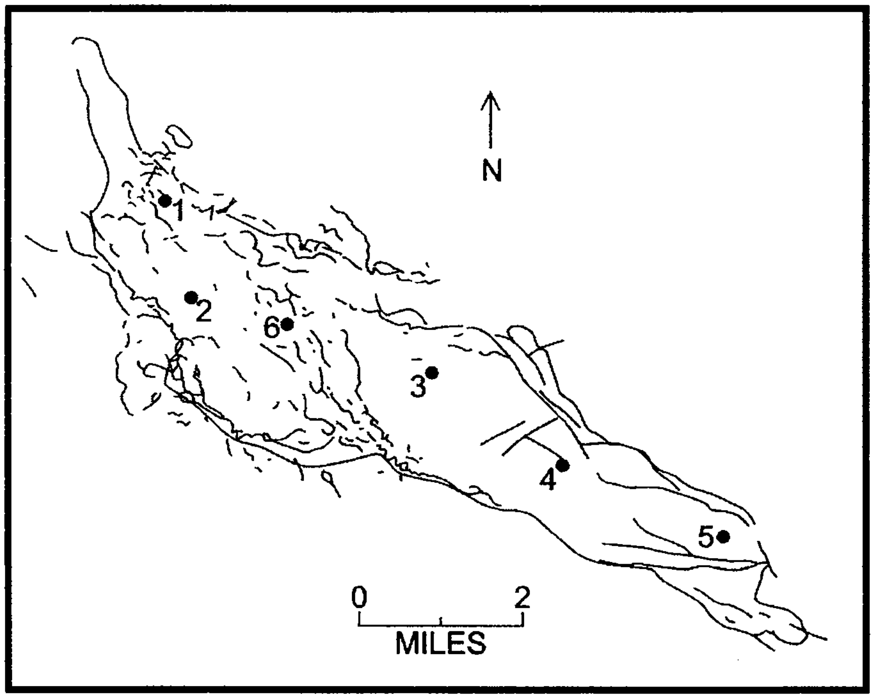


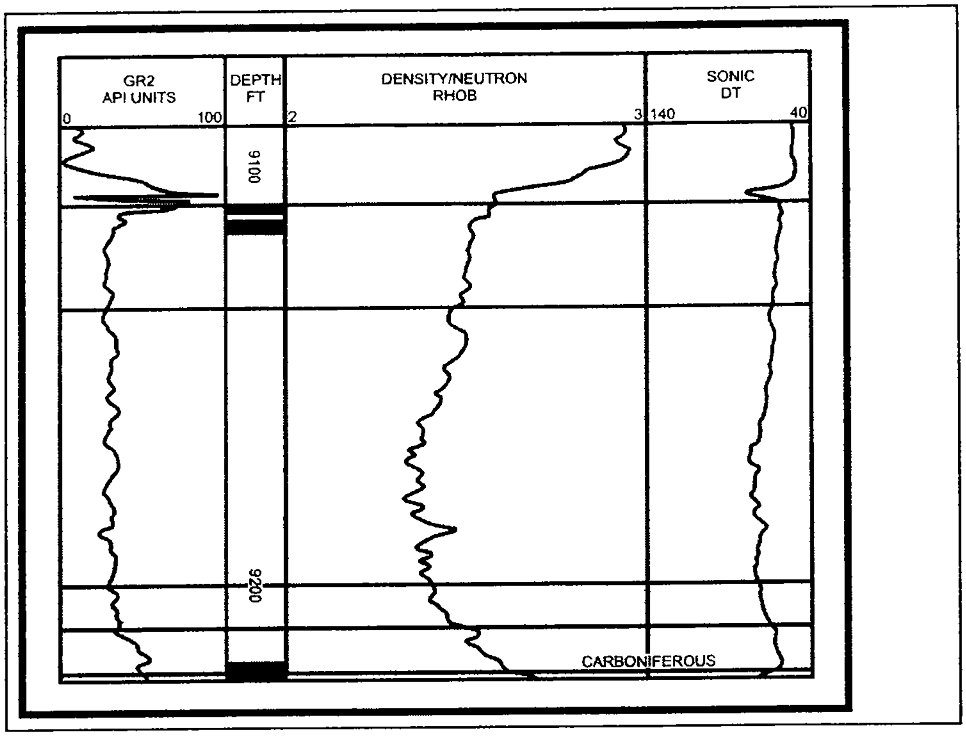
WEBER SANDSTONE, RANGELY FIELD, CO.

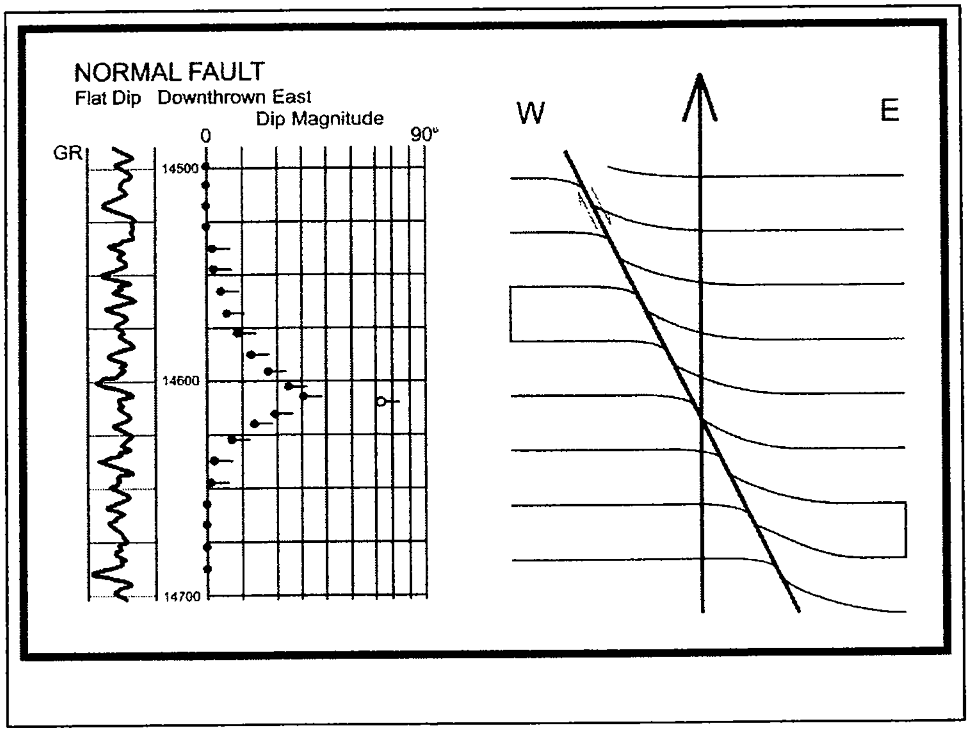


Pickerill Field, North Sea produces from Rotliegendes Sandstone (Permian)


NORTH SEA AREAS
SOUTHERN (SNS)
CENTRAL (CNS)
NORTHERN (NNS)
PRINCIPAL RESERVOIRS
PALAEOGENE
PAL.
EOCENE
CRETACEOUS
UPPER
LOWER
JURASSIC
U.
M
LWR
TRIASSIC
PERMIAN
UL
LWR.
CARBONIFEROUS
STEPH.
WESPH.
NAMURIAN
TOURNAISIAN VISEAN
DEV
FRIGG FORMATION (NNS)
MONTROSE GROUP
SCAPA SANDSTONE (CNS)
CLAYMORE SANDSTONE (CNS)
BRAE, MAGNUS SANDSTONE (NNS)
PIPER FORMATION (CNS)
BRENT GROUP (NNS)
STATFJORD FORMATION (NNS)
BUNTER SANDSTONE (SNS)
HEWETT SANDSTONE (SNS)
ZECHSTEIN (CNS)
LEMAN SANDSTONE (SNS)
AUK FORMATION (CNS)
FORTH FORMATION (CNS)
OLD RED SANDSTONE (CNS)
KEY
LIMESTONE
VOLCANICS
COAL
SANDSTONE
SHALE
EVAPORITES
?
Gas Source
Rotliegand

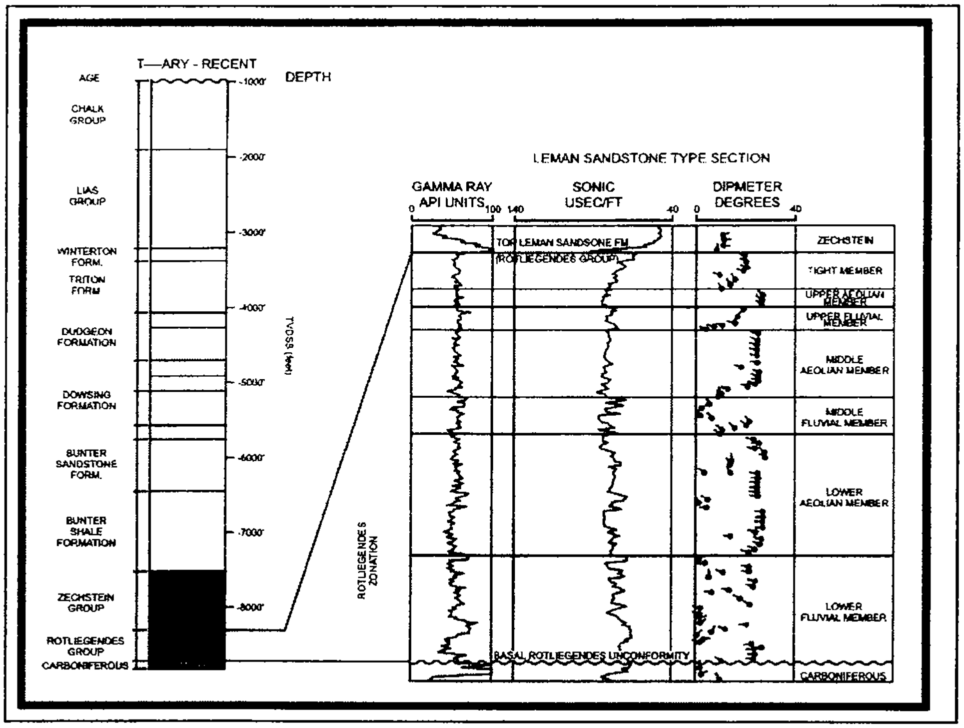

N
1
2
3
4
5
6
0
2
MILES

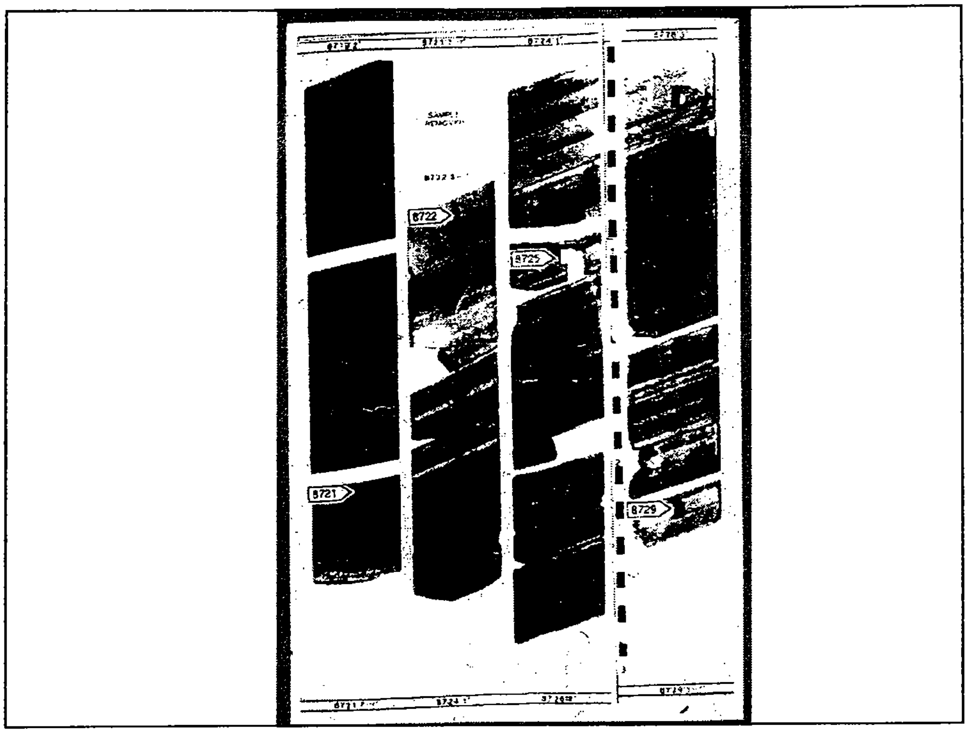


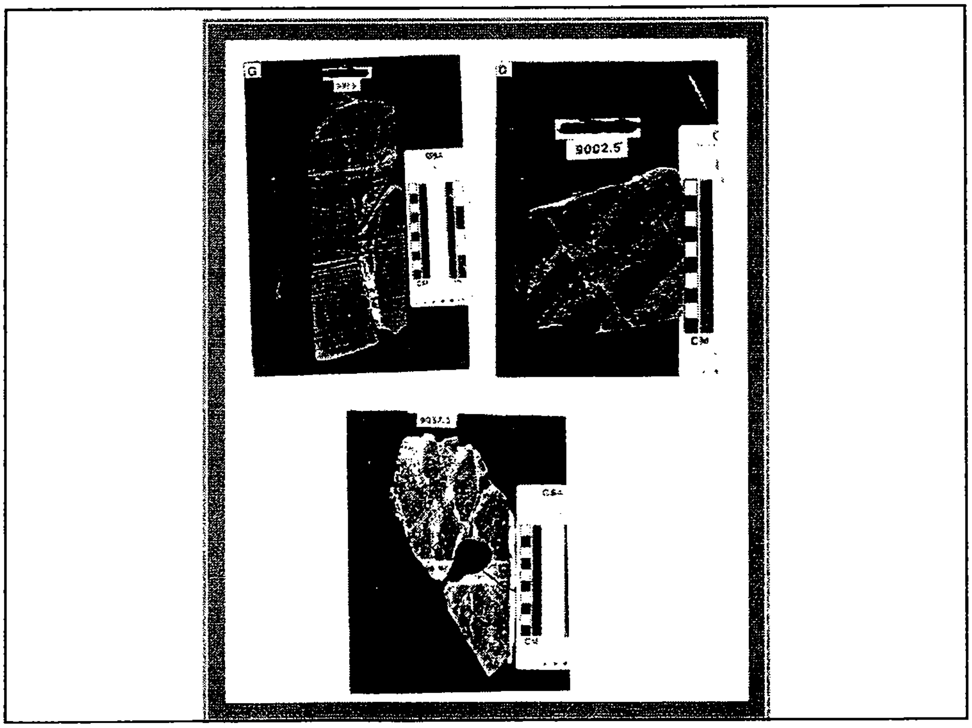


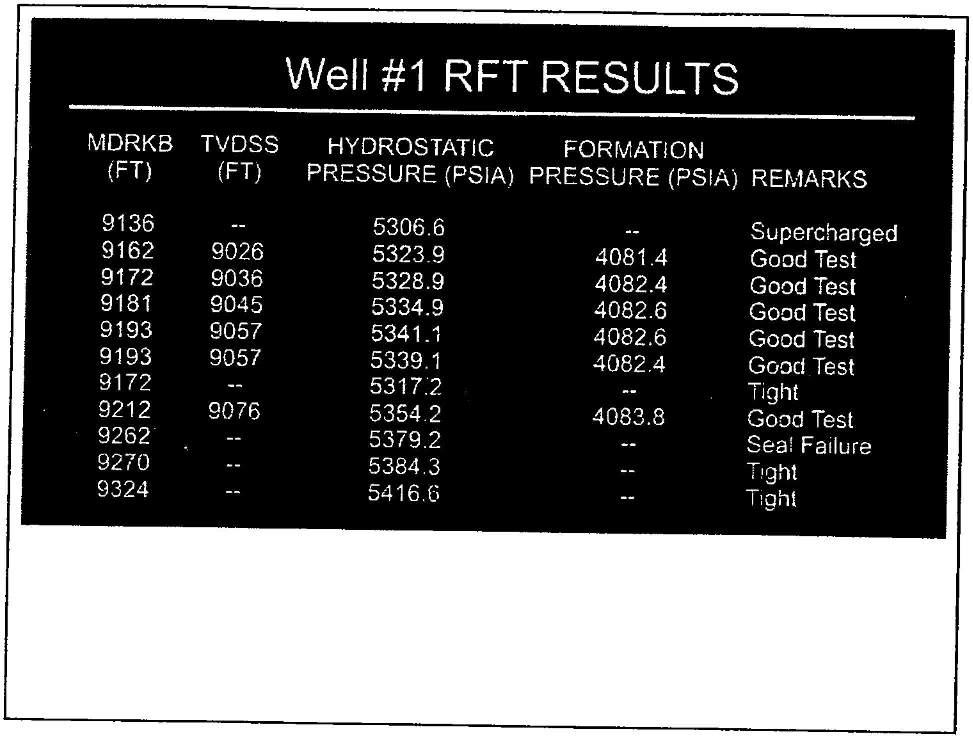
NORMAL FAULT

Flat Dip Downthrown East


T—ARY - RECENT
AGE
DEPTH
CHALK GROUP
LIAS GROUP
WINTERTON FORM.
TRITON FORM
DUDGEON FORMATION
DOWSING FORMATION
BUNTER SANDSTONE FORM.
BUNTER SHALE FORMATION
ZECHSTEIN GROUP
ROTLIEGENDES GROUP
CARBONIFEROUS
-1000'
-2000'
-3000'
-4000'
-5000'
-6000'
-7000'
-8000'
TVDSS (feet)
ROTLIEGENDES ZONATION
LEMAN SANDSTONE TYPE SECTION
GAMMA RAY API UNITS
0
100
SONIC USEC/FT
140
40
DIPMETER DEGREES
0
40
TOP LEMAN SANDSONE FM
(ROTLIEGENDES GROUP)
BASAL ROTLIEGENDES UNCONFORMITY
ZECHSTEIN
TIGHT MEMBER
UPPER AEOLIAN MEMBER
UPPER FLUVIAL MEMBER
MIDDLE AEOLIAN MEMBER
MIDDLE FLUVIAL MEMBER
LOWER AEOLIAN MEMBER
LOWER FLUVIAL MEMBER
CARBONIFEROUS

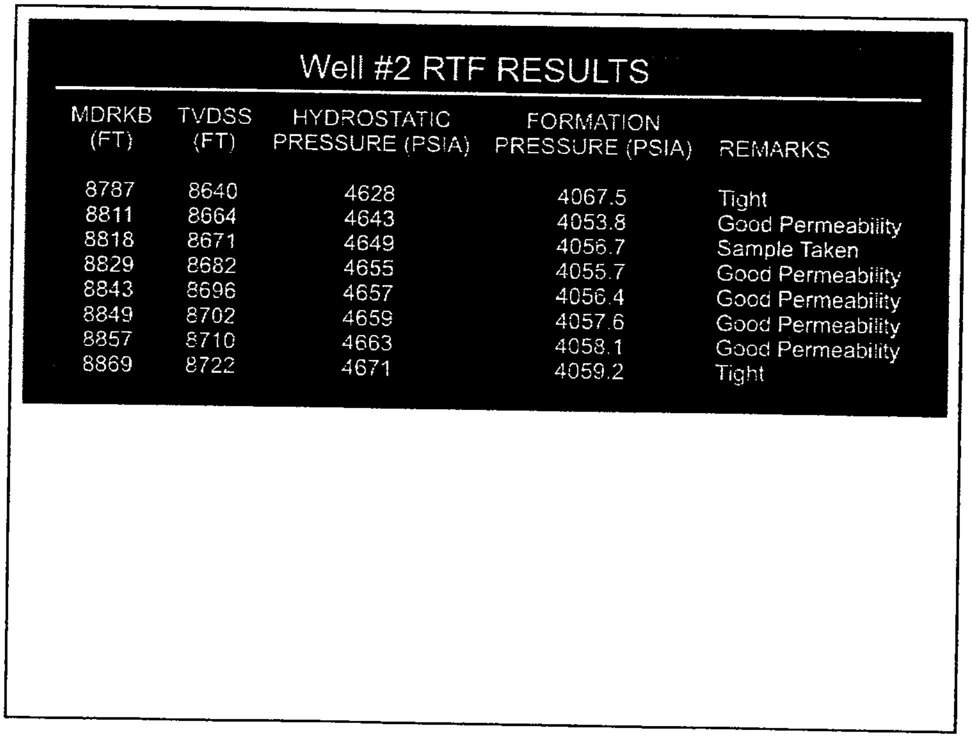

SAMPLE REMOVED
8722
8725
8721
8729


G
G
9002.5'
CM
CM
CM



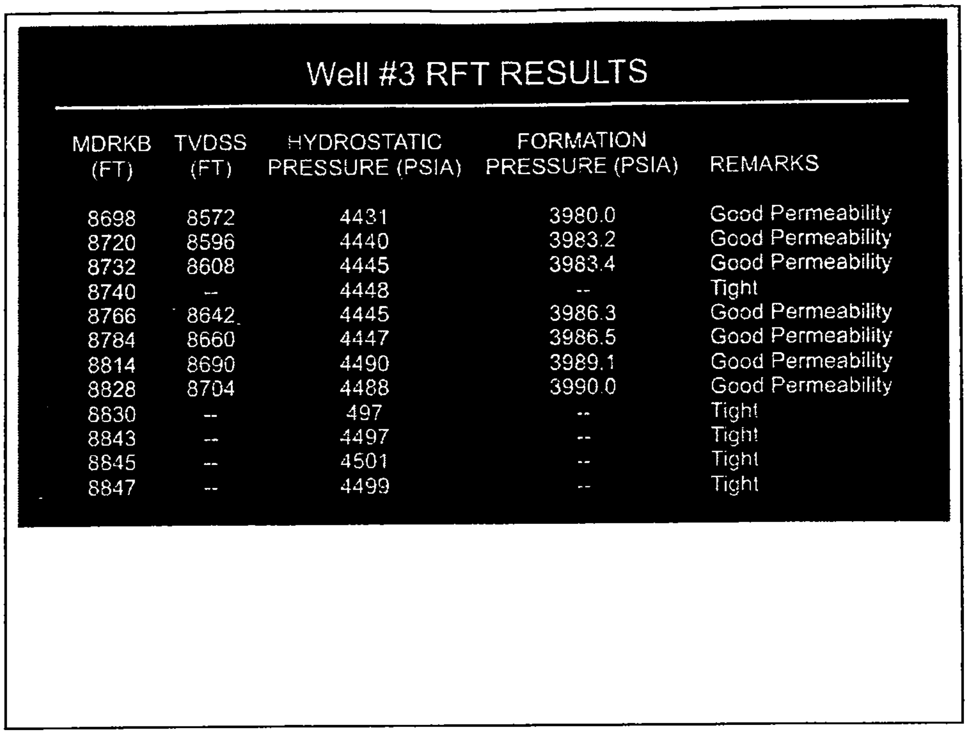
Well #1 RFT RESULTS

MDRKB (FT)	TVDSS (FT)	HYDROSTATIC PRESSURE (PSIA)	FORMATION PRESSURE (PSIA)	REMARKS
9136	--	5306.6	--	Supercharged
9162	9026	5323.9	4081.4	Good Test
9172	9036	5328.9	4082.4	Good Test
9181	9045	5334.9	4082.6	Good Test
9193	9057	5341.1	4082.6	Good Test
9193	9057	5339.1	4082.4	Good Test
9172	--	5317.2	--	Tight
9212	9076	5354.2	4083.8	Good Test
9262	--	5379.2	--	Seal Failure
9270	--	5384.3	--	Tight
9324	--	5416.6	--	Tight



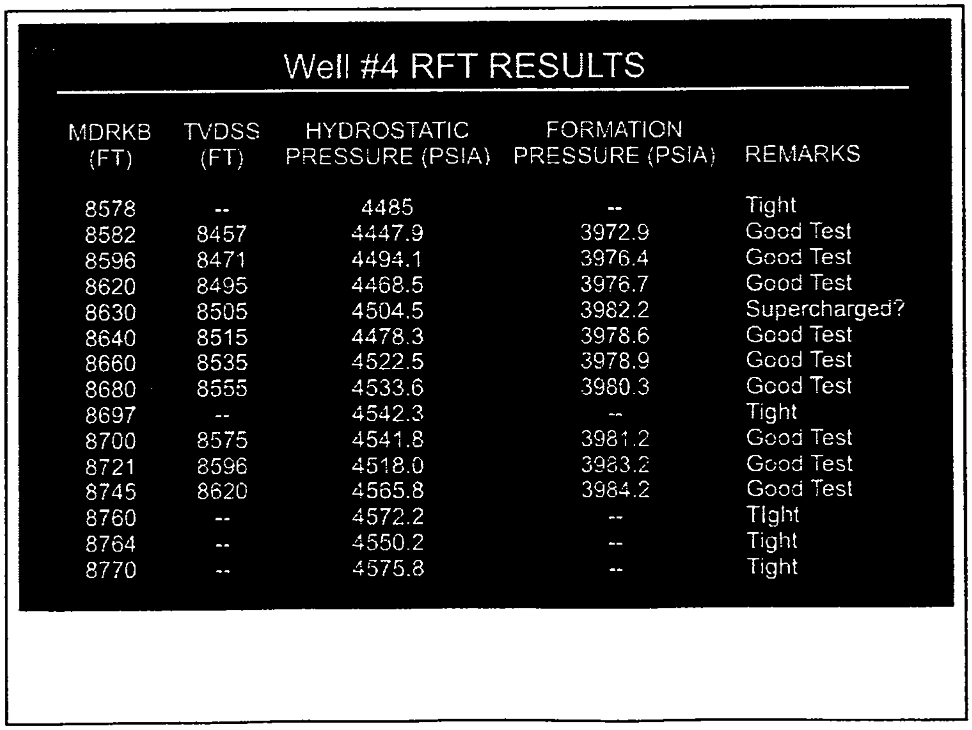
Well #2 RTF RESULTS

MDRKB (FT)	TVDSS (FT)	HYDROSTATIC PRESSURE (PSIA)	FORMATION PRESSURE (PSIA)	REMARKS
8787	8640	4628	4067.5	Tight
8811	8664	4643	4053.8	Good Permeability
8818	8671	4649	4056.7	Sample Taken
8829	8682	4655	4055.7	Good Permeability
8843	8696	4657	4056.4	Good Permeability
8849	8702	4659	4057.6	Good Permeability
8857	8710	4663	4058.1	Good Permeability
8869	8722	4671	4059.2	Tight



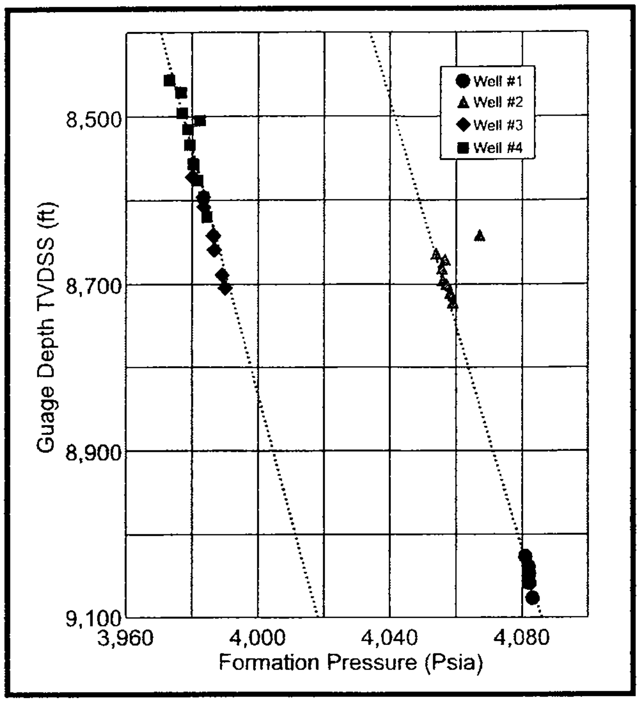
Well #3 RFT RESULTS

MDRKB (FT)	TVDSS (FT)	HYDROSTATIC PRESSURE (PSIA)	FORMATION PRESSURE (PSIA)	REMARKS
8698	8572	4431	3980.0	Good Permeability
8720	8596	4440	3983.2	Good Permeability
8732	8608	4445	3983.4	Good Permeability
8740	--	4448	--	Tight
8766	8642	4445	3986.3	Good Permeability
8784	8660	4447	3986.5	Good Permeability
8814	8690	4490	3989.1	Good Permeability
8828	8704	4488	3990.0	Good Permeability
8830	--	497	--	Tight
8843	--	4497	--	Tight
8845	--	4501	--	Tight
8847	--	4499	--	Tight

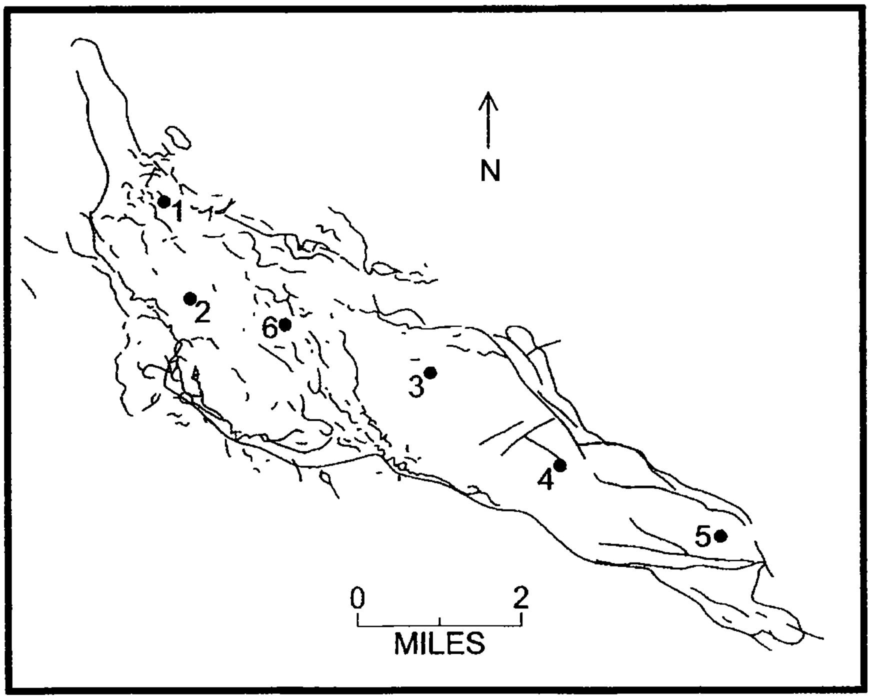


Well #4 RFT RESULTS

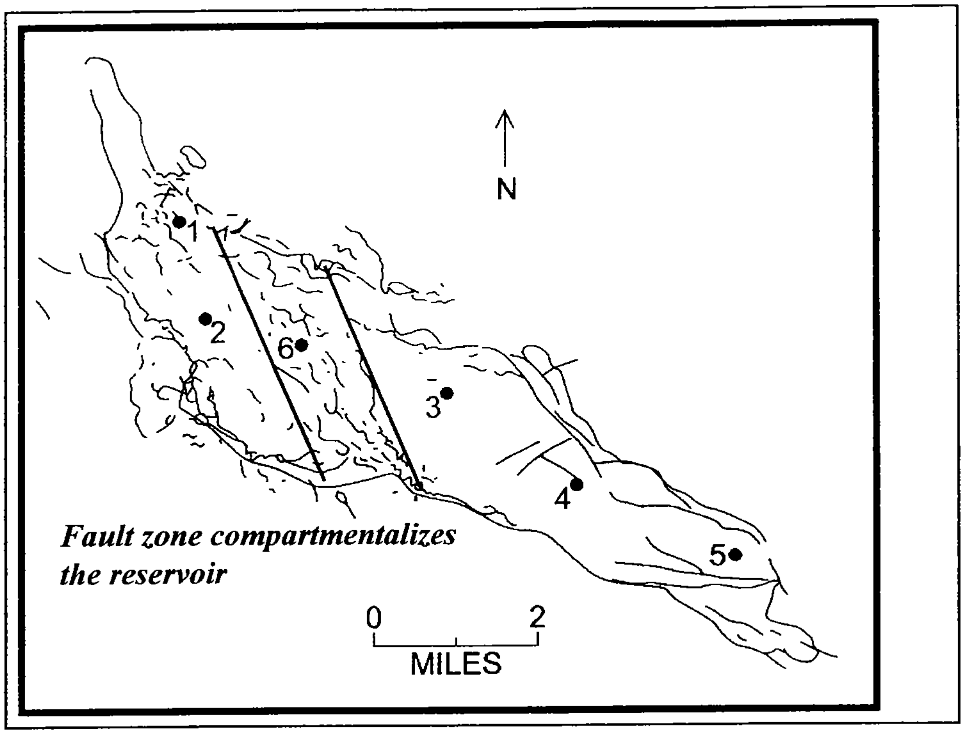
MDRKB (FT)	TVDSS (FT)	HYDROSTATIC PRESSURE (PSIA)	FORMATION PRESSURE (PSIA)	REMARKS
8578	--	4485	--	Tight
8582	8457	4447.9	3972.9	Good Test
8596	8471	4494.1	3976.4	Good Test
8620	8495	4468.5	3976.7	Good Test
8630	8505	4504.5	3982.2	Supercharged?
8640	8515	4478.3	3978.6	Good Test
8660	8535	4522.5	3978.9	Good Test
8680	8555	4533.6	3980.3	Good Test
8697	--	4542.3	--	Tight
8700	8575	4541.8	3981.2	Good Test
8721	8596	4518.0	3983.2	Good Test
8745	8620	4565.8	3984.2	Good Test
8760	--	4572.2	--	Tight
8764	--	4550.2	--	Tight
8770	--	4575.8	--	Tight



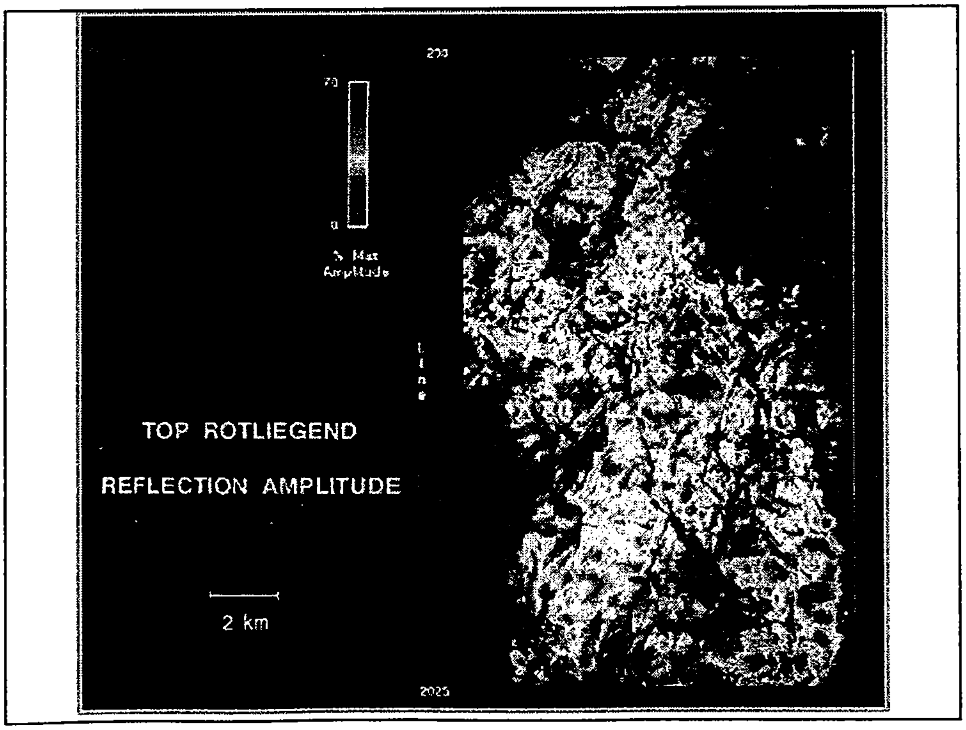
Well #1
Well #2
Well #3
Well #4
Guage Depth TVDSS (ft)
8,500
8,700
8,900
9,100
3,960
4,000
4,040
4,080
Formation Pressure (Psia)



N
1
2
6
3
4
5
0
2
MILES

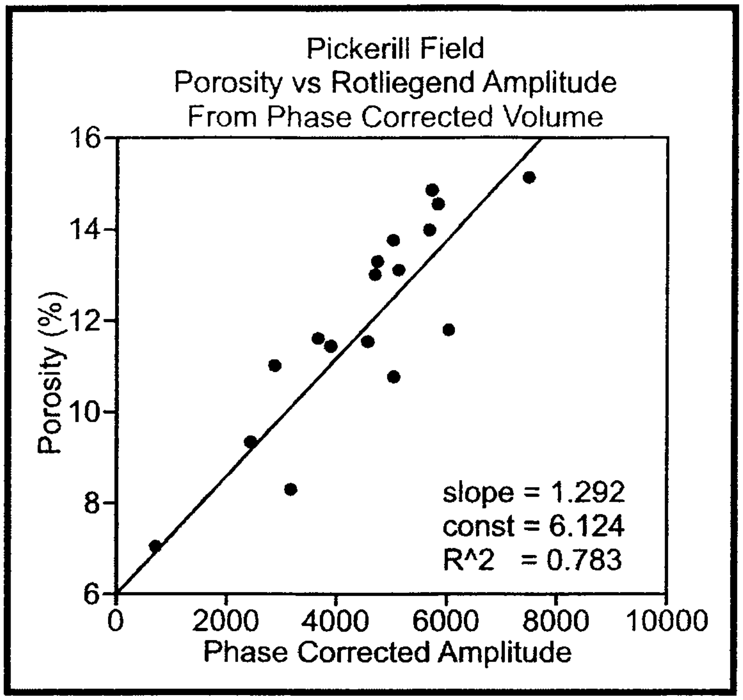


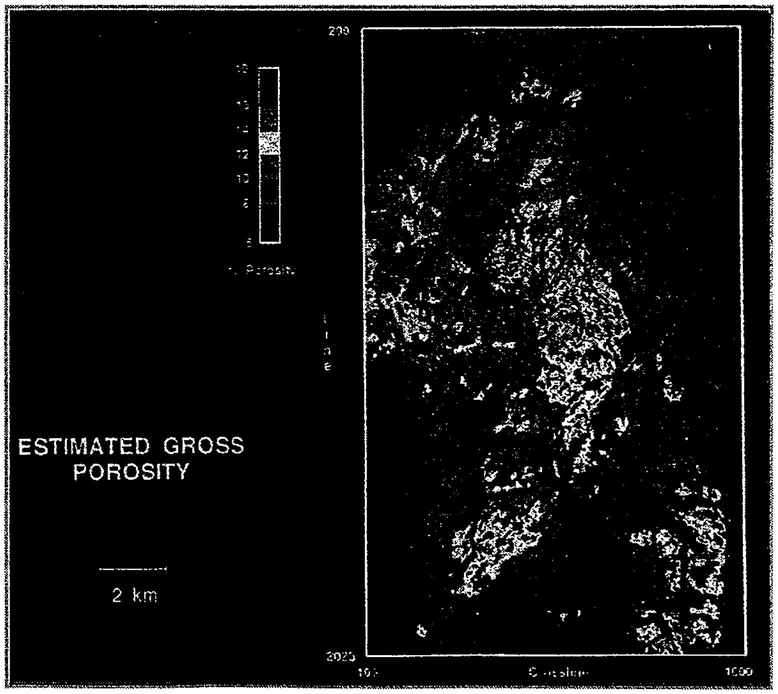
Fault zone compartmentalizes the reservoir



TOP ROTLIEGEND

REFLECTION AMPLITUDE


Pickerill Field
Porosity vs Rotliegend Amplitude
From Phase Corrected Volume
Porosity (%)
16
14
12
10
8
6
0
2000
4000
6000
8000
10000
Phase Corrected Amplitude
slope = 1.292
const = 6.124
R^2 = 0.783


ESTIMATED GROSS
POROSITY
2 km
% Porosity
12
10
Line
200
2025
Crossline
1000

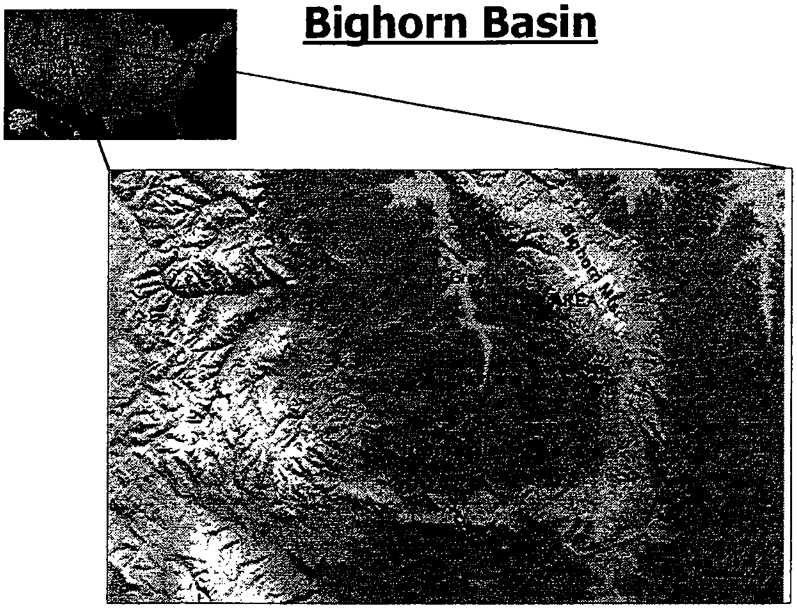
Recent Advances in Outcrop-Based 3-D Modeling

Neil Hurley
Bozkurt Ciftci
Ali Raba'a
Chris Zahm
Colorado School of Mines

Research Objectives: Tensleep Sandstone

Use superb outcrop exposures in parallel canyon walls to identify the geometry and volumetric sizes of dune-related reservoir compartments.

Bighorn Basin



Tensleep Sandstone

■	**Eolian Sandstones**
▨	**Marine Sandstones**
■	**Carbonates**
■	**Mudstones**

Goose Egg Formation

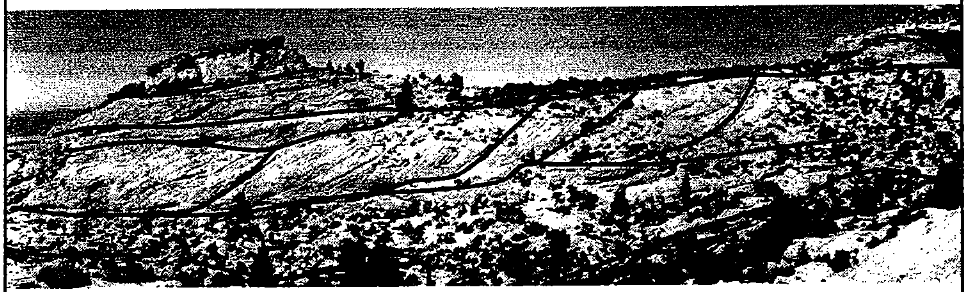
Upper Tensleep

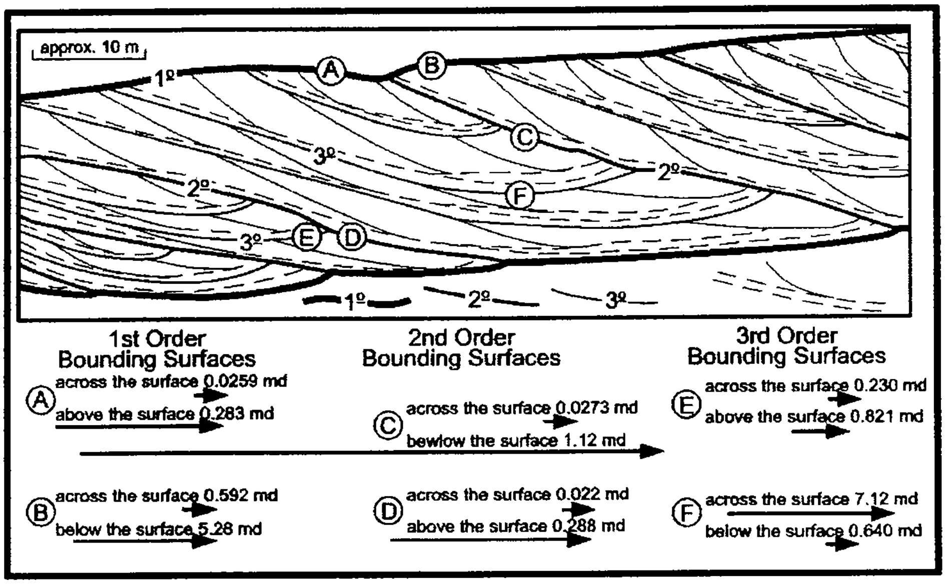
Lower Tensleep

Ranchester Limestone

Wheeler, 1986

Bounding Surfaces in the Tensleep





1st Order Bounding Surfaces

Ⓐ across the surface 0.0259 md
above the surface 0.283 md

Ⓑ across the surface 0.592 md
below the surface 5.28 md

2nd Order Bounding Surfaces

Ⓒ across the surface 0.0273 md
bewlow the surface 1.12 md

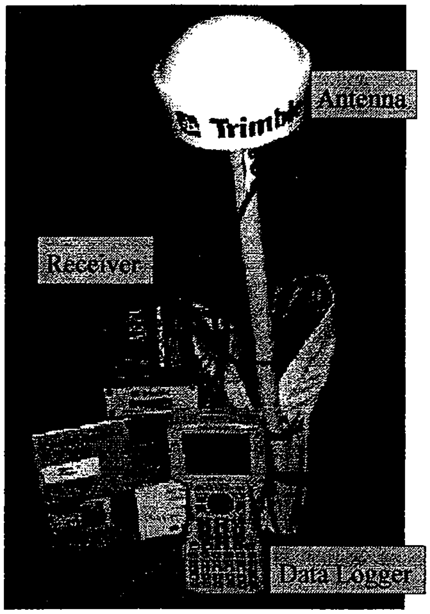
Ⓓ across the surface 0.022 md
above the surface 0.288 md

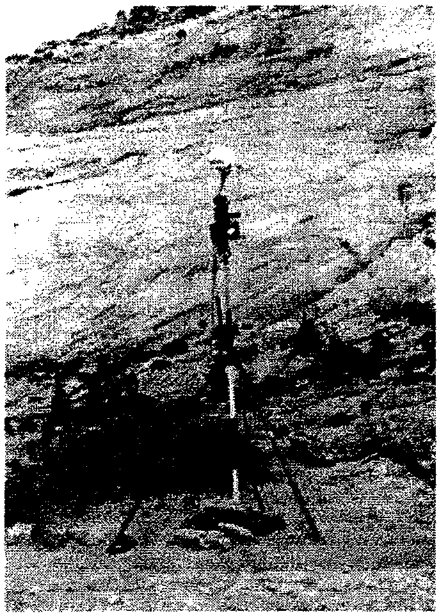
3rd Order Bounding Surfaces

Ⓔ across the surface 0.230 md
above the surface 0.821 md

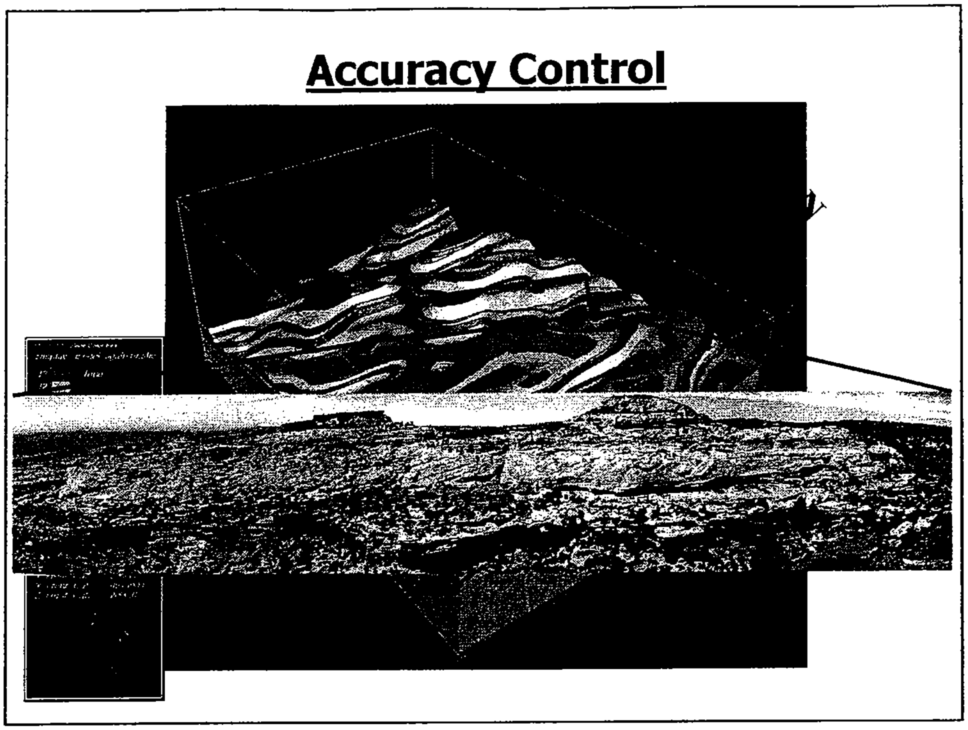
Ⓕ across the surface 7.12 md
below the surface 0.640 md

GPS (Global Positioning System)

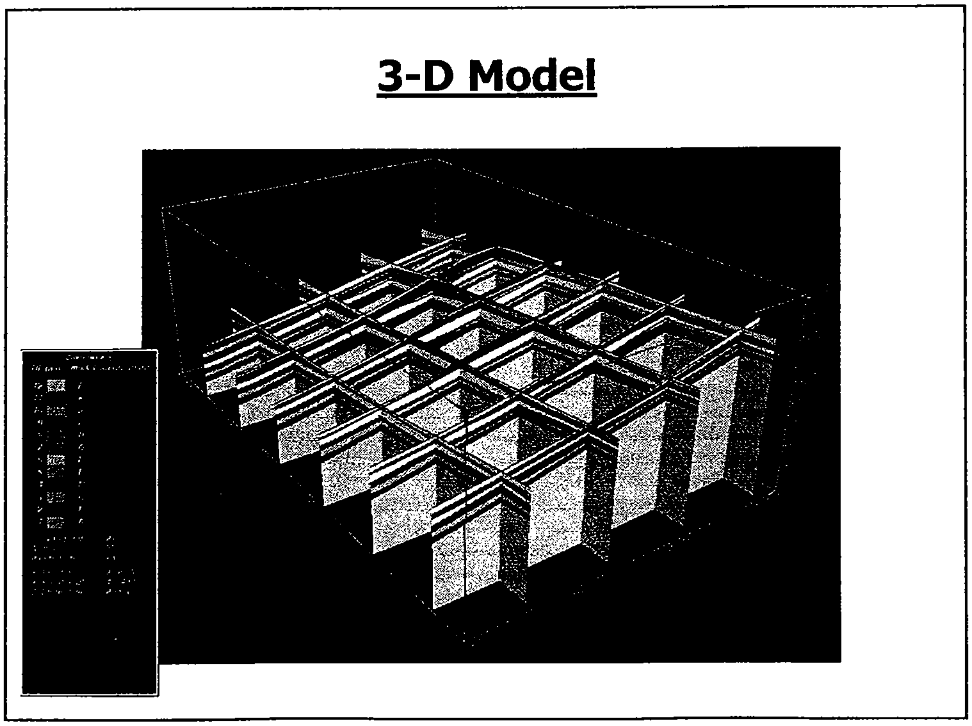




Field Work



Accuracy Control



3-D Model

APPLIED RESERVOIR CHARACTERIZATION FOR THE INDEPENDENT OPERATOR: WITH EMPHASIS ON COMPARTMENTALIZED RESERVOIRS AND ROUTINE TECHNIQUES FOR DETECTING COMPARTMENTS

UNIT 1: INTRODUCTION TO RESERVOIR CHARACTERIZATION

UNIT 2: EXAMPLES OF COMPARTMENTALIZED RESERVOIRS

UNIT 3: GEOLOGIC CONTROLS ON POROSITY AND PERMEABILITY

UNIT 3A: SEISMIC POROSITY DETECTION IN A CARBONATE RESERVOIR

UNIT 4: FLOW UNIT DETERMINATION & CHARACTERIZATION

UNIT 5: BASICS OF SEQUENCE STRATIGRAPHY

UNIT 6: FLUVIAL DEPOSITS AND RESERVOIRS

UNIT 7: EOLIAN DEPOSITS AND RESERVOIRS

***UNIT 8: SHOREFACE DEPOSITS AND RESERVOIRS**

UNIT 9: DELTAIC DEPOSITS AND RESERVOIRS

UNIT 10: DEEP-WATER (TURBIDITE) DEPOSITS AND RESERVOIRS

UNIT 11: BOREHOLE IMAGE LOGS AND APPLICATIONS

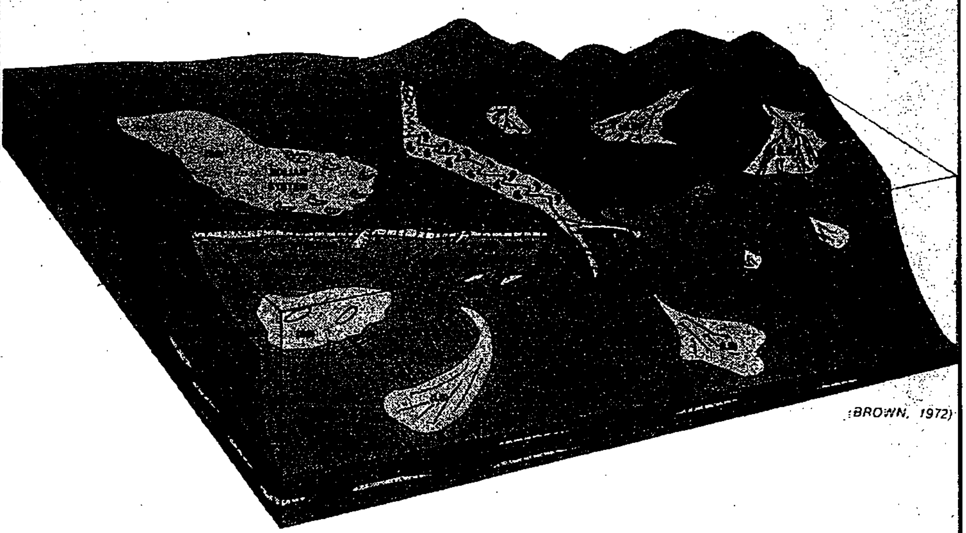
UNIT 12: DIPMETER LOGS AND APPLICATIONS

UNIT 13: STRUCTURALLY COMPARTMENTALIZED RESERVOIRS

KEY REFERENCES TO INDIVIDUAL UNITS

SHOREFACE & BARRIER ISLAND DEPOSITS & RESERVOIRS

ENVIRONMENTAL SETTING OF CLASTIC STRATIGRAPHIC TRAPS



(BROWN, 1972)

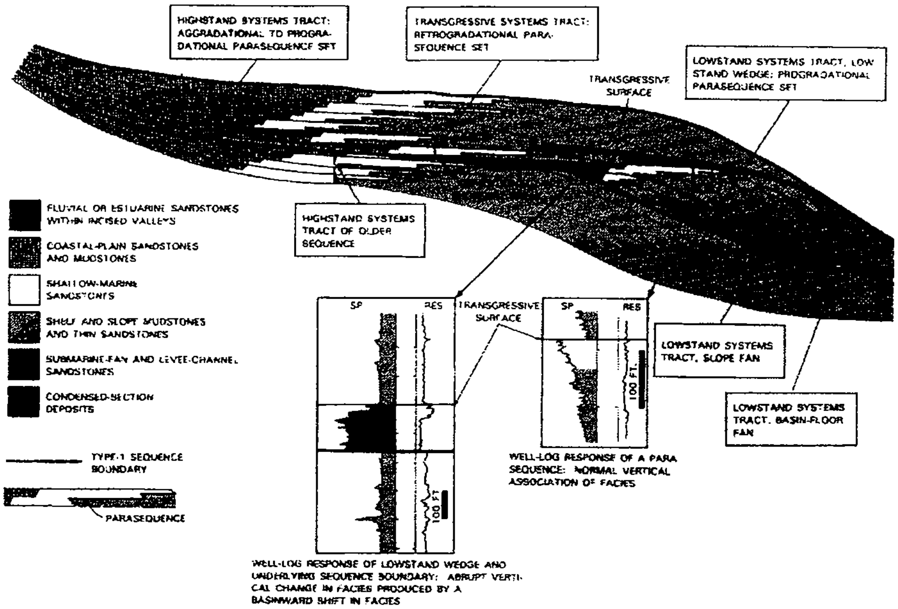


Figure 19—Stratal patterns in a type-1 sequence deposited in a basin with a shelf break.

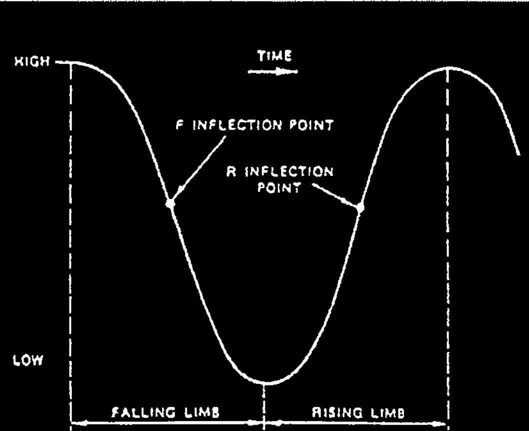
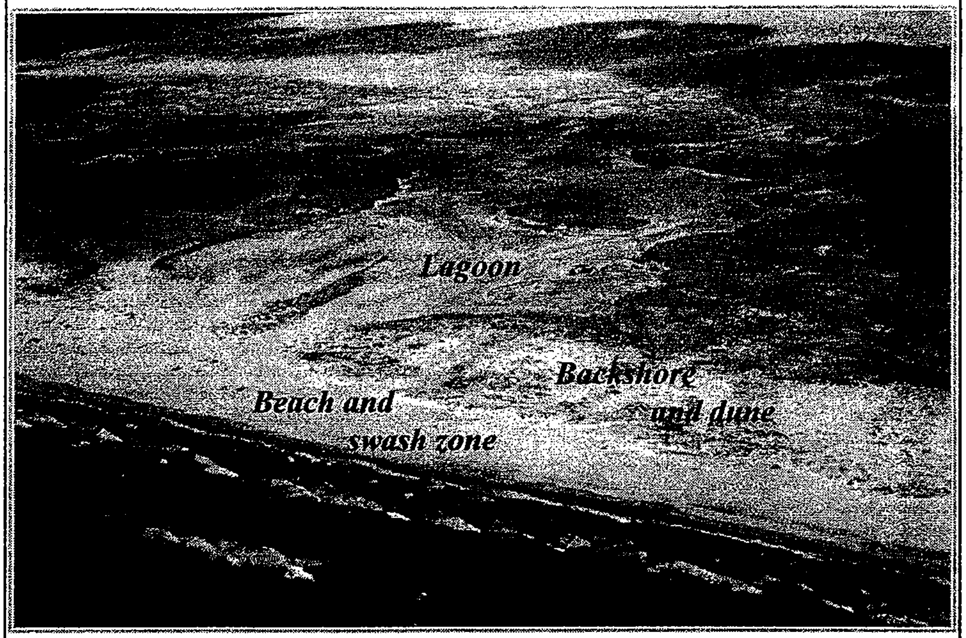
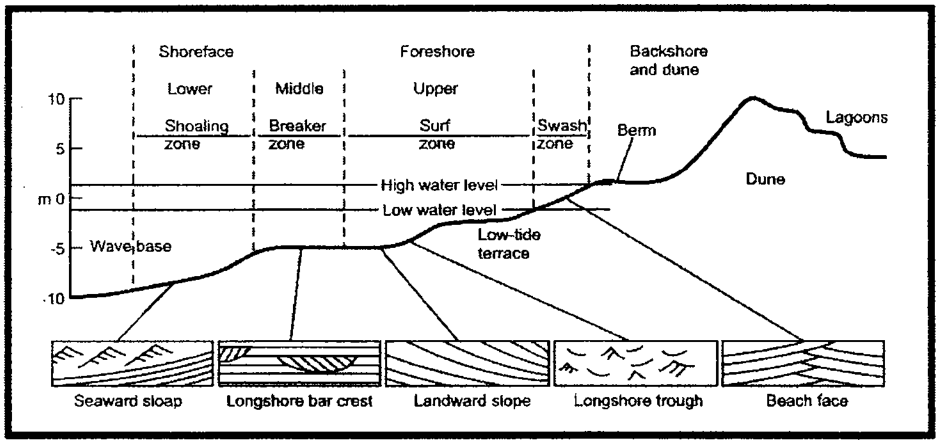
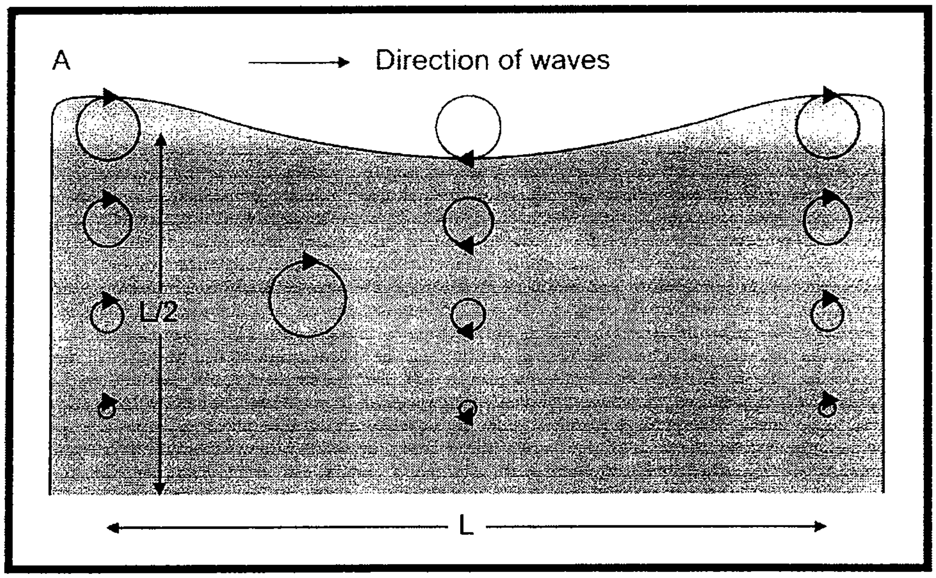


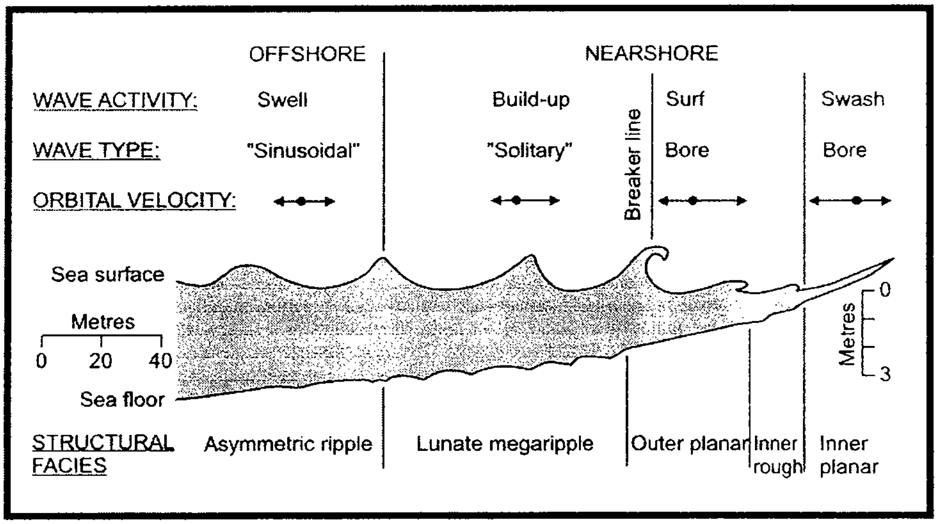
Figure 1. Elements of eustatic change. Maximum rates of rise and fall coincide with R- and F-inflection points. From Posamentier and others, 1988. Reprinted by permission of SEPM.

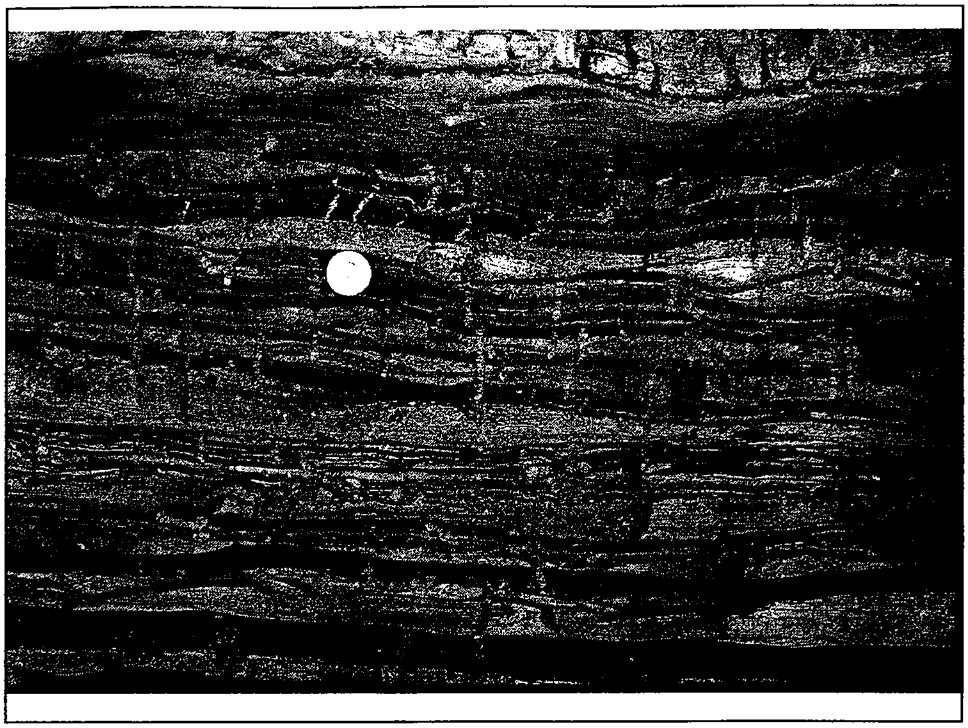
SHOREFACE DEPOSITS & RESERVOIRS


Lagoon
Backshore and dune
Beach and swash zone


Shoreface
Foreshore
Backshore and dune
Lower
Middle
Upper
Shoaling zone
Breaker zone
Surf zone
Swash zone
Berm
Lagoons
Dune
10
5
m 0
-5
-10
High water level
Low water level
Wave base
Low-tide terrace
Seaward sloap
Longshore bar crest
Landward slope
Longshore trough
Beach face


A
Direction of waves
L/2
L


OFFSHORE
NEARSHORE
WAVE ACTIVITY:
Swell
Build-up
Breaker line
Surf
Swash
WAVE TYPE:
"Sinusoidal"
"Solitary"
Bore
Bore
ORBITAL VELOCITY:
Sea surface
Metres
0
20
40
Sea floor
Metres
0
3
STRUCTURAL FACIES
Asymmetric ripple
Lunate megaripple
Outer planar
Inner rough
Inner planar



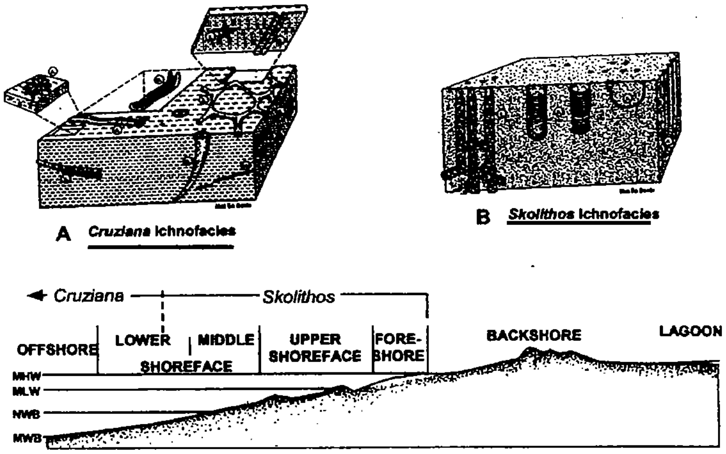
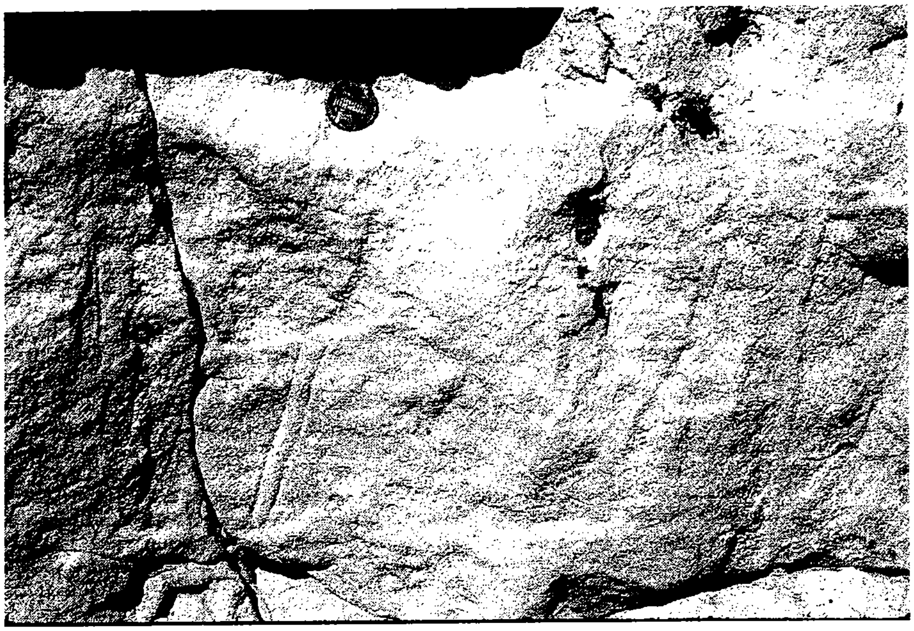
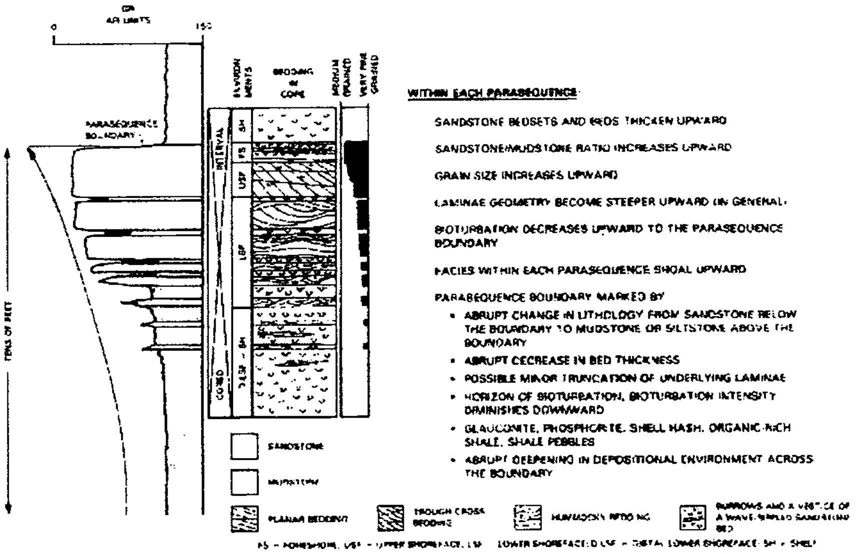


Figure 3.20 The offshore to coastal plain cross section, and distribution of the facies relative to normal wave base. Note the distibution of the Cruziana and Skolithos ichnofacies to the Cretaceous of the Western Interior Sea way of North America. A)The Cruziana ichnofacies comprises 1) Asteriacites*, 2) Cruziana*, 3) Rhizocorallium, 4) Aulichnites*, 5) Thalassinoides, 6)Chondrites, 7) Teichichnus, 8) Asterosoma, 9) Rosselia and 9) Planolites. . The trace fossils marked with asterisk are not represented in the Cruziana ichnofacies described in the reference study. B) The skolithos ichnofacies comprises 1) Ophiomorpha 2) Diplocraterion, 3) Skolithos and 4) Arenicolites.(MHW - Mean High Water, MLW - Mean Low Water, NWB - Normal Wave Base, MWB - Maximum Wave base. (Modified from Pemberton, el al. 1997)



Vertical ophiomorhpa burrows in side view.



WITHIN EACH PARASEQUENCE:

SANDSTONE BEDSETS AND BEDS THICKEN UPWARD

SANDSTONE/MUDSTONE RATIO INCREASES UPWARD

GRAIN SIZE INCREASES UPWARD

LAMINAE GEOMETRY BECOME STEEPER UPWARD (IN GENERAL)

BIOTURBATION DECREASES UPWARD TO THE PARASEQUENCE BOUNDARY

FACIES WITHIN EACH PARASEQUENCE SHOAL UPWARD

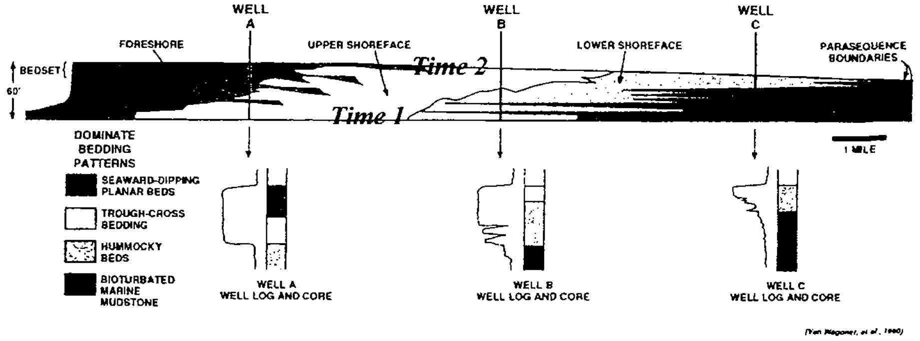
PARASEQUENCE BOUNDARY MARKED BY

- ABRUPT CHANGE IN LITHOLOGY FROM SANDSTONE BELOW THE BOUNDARY TO MUDSTONE OR SILTSTONE ABOVE THE BOUNDARY
- ABRUPT DECREASE IN BED THICKNESS
- POSSIBLE MINOR TRUNCATION OF UNDERLYING LAMINAE
- HORIZON OF BIOTURBATION, BIOTURBATION INTENSITY DIMINISHES DOWNWARD
- GLAUCONITE, PHOSPHORITE, SHELL HASH, ORGANIC-RICH SHALE, SHALE PEBBLES
- ABRUPT DEEPENING IN DEPOSITIONAL ENVIRONMENT ACROSS THE BOUNDARY

Figure 3A—Stratal characteristics of an upward-coarsening parasequence. This type of parasequence is interpreted to form in a beach environment on a sandy, wave- or fluvial-dominated shoreline.

Upward-coarsening/thickening shoreface parasequence

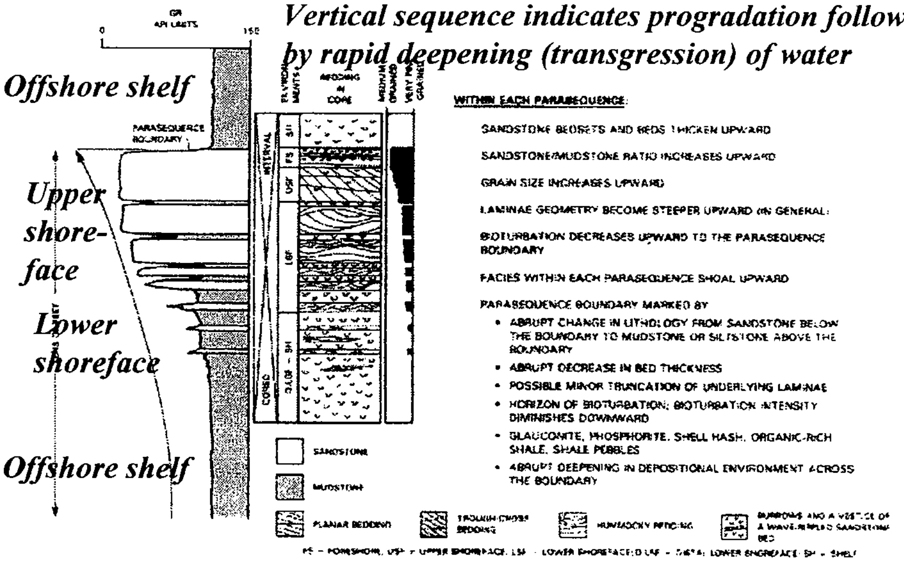
Seaward to right



(Van Wagoner, et al., 1990)

Seaward progradation during relative stillstand of sea level

Vertical sequence indicates progradation followed by rapid deepening (transgression) of water



WITHIN EACH PARASEQUENCE:

SANDSTONE BEDSETS AND BEDS THICKEN UPWARD

SANDSTONE/MUDSTONE RATIO INCREASES UPWARD

GRAIN SIZE INCREASES UPWARD

LAMINAE GEOMETRY BECOME STEEPER UPWARD (IN GENERAL)

BIOTURBATION DECREASES UPWARD TO THE PARASEQUENCE BOUNDARY

FACIES WITHIN EACH PARASEQUENCE SHOAL UPWARD

PARASEQUENCE BOUNDARY MARKED BY
- ABRUPT CHANGE IN LITHOLOGY FROM SANDSTONE BELOW THE BOUNDARY TO MUDSTONE OR SILTSTONE ABOVE THE BOUNDARY
- ABRUPT DECREASE IN BED THICKNESS
- POSSIBLE MINOR TRUNCATION OF UNDERLYING LAMINAE
- HORIZON OF BIOTURBATION; BIOTURBATION INTENSITY DIMINISHES DOWNWARD
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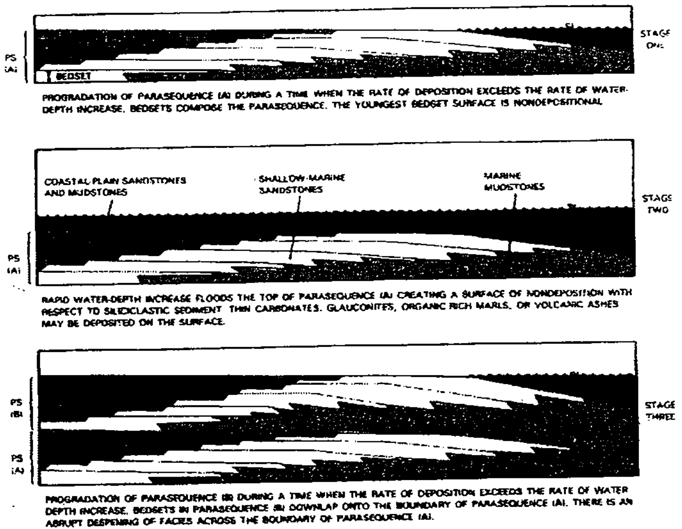
Figure 3A—Stratal characteristics of an upward-coarsening parasequence. This type of parasequence is interpreted to form in a beach environment on a sandy, wave- or fluvial-dominated shoreline.

Upward-coarsening/thickening shoreface parasequence



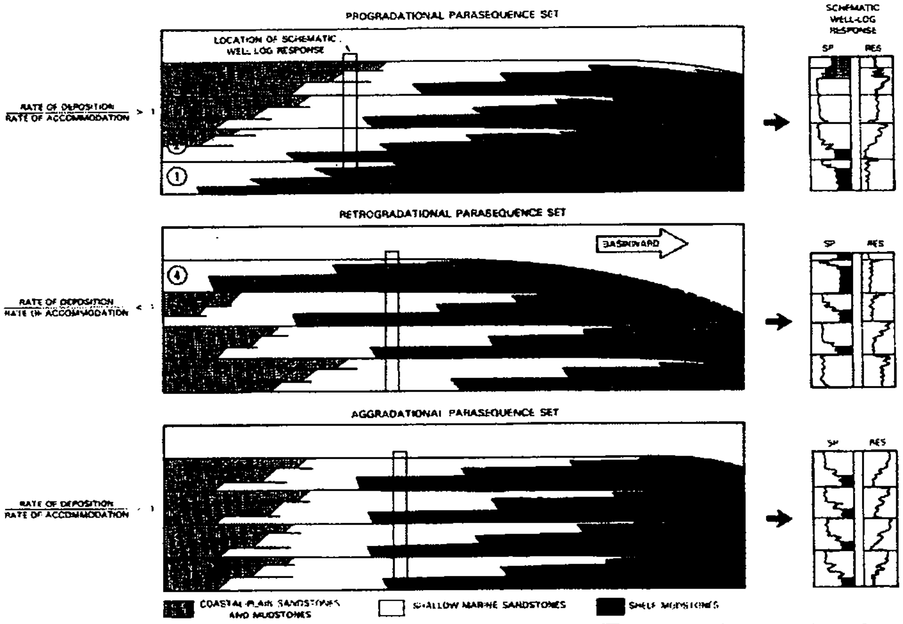
PROGRADATION OF PARASEQUENCE (A) DURING A TIME WHEN THE RATE OF DEPOSITION EXCEEDS THE RATE OF WATER-DEPTH INCREASE. BEDSETS COMPOSE THE PARASEQUENCE. THE YOUNGEST BEDSET SURFACE IS NONDEPOSITIONAL

RAPID WATER-DEPTH INCREASE FLOODS THE TOP OF PARASEQUENCE (A) CREATING A SURFACE OF NONDEPOSITION WITH RESPECT TO SILICICLASTIC SEDIMENT. THIN CARBONATES, GLAUCONITES, ORGANIC RICH MARLS, OR VOLCANIC ASHES MAY BE DEPOSITED ON THE SURFACE.

PROGRADATION OF PARASEQUENCE (B) DURING A TIME WHEN THE RATE OF DEPOSITION EXCEEDS THE RATE OF WATER DEPTH INCREASE. BEDSETS IN PARASEQUENCE (B) DOWNLAP ONTO THE BOUNDARY OF PARASEQUENCE (A). THERE IS AN ABRUPT DEEPENING OF FACIES ACROSS THE BOUNDARY OF PARASEQUENCE (A).

Figure 4—Progressive development of a parasequence boundary.

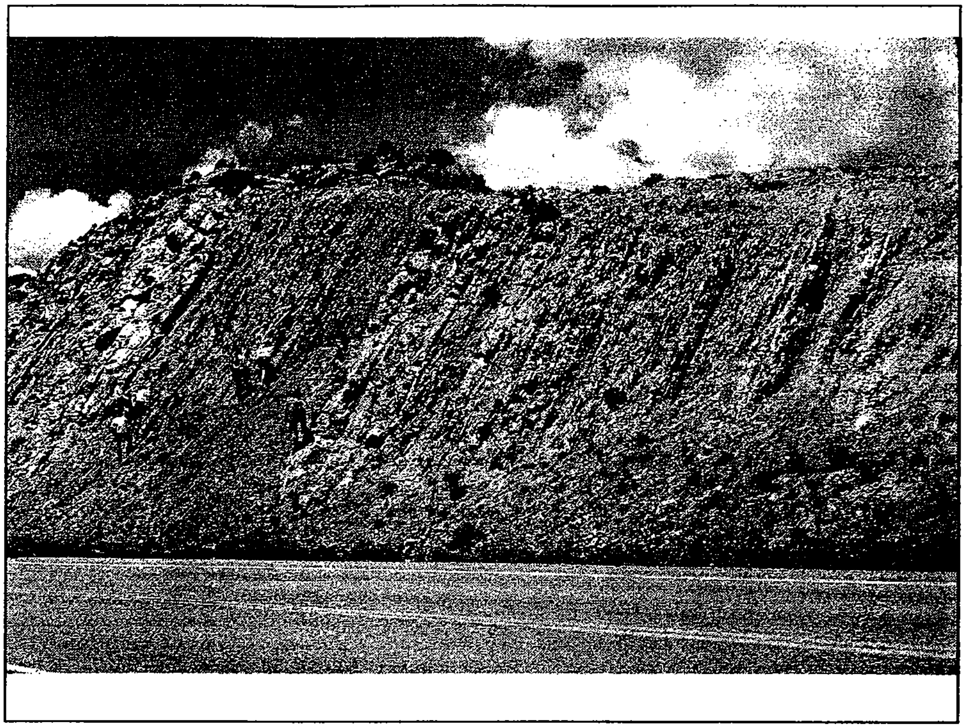
Two cycles of progradation and transgression to give two parasequences

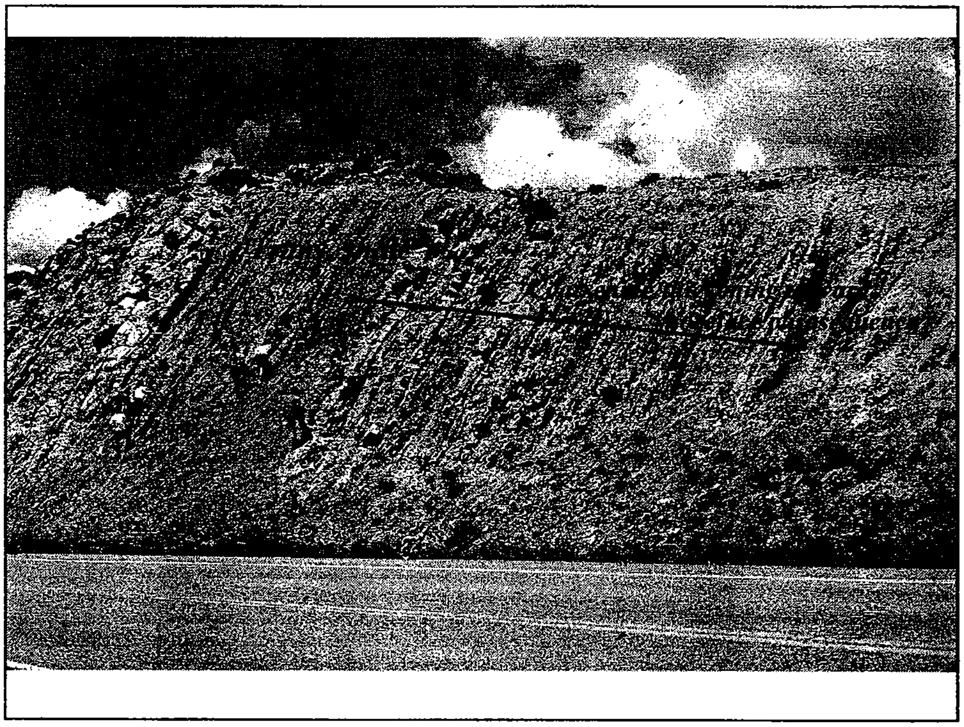


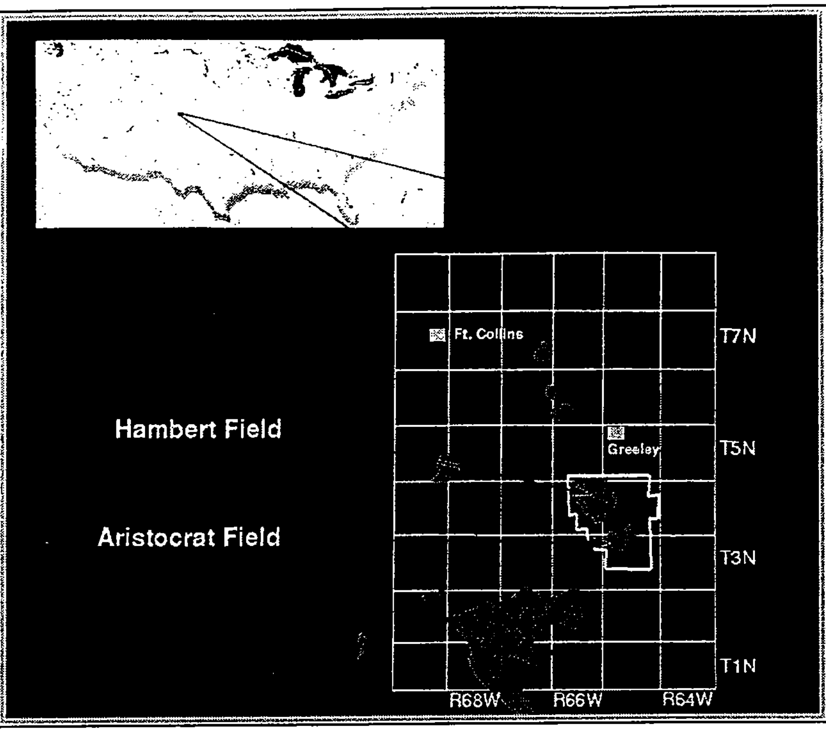
① ④ INDIVIDUAL PARASEQUENCES

Figure 10—Parasequence-stacking patterns in parasequence sets; cross-section and well-log expression.

Four cycles to give four parasequences

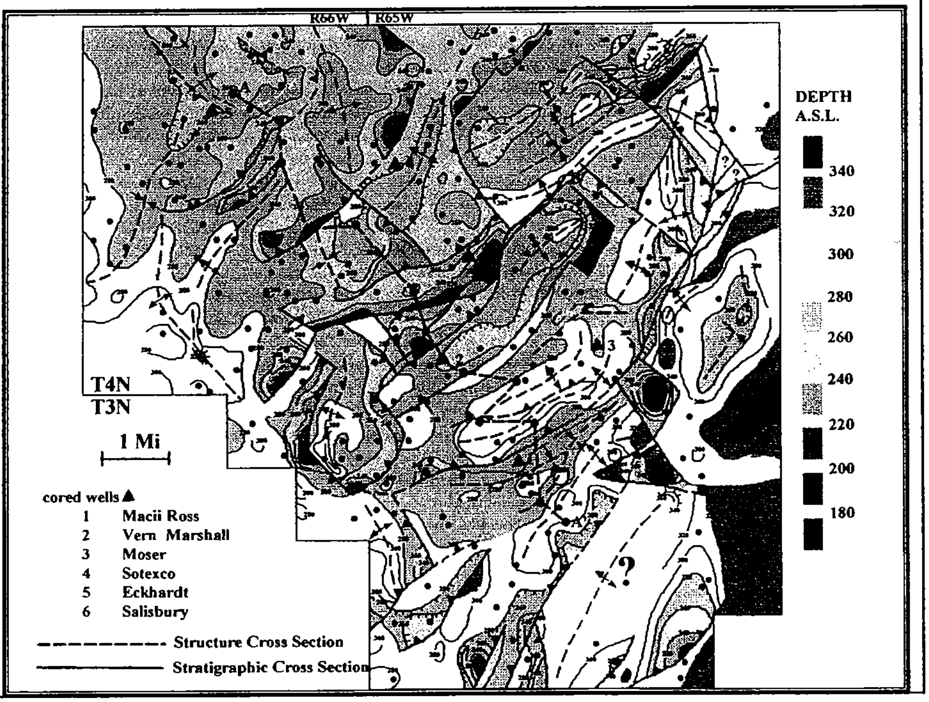


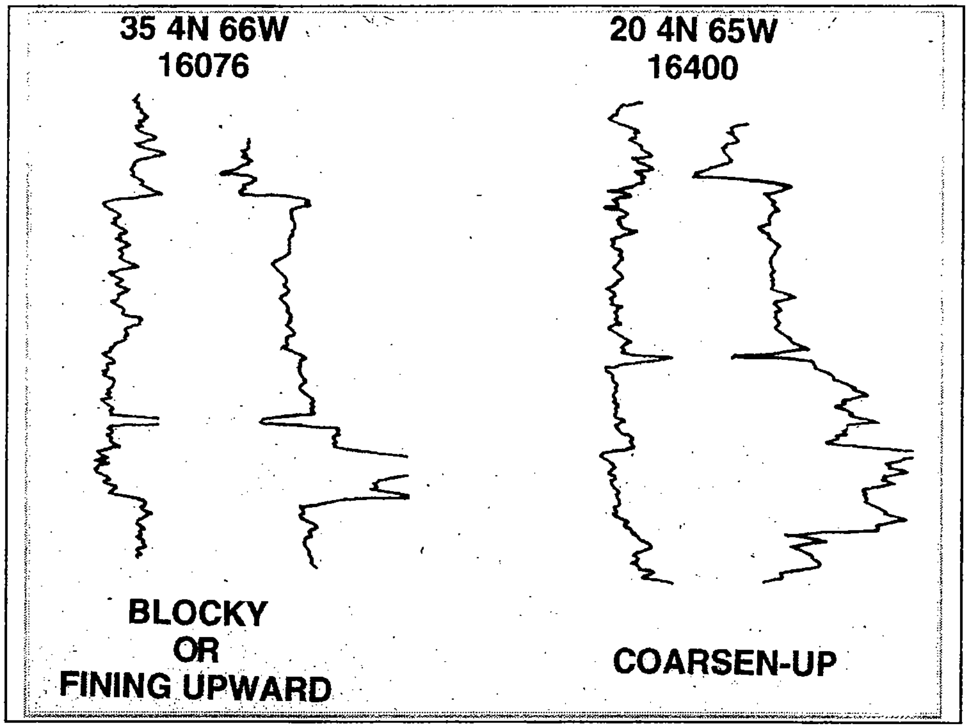


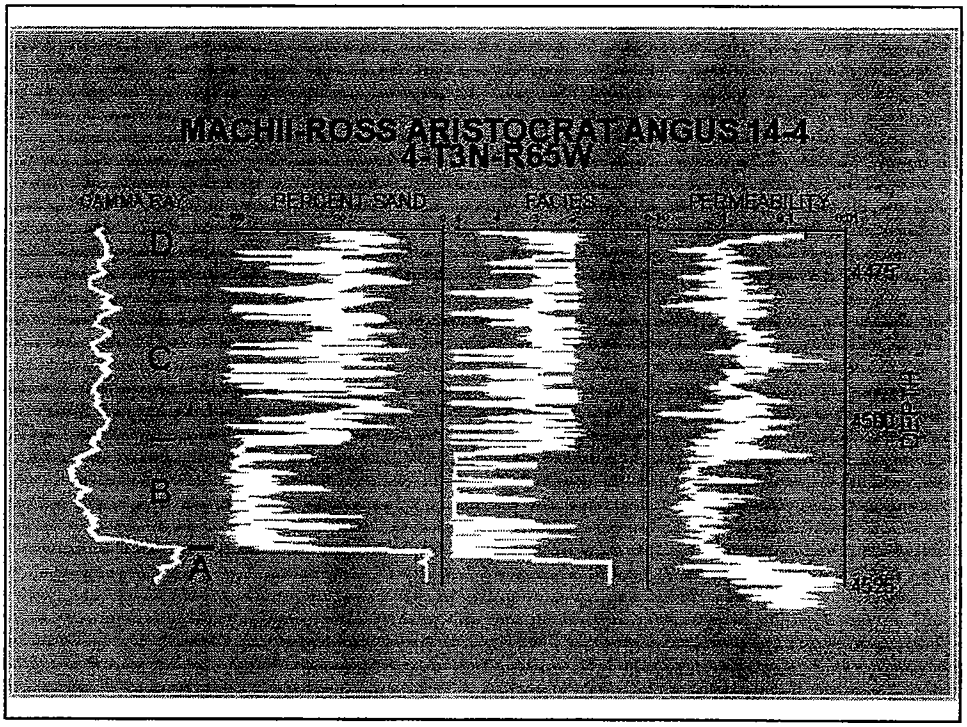


Hambert Field

Aristocrat Field

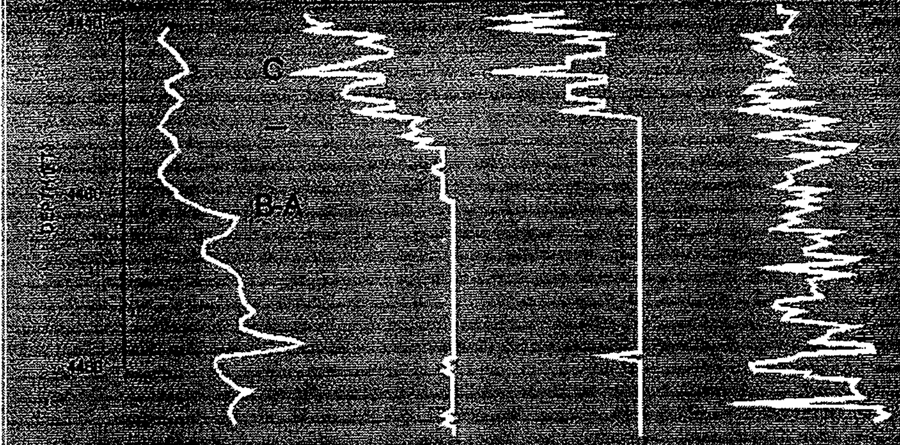


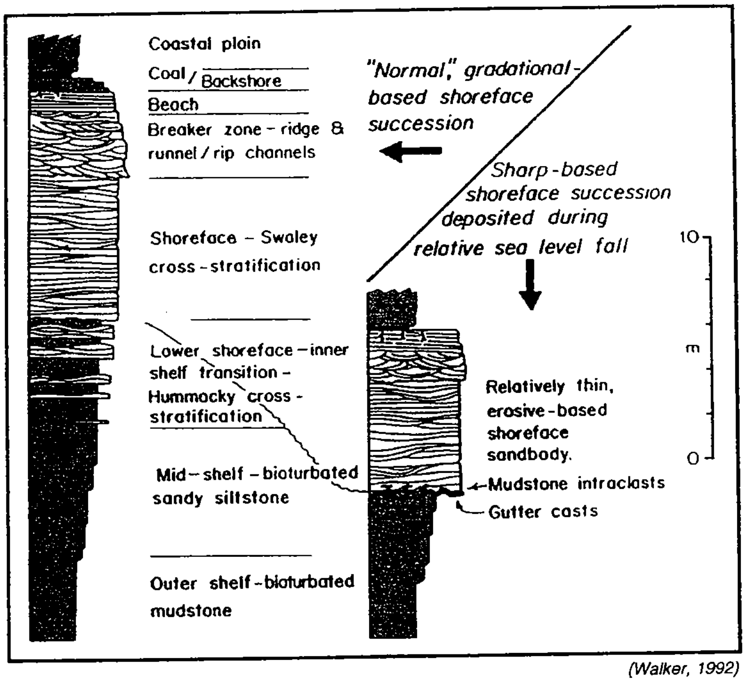




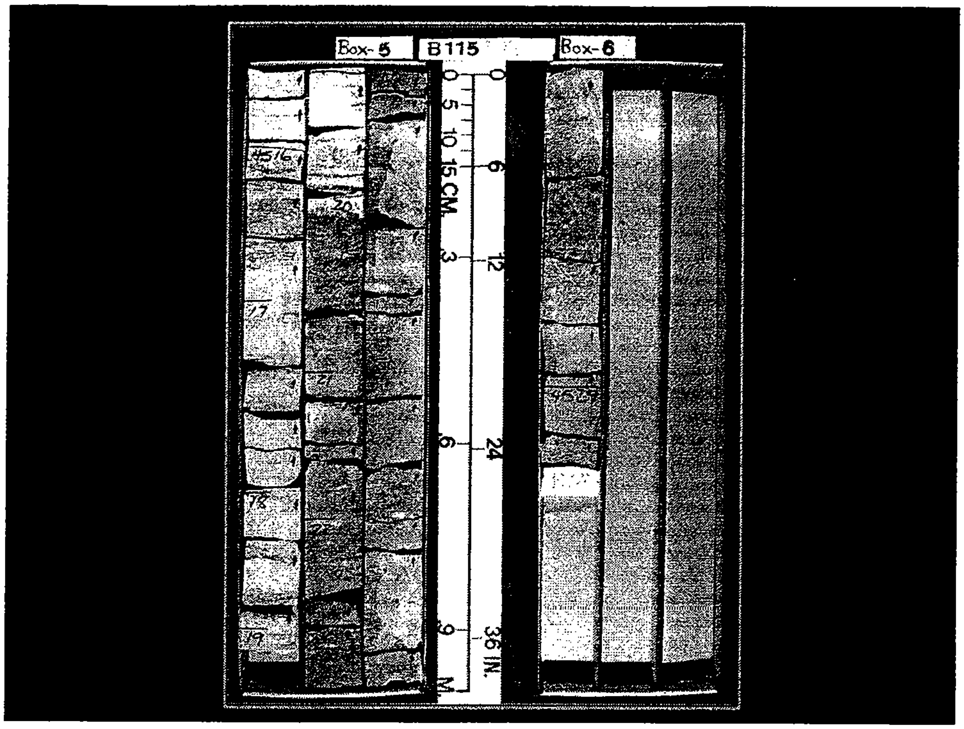
MACHII-ROSS ARISTOCRAT ANGUS 14-4
4-T3N-R65W

#1 DONALD MOSER
34-T4N-R65W

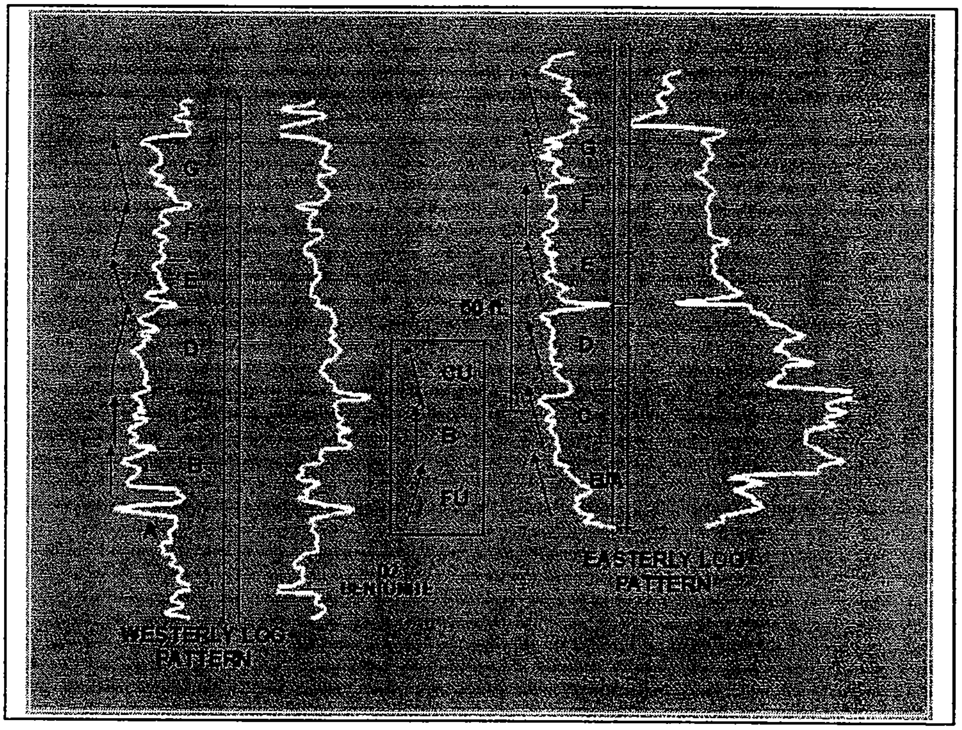




(Walker, 1992)



Box-5
B115
Box-6
0 5 10 15 CM.
3
6
9
M.
0
6
12
24
36 IN.
4516
20
17
21
78
19



G
F
E
D
C
B
60 ft.
CU
B
FU
G
F
E
D
C
BM
WESTERLY LOG PATTERN
EASTERLY LOG PATTERN

EXERCISE ON HAMBERT-ARISTOCRAT FIELD

CONCLUSIONS

- SHOREFACE SEQUENCES ARE INTERNALLY COMPLEX
- INDIVIDUAL SANDSTONES ARE SEPARATED BY LATERALLY CONTINUOUS TRANSGRESSIVE MARINE SHALES WHICH CAN VERTICALLY ISOLATE INDIVIDUAL SANDSTONES
- PORO./PERM. VALUES WILL VARY WITH FACIES (UPPER, MIDDLE, LOWER SHOREFACE)
- HIGH RESOLUTION SEQUENCE STRATIGRAPHY SHOULD BE APPLIED TO SHOREFACE SEQUENCES

BARRIER
ISLAND DEPOSITS & RESERVOIRS

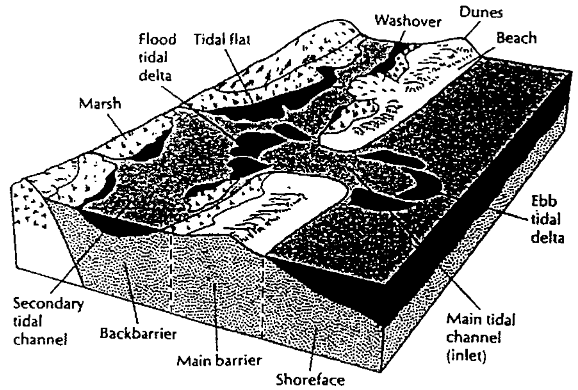
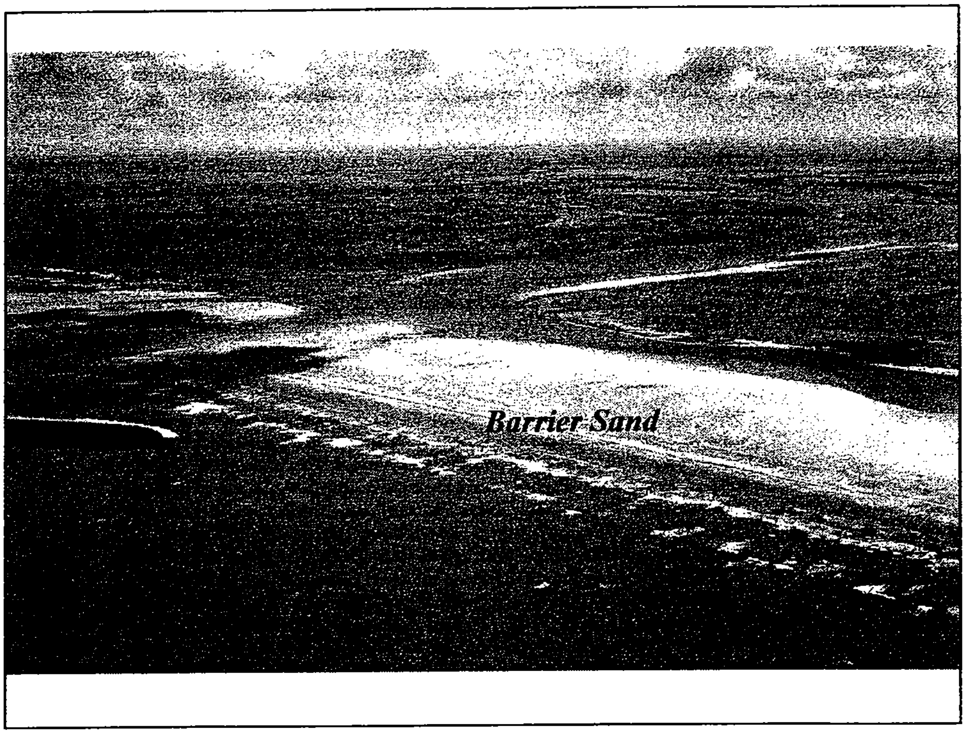
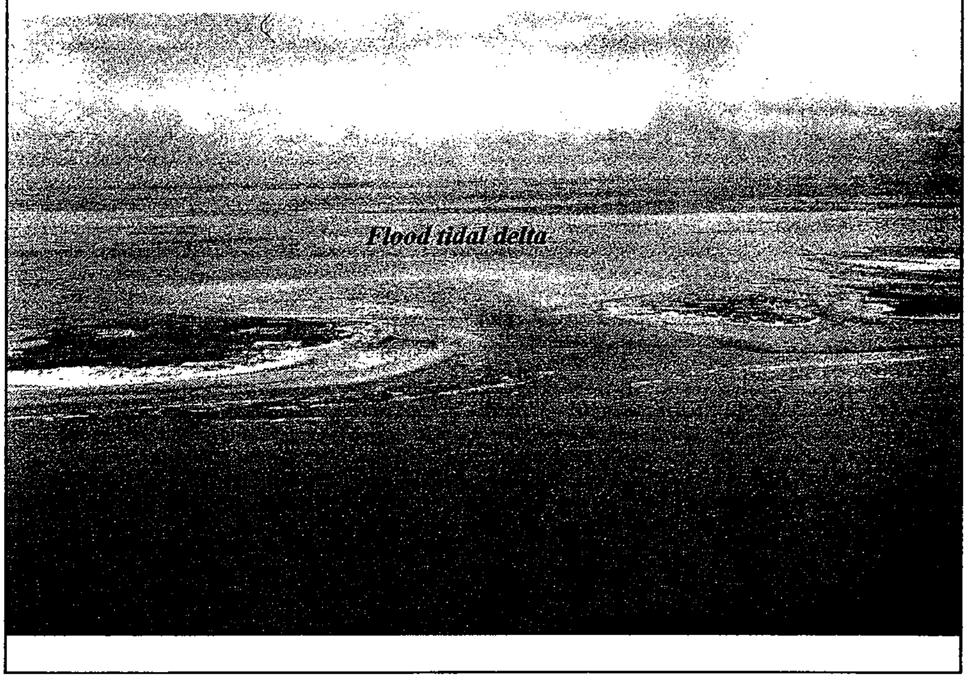
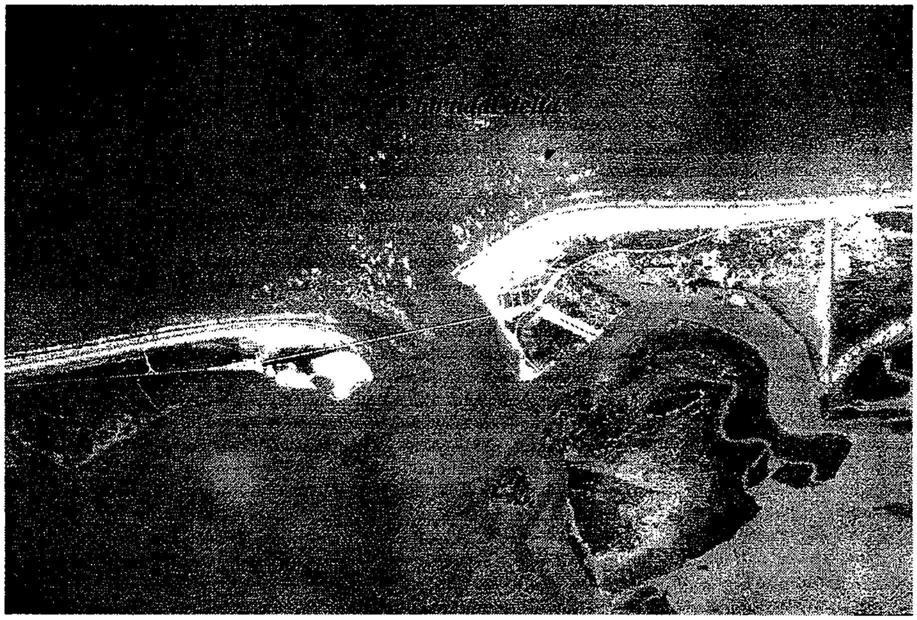


Figure 9.14

Subenvironments in a barrier-island system. (From Walker, 1984.)


Barrier Sand


Flood tidal delta



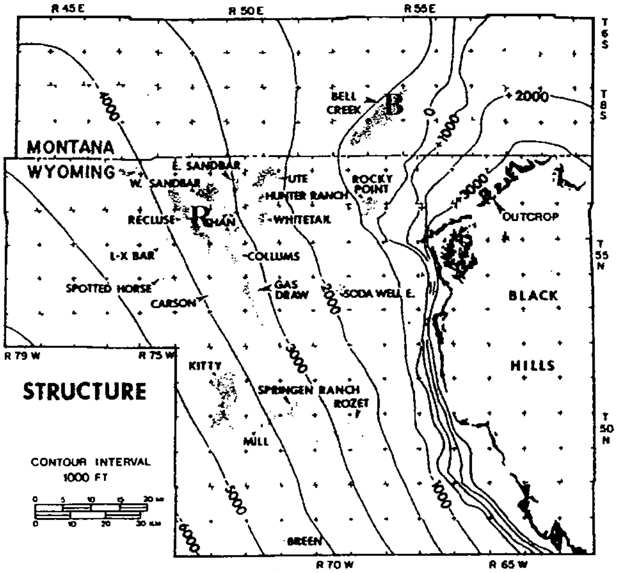


Figure 7-13 Structure on top of the Muddy Formation, northeastern Powder River basin, and location of Muddy stratigraphic oil fields. Contour interval 1000 ft (300 m). [Map drawn by L. D. Recker.] Map area shown in Figure 7-12.

TABLE 7-1. OIL PRODUCTION FROM SELECTED MUDDY FIELDS, NORTHEASTERN POWDER RIVER BASIN, MONTANA AND WYOMING

Name	Discovery date (mo/yr)	Producing wells (Total Jan. 1, 1977)		Production^a (Annual 1976)	Production^a (Cumulative Jan. 1, 1977)
Bell Creek **B**	6/67	196	180	8.75	86.3
Hilight	2/69	195	176	3.82	57.6
Recluse **R**	8/67	58	46	8.38	20.8
Gas Draw	8/68	83	47	1.8	19.7
Rozet	4/59	28	28	0.70	15.7
Kitty	8/65	175	161	0.50	15.1
Springen Ranch	11/68	43	28	0.70	8.9
Collums	2/69	42	23	0.20	5.4
Sandbar, East	1/68	24	12	0.10	4.2
Sandbar, West	2/68	16	11	0.06	3.3
Rozet East	6/61	8	8	0.16	1.7
Mill	3/69	22	22	0.01	1.5
Gillette	10/62	11	0	0	1.3
Recluse SE	12/68	5	4	0.02	0.4
L-X Bar	2/73	7	7	0.10	0.6

SOURCE: Data from International Oil Scouts Association, *Yearbook 1977.*

[a] Production in million barrels of crude oil.

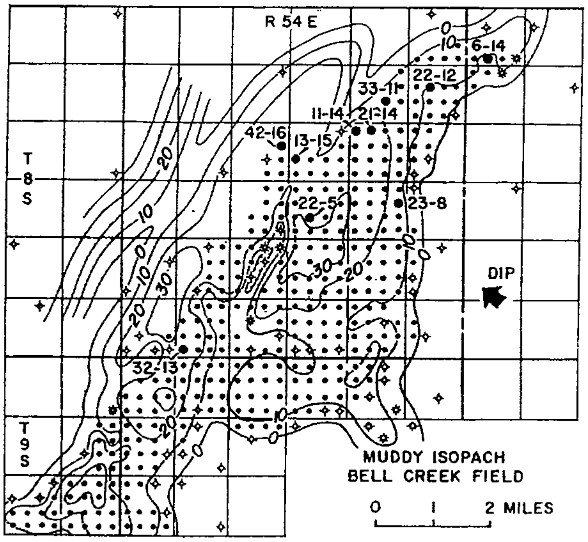


Figure 7-27 Thickness of Muddy sandstones at Bell Creek field, Montana, showing linear barrier-island sandstones partly overlapped in the center of the field. Regional dip is toward the northwest at 100 ft/mi (19 m/km). [Modified from Berg and Davies 1968.]

Sedimentary structures. The Muddy sandstone shows a sequence similar to that of the barrier island, and a typical section is shown in a core from the well Boekel 21-14, as follows:

Unit	*Thickness ft (m)*
1. Eolian sandstone, very fine grained, massive.	5 (1.5)
2. Beach and upper-shoreface sandstone, fine grained, laminated.	5 (1.5)
3. Middle-shoreface sandstone, fine grained, massive or with discontinuous laminae.	10 (3)
4. Lower-shoreface mudstone, shaly, highly bioturbated.	3 (0.9)
Total	23 (7)

This sequence is identical to that of the modern barrier island at Galveston Island (Figure 7-4).

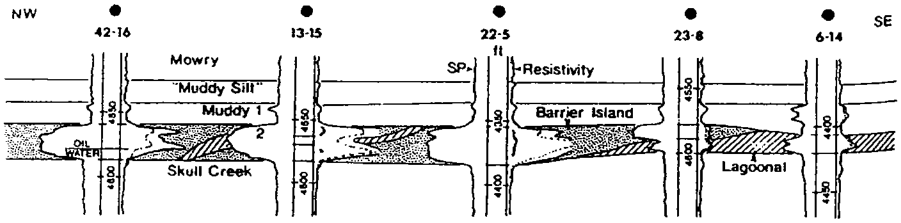


Figure 7-31 Correlation of electric logs from cored wells across Bell Creek field showing overlap of two barrier-island sandstones and adjoining lagoonal facies. No horizontal scale.

Cross-hatched intervals are shales which separate sandstones.

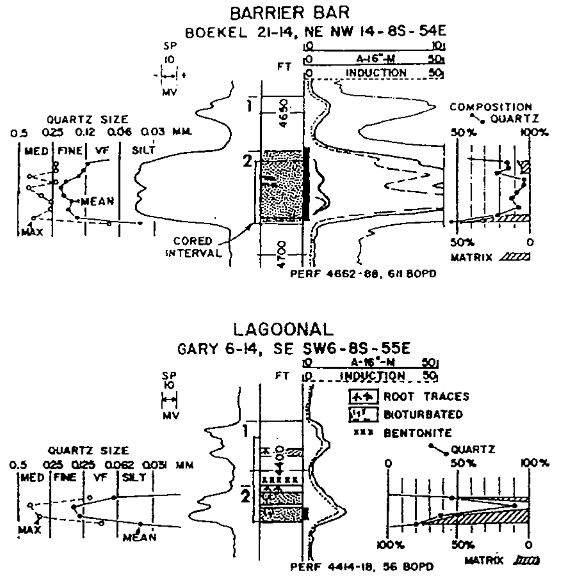


Figure 7–29 Electric logs, texture, and composition of typical barrier-island and lagoonal sections, Bell Creek field. Location of wells shown in Figure 7–27. Sedimentary structures for these wells are shown in Figure 7–28.

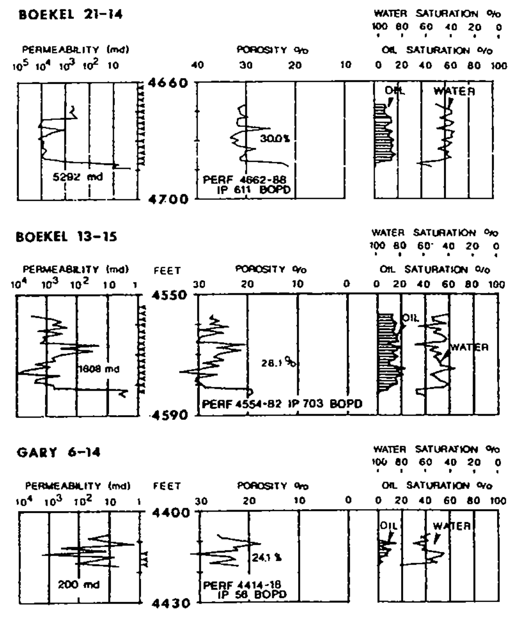


Figure 7–32 Permeabilities, porosities, and fluid saturations in barrier-island and lagoonal sandstones, Bell Creek field. Texture and composition for the sections are illustrated in Figures 7–29 and 7–30. Note change in scales.

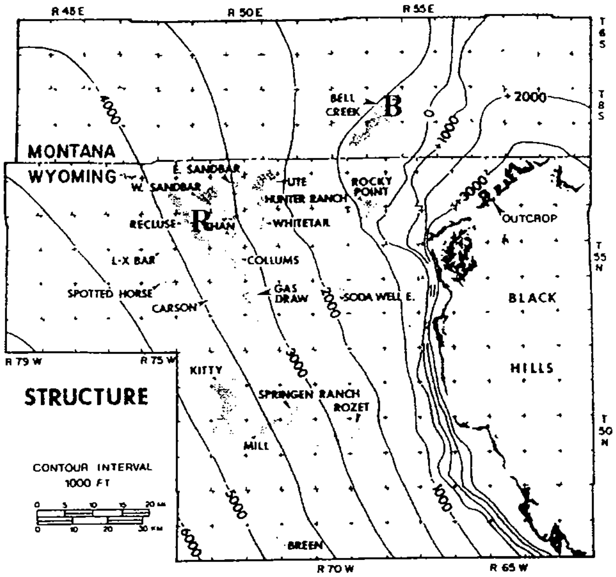


Figure 7-13 Structure on top of the Muddy Formation, northeastern Powder River basin, and location of Muddy stratigraphic oil fields. Contour interval 1000 ft (300 m). [Map drawn by L. D. Recker.] Map area shown in Figure 7-12.

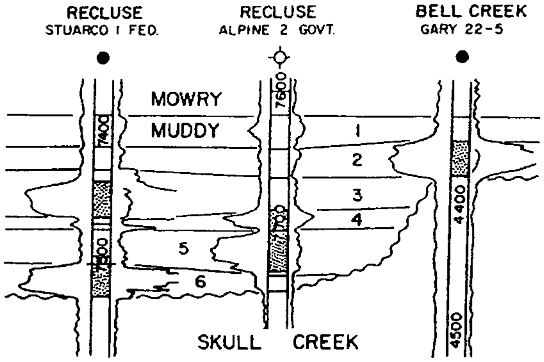


Figure 7-14 Correlation of electric logs showing six zones within the Muddy Formation from Bell Creek field on the northeast to the vicinity of Recluse field on the southwest. Location of Bell Creek and Recluse fields given in Figure 7-12. No horizontal scale.

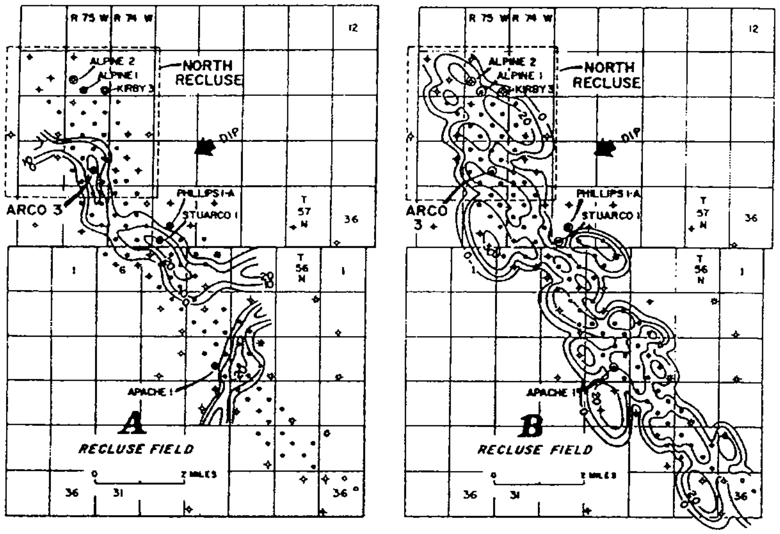


Figure 7-24 Gross thickness of sixth Muddy sandstones (A) and Fifth Muddy sandstones (B) at Recluse field. Contour interval 10 ft (3 m). Cores or samples were examined from circled and named wells. The north Recluse area is shown in Figure 7-25. [Maps from Berg 1976*a* and published with the permission of the Wyoming Geological Association.]

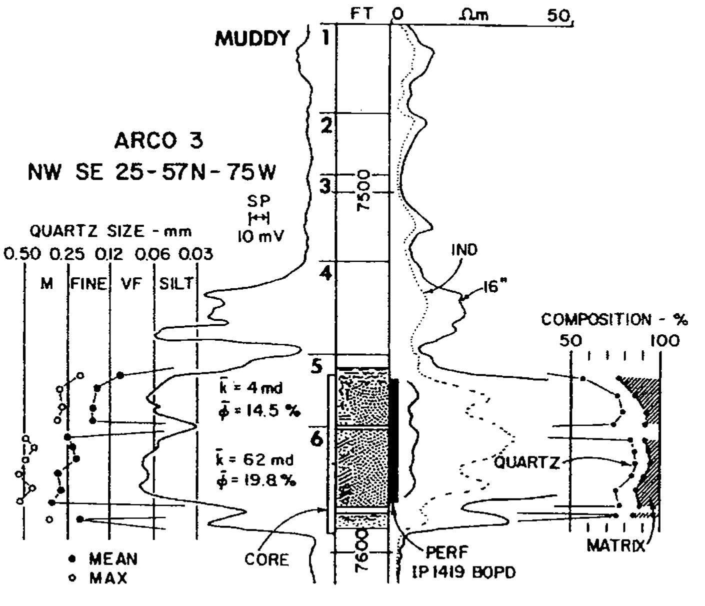


Figure 7-18 Electric logs, texture, and composition of the fifth and sixth Muddy sandstones in the ARCO Bow and Arrow 3 core. Location of well shown in Figure 7-25.

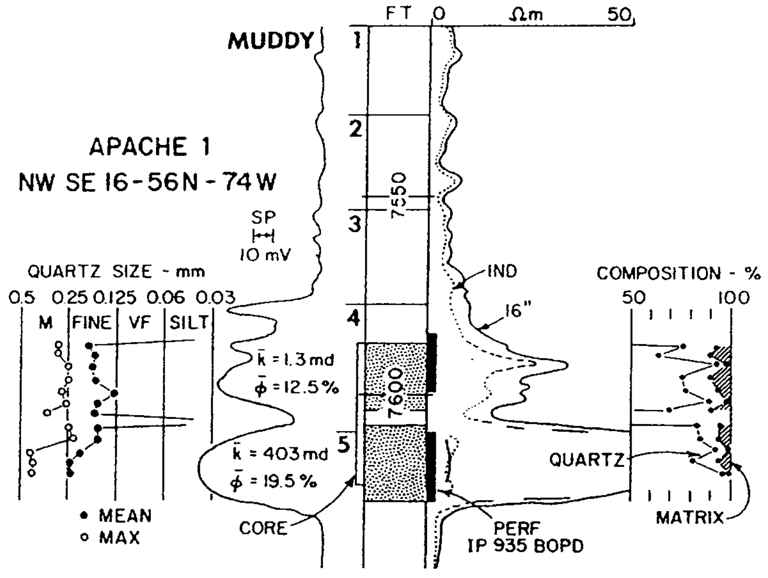


Figure 7-19 Electric logs, texture, and composition of the fourth and fifth Muddy sandstones, Apache State 1 well, Recluse field. Location of well shown in Figure 7-25.

Coastal Sandstones

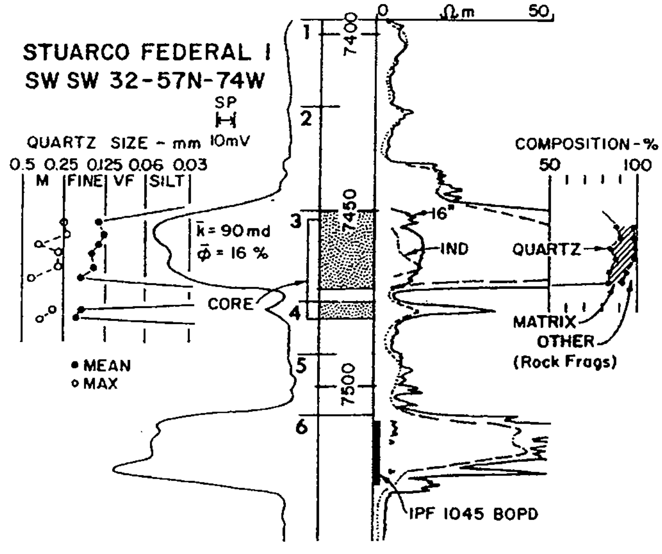
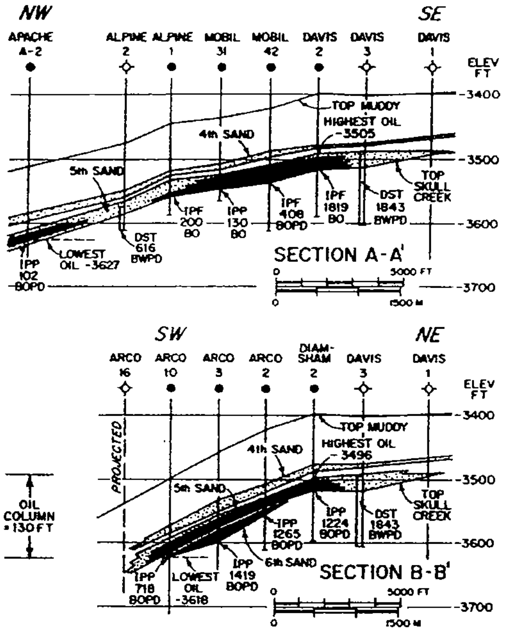


Figure 7-21 Electric logs, texture, and composition of the third Muddy sandstone, Stuarco Federal 1 well, Recluse field. Location of well shown in Figure 7-25.



Note upward (structurally) increase in IPF oil, then water.

Figure 7-26 Cross sections AA' and BB' in the north part of Recluse field showing water recovery adjacent to oil production and an oil column greater than 100 ft (30 m). Location of cross sections shown in Figure 7-25. BOPD = bbls oil/day; BWPD = bbls water/day. [From Berg 1976*a* and published with the permission of the Wyoming Geological Association.]

CONCLUSIONS

- BARRIER ISLAND DEPOSITS ARE INTERNALLY COMPLEX
- INDIVIDUAL SANDSTONES MAY BE SEPARATED BY LAGOONAL SHALES WHICH CAN ISOLATE INDIVIDUAL SANDSTONES
- PORO./PERM. VALUES WILL VARY WITH FACIES AND GRAIN SIZE

APPLIED RESERVOIR CHARACTERIZATION FOR THE INDEPENDENT OPERATOR: WITH EMPHASIS ON COMPARTMENTALIZED RESERVOIRS AND ROUTINE TECHNIQUES FOR DETECTING COMPARTMENTS

UNIT 1: INTRODUCTION TO RESERVOIR CHARACTERIZATION

UNIT 2: EXAMPLES OF COMPARTMENTALIZED RESERVOIRS

UNIT 3: GEOLOGIC CONTROLS ON POROSITY AND PERMEABILITY

UNIT 3A: SEISMIC POROSITY DETECTION IN A CARBONATE RESERVOIR

UNIT 4: FLOW UNIT DETERMINATION & CHARACTERIZATION

UNIT 5: BASICS OF SEQUENCE STRATIGRAPHY

UNIT 6: FLUVIAL DEPOSITS AND RESERVOIRS

UNIT 7: EOLIAN DEPOSITS AND RESERVOIRS

UNIT 8: SHOREFACE DEPOSITS AND RESERVOIRS

*UNIT 9: DELTAIC DEPOSITS AND RESERVOIRS

UNIT 10: DEEP-WATER (TURBIDITE) DEPOSITS AND RESERVOIRS

UNIT 11: BOREHOLE IMAGE LOGS AND APPLICATIONS

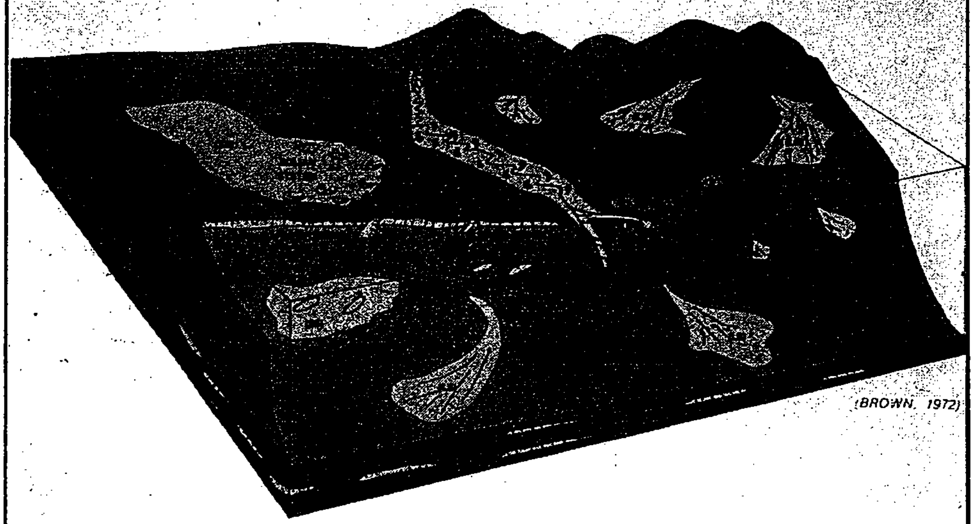
UNIT 12: DIPMETER LOGS AND APPLICATIONS

UNIT 13: STRUCTURALLY COMPARTMENTALIZED RESERVOIRS

KEY REFERENCES TO INDIVIDUAL UNITS

DELTAIC DEPOSITS & RESERVOIRS

ENVIRONMENTAL SETTING OF CLASTIC STRATIGRAPHIC TRAPS



(BROWN, 1972)

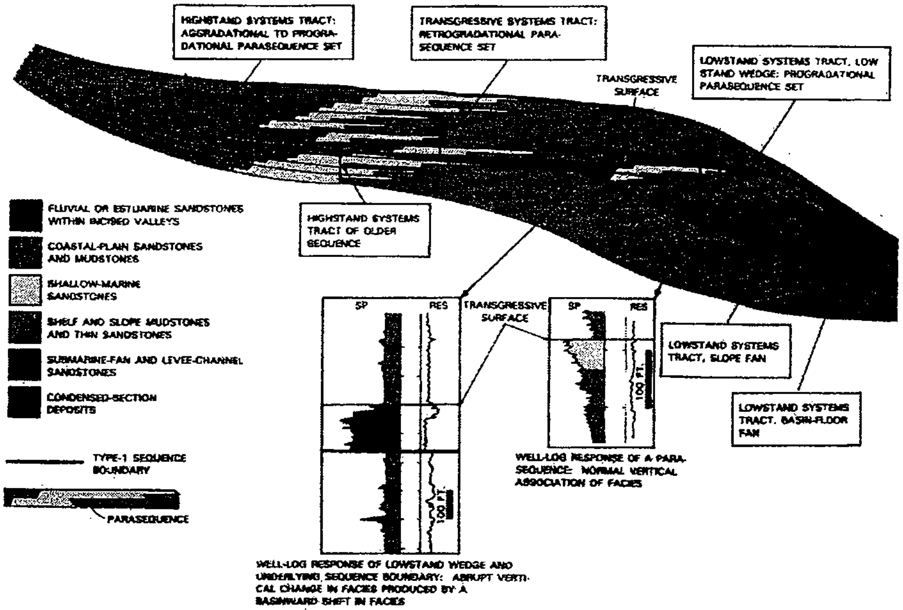


Figure 19—Stratal patterns in a type-1 sequence deposited in a basin with a shelf break.

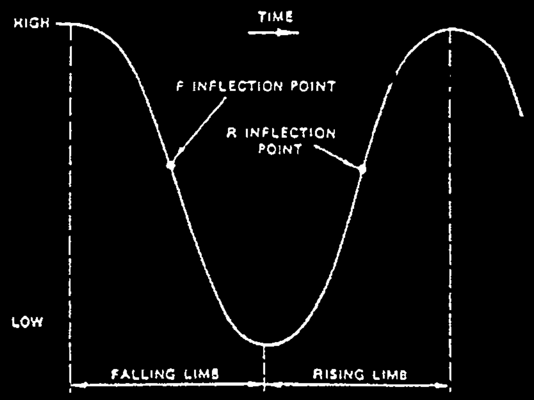
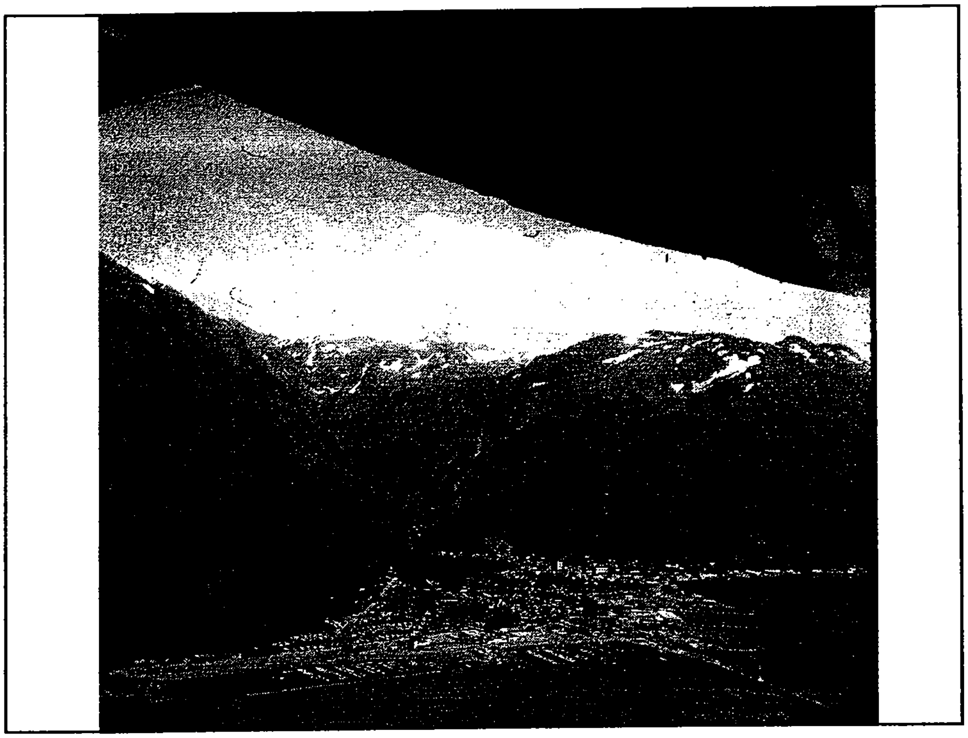
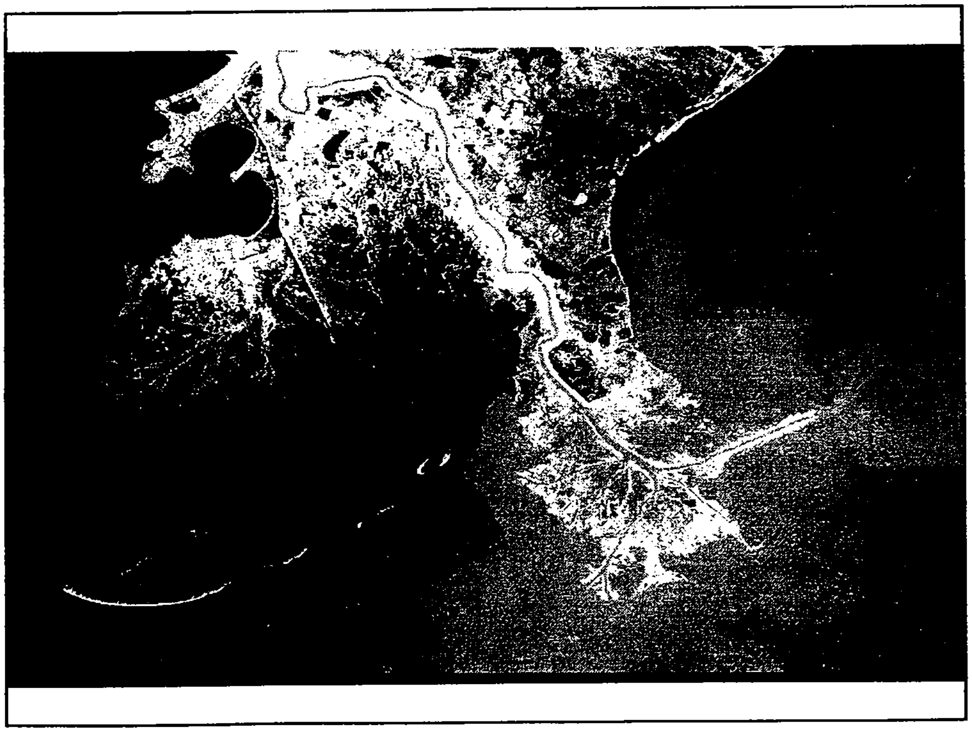
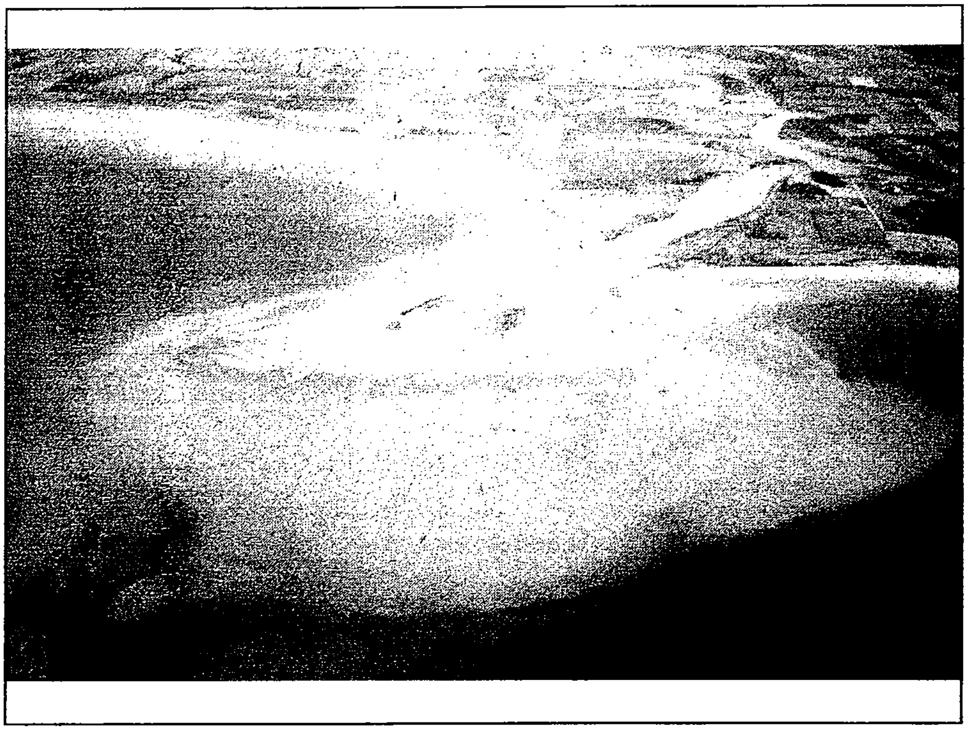
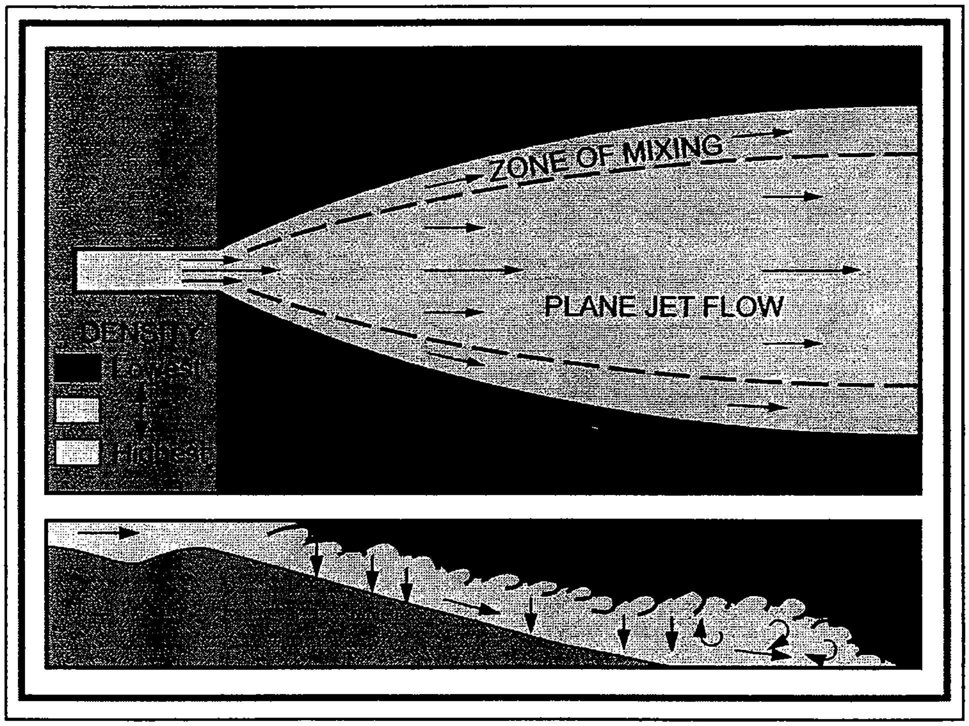


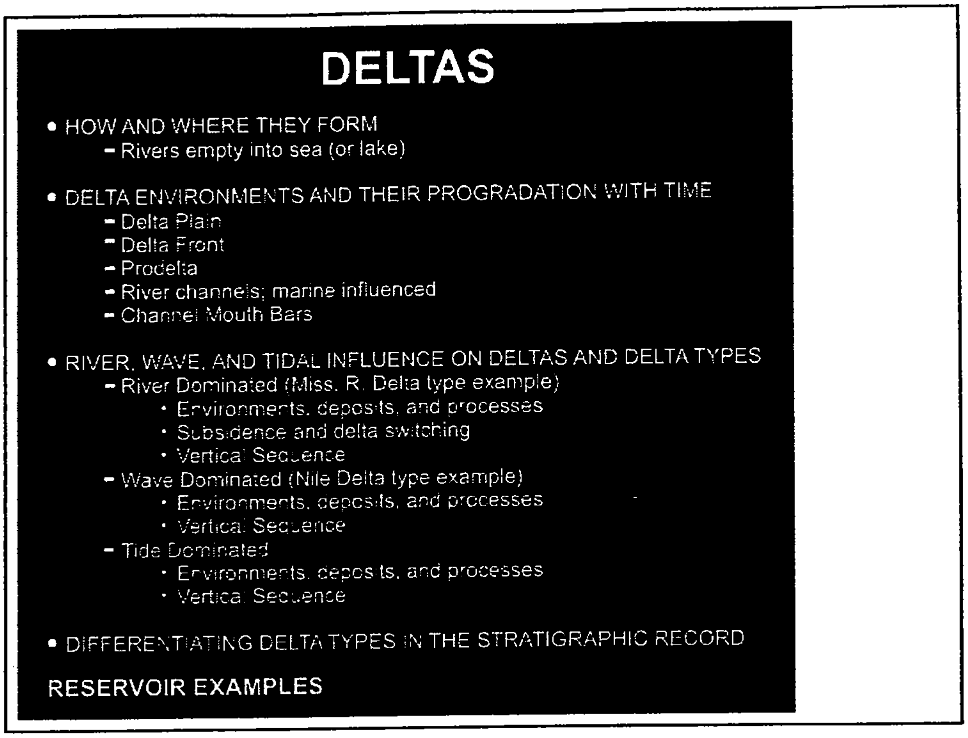
Figure 1. Elements of eustatic change. Maximum rates of rise and fall coincide with R- and F-inflection points. From Posamentier and others, 1988. Reprinted by permission of SEPM.







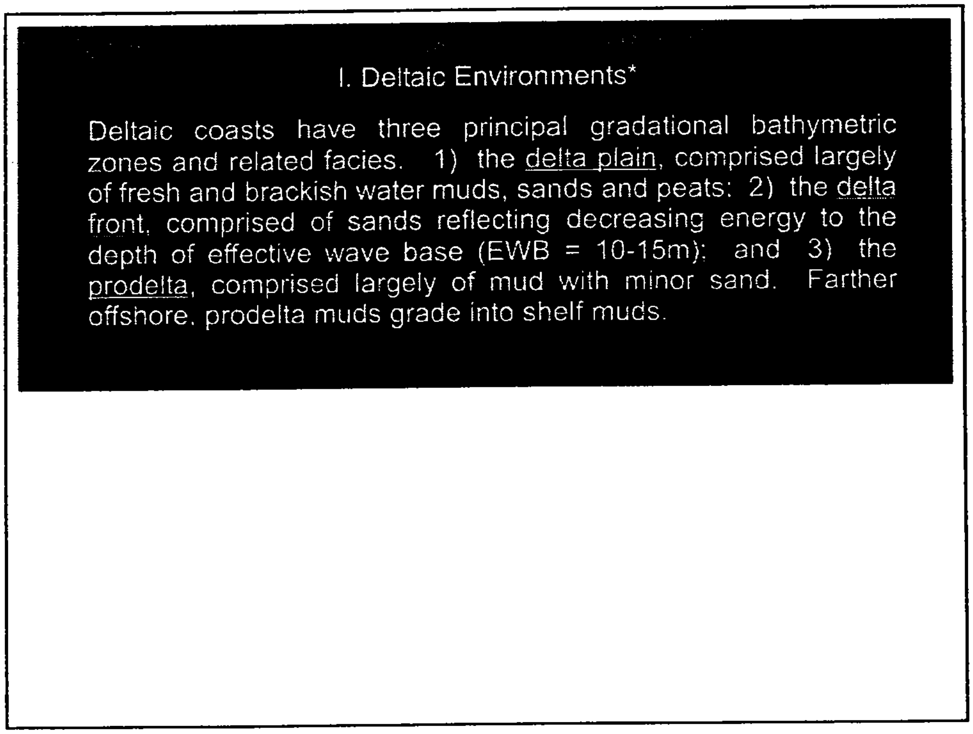

ZONE OF MIXING
PLANE JET FLOW
DENSITY
Lowest
Highest



DELTAS

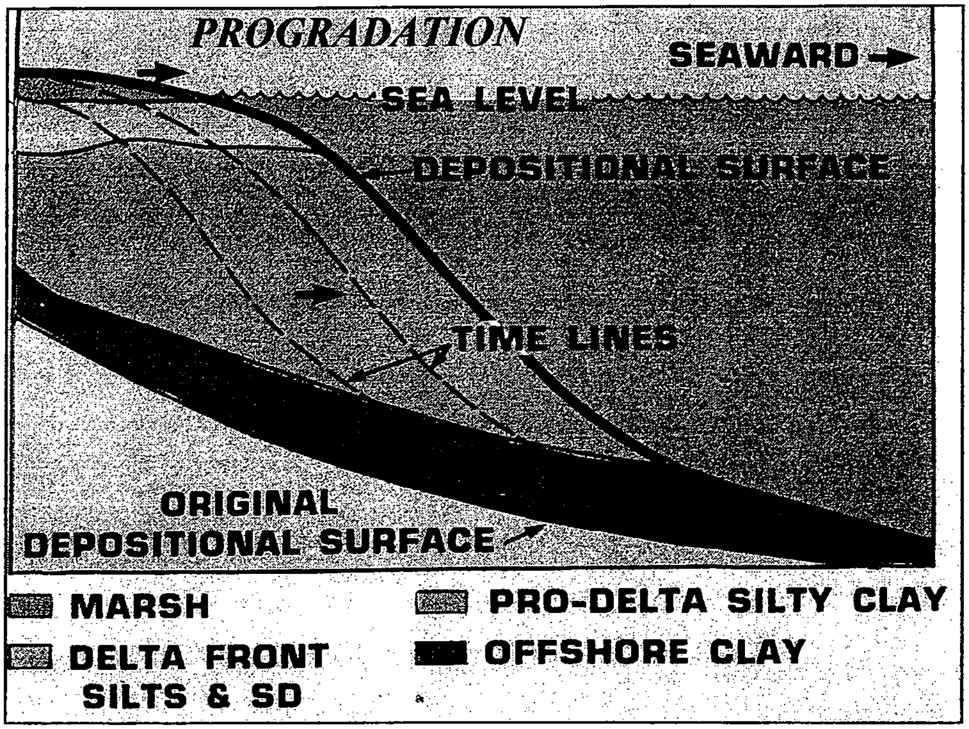
- HOW AND WHERE THEY FORM
  - Rivers empty into sea (or lake)
- DELTA ENVIRONMENTS AND THEIR PROGRADATION WITH TIME
  - Delta Plain
  - Delta Front
  - Prodelta
  - River channels; marine influenced
  - Channel Mouth Bars
- RIVER, WAVE, AND TIDAL INFLUENCE ON DELTAS AND DELTA TYPES
  - River Dominated (Miss. R. Delta type example)
    - Environments, deposits, and processes
    - Subsidence and delta switching
    - Vertical Sequence
  - Wave Dominated (Nile Delta type example)
    - Environments, deposits, and processes
    - Vertical Sequence
  - Tide Dominated
    - Environments, deposits, and processes
    - Vertical Sequence
- DIFFERENTIATING DELTA TYPES IN THE STRATIGRAPHIC RECORD

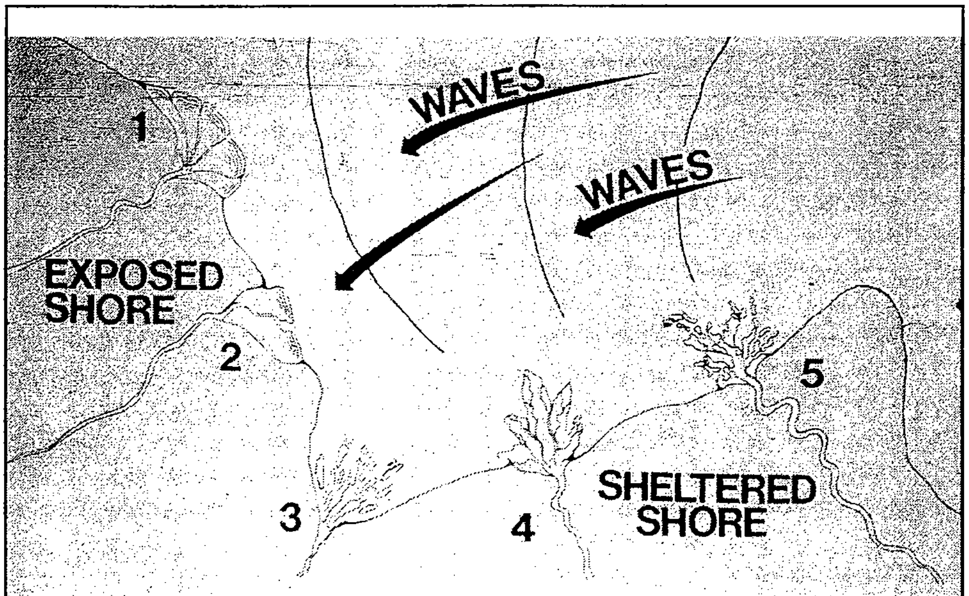
RESERVOIR EXAMPLES



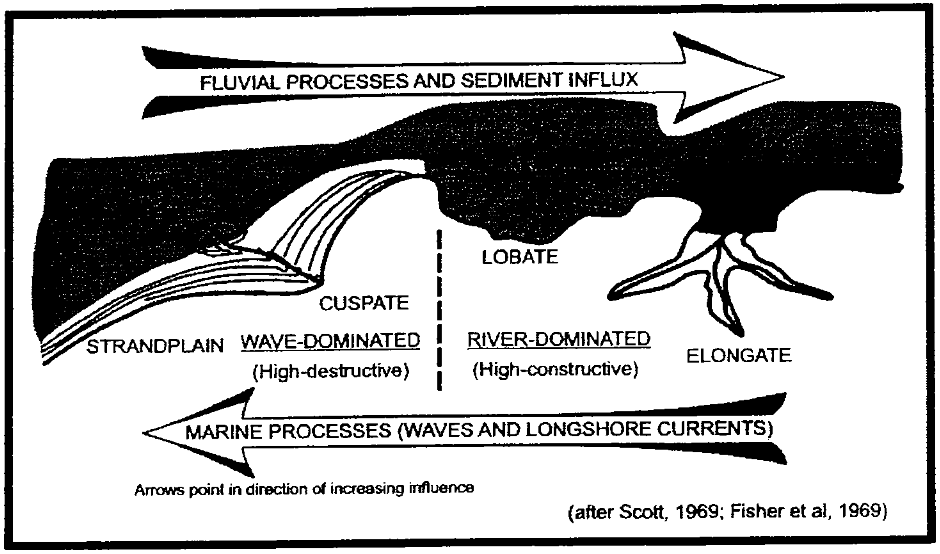
I. Deltaic Environments*

Deltaic coasts have three principal gradational bathymetric zones and related facies. 1) the delta plain, comprised largely of fresh and brackish water muds, sands and peats; 2) the delta front, comprised of sands reflecting decreasing energy to the depth of effective wave base (EWB = 10-15m); and 3) the prodelta, comprised largely of mud with minor sand. Farther offshore, prodelta muds grade into shelf muds.



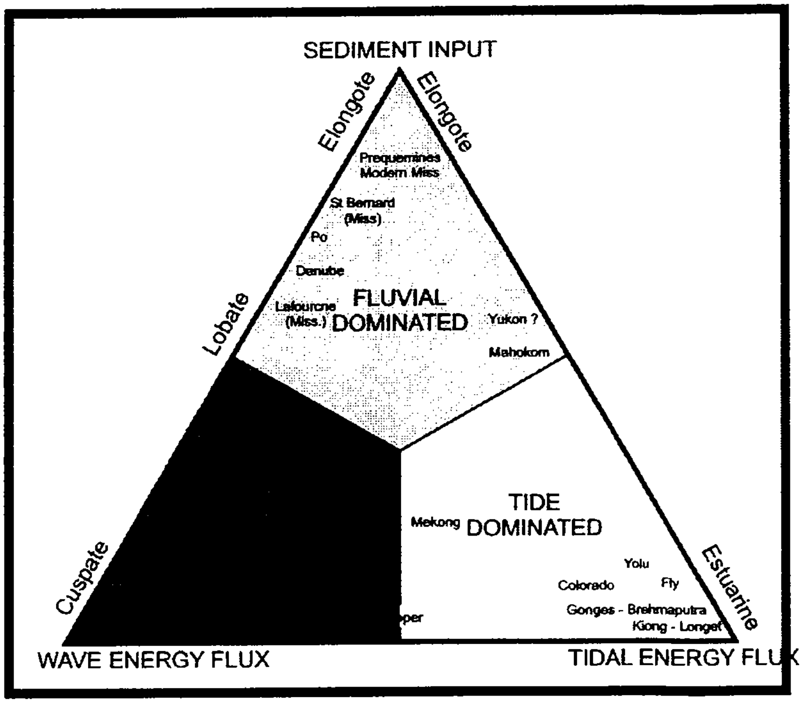


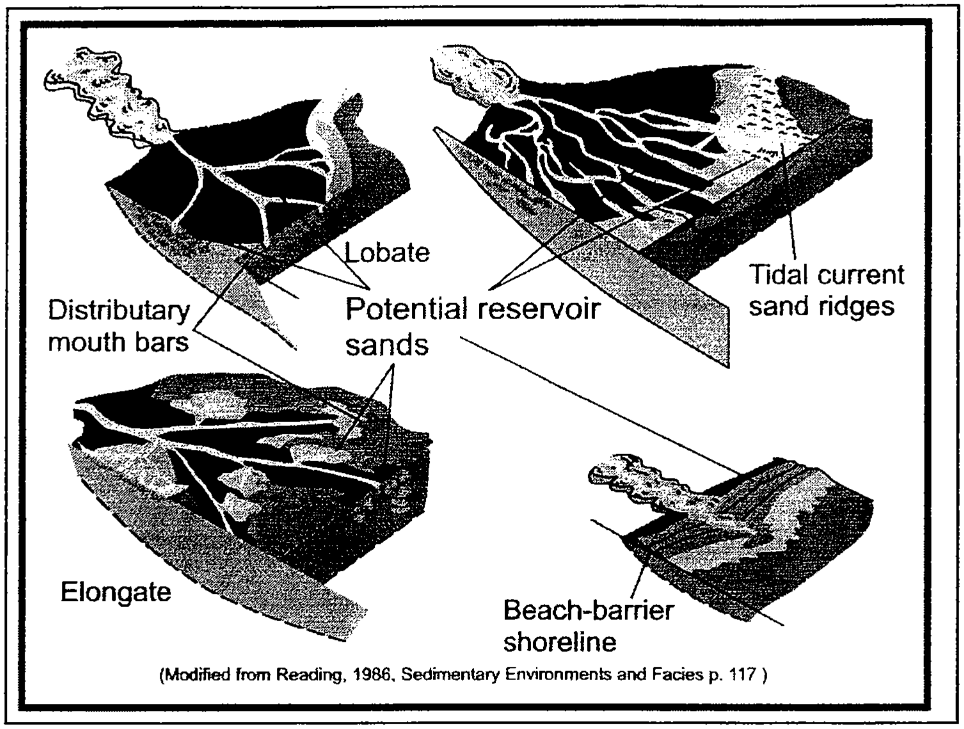
Delta Types - Shoreline Embayment



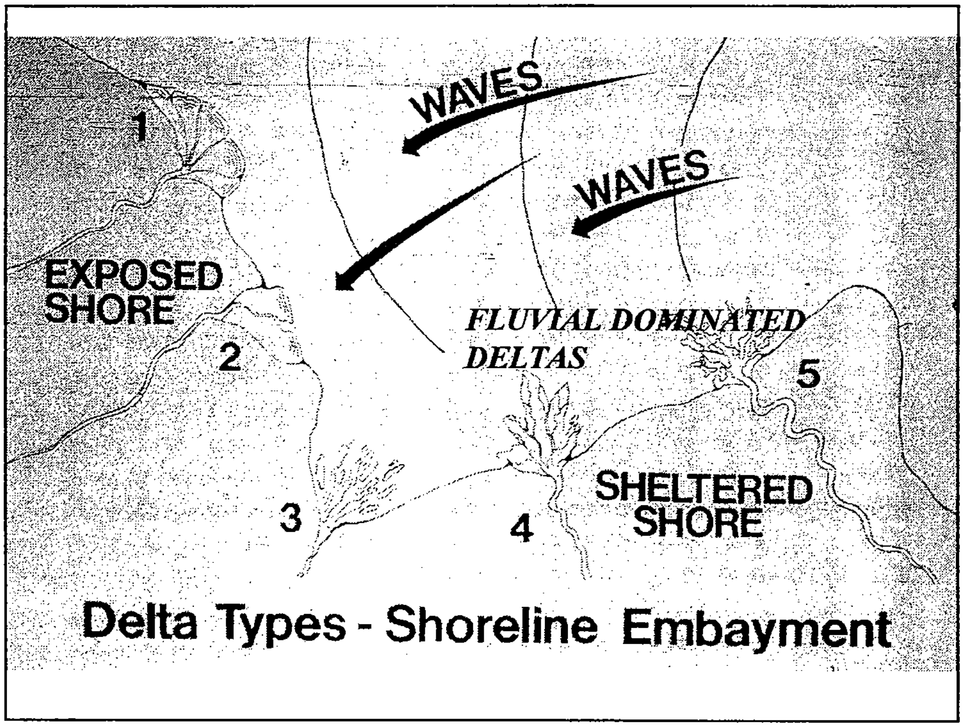
Arrows point in direction of increasing influence

(after Scott, 1969; Fisher et al, 1969)



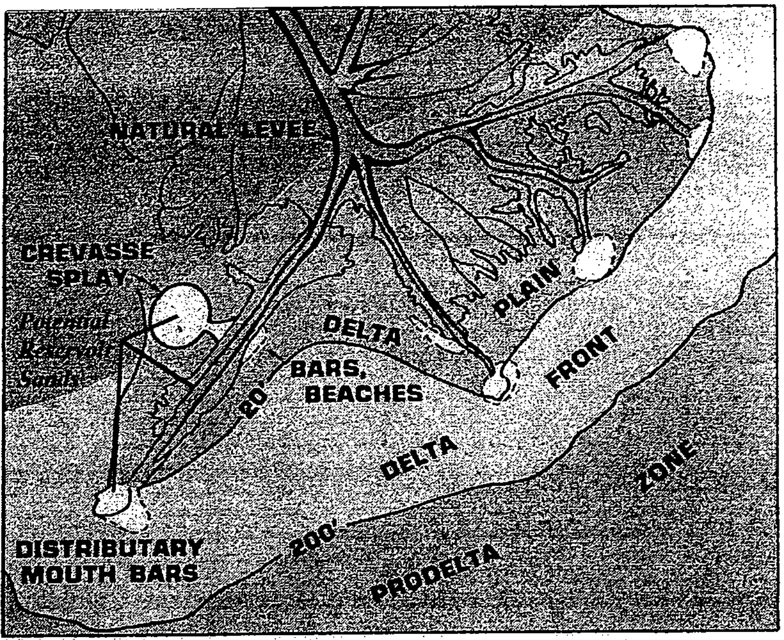


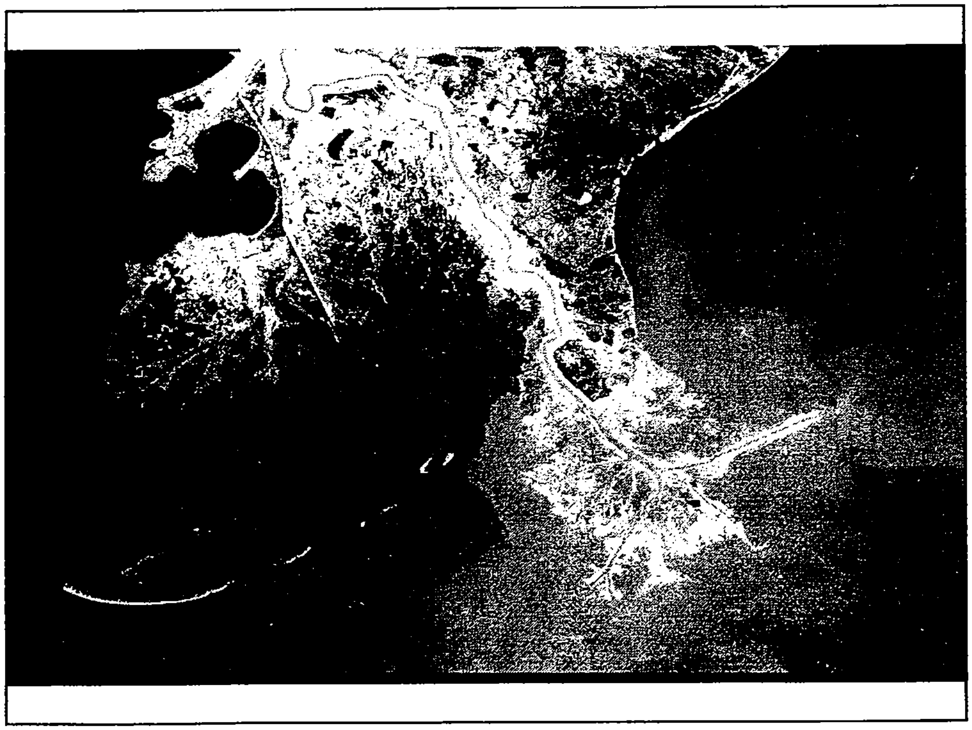
(Modified from Reading, 1986, Sedimentary Environments and Facies p. 117)



Delta Types - Shoreline Embayment

PRINCIPAL DELTA ENVIRONMENTS





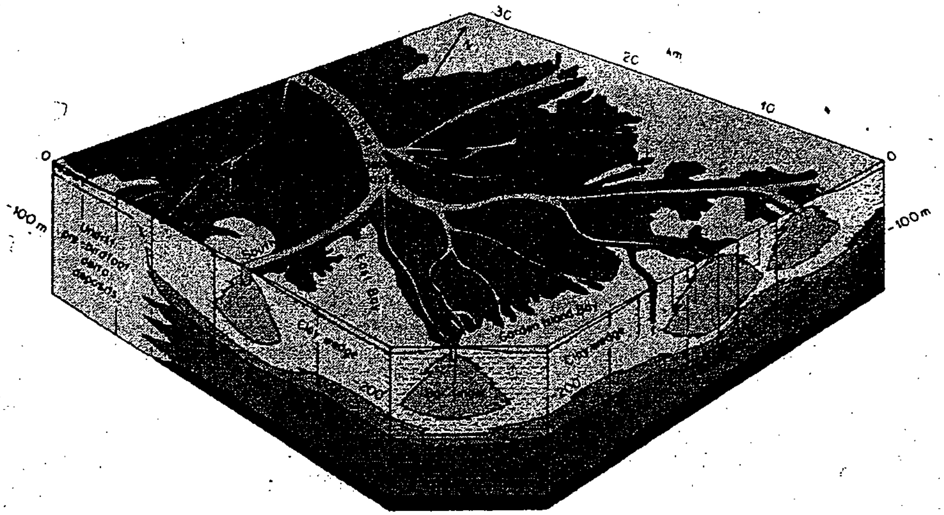
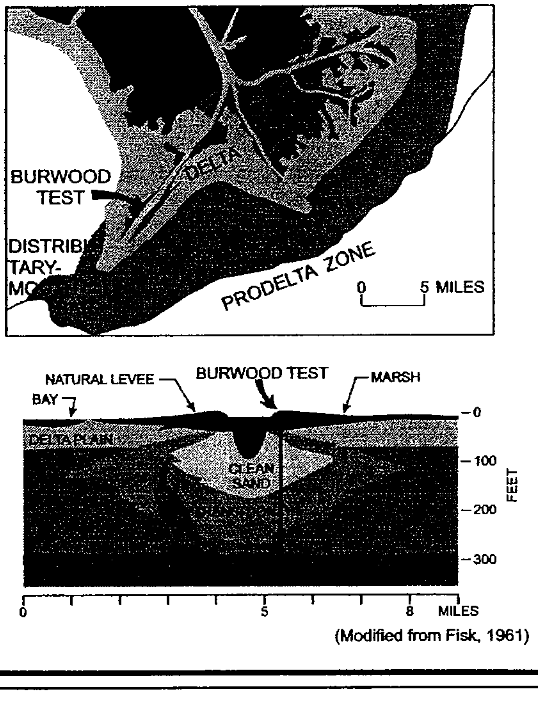
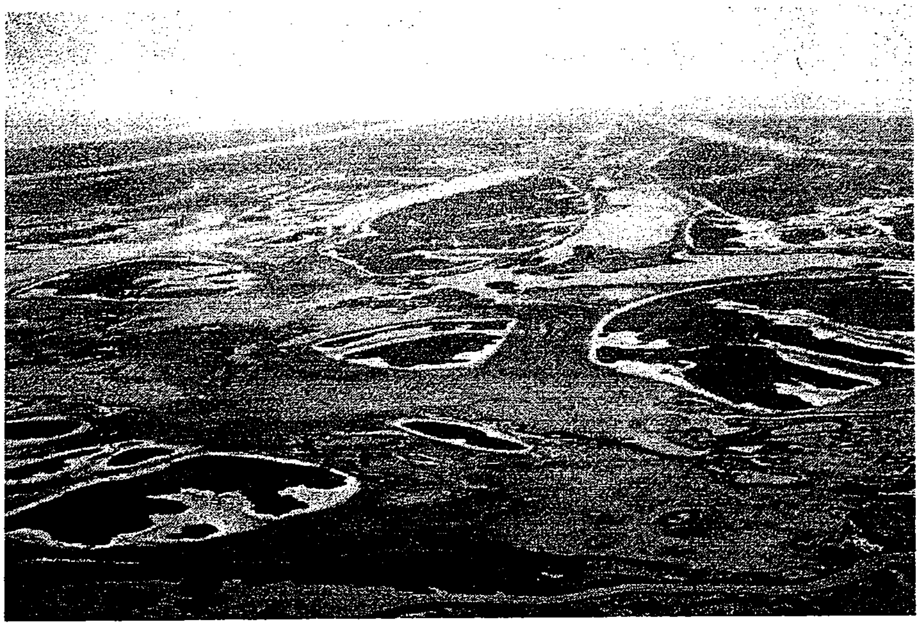


Fig. 7-11 Block diagram indicating geometric arrangement of bar-finger sand, fine-grained sediments, and topset marsh deposits of the modern Birdfoot delta of the Mississippi River. (After Fisk *et al.*, 1954.)



(Modified from Fisk, 1961)



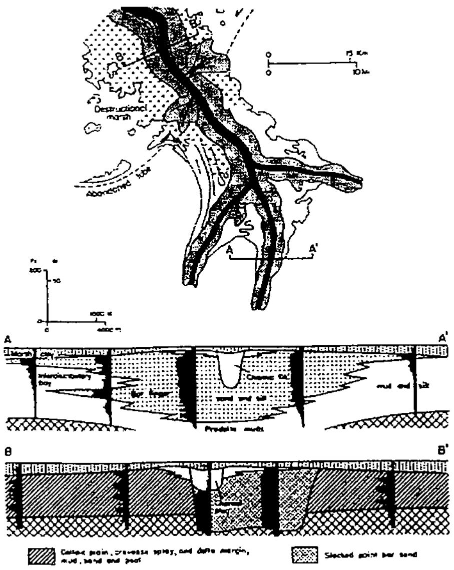
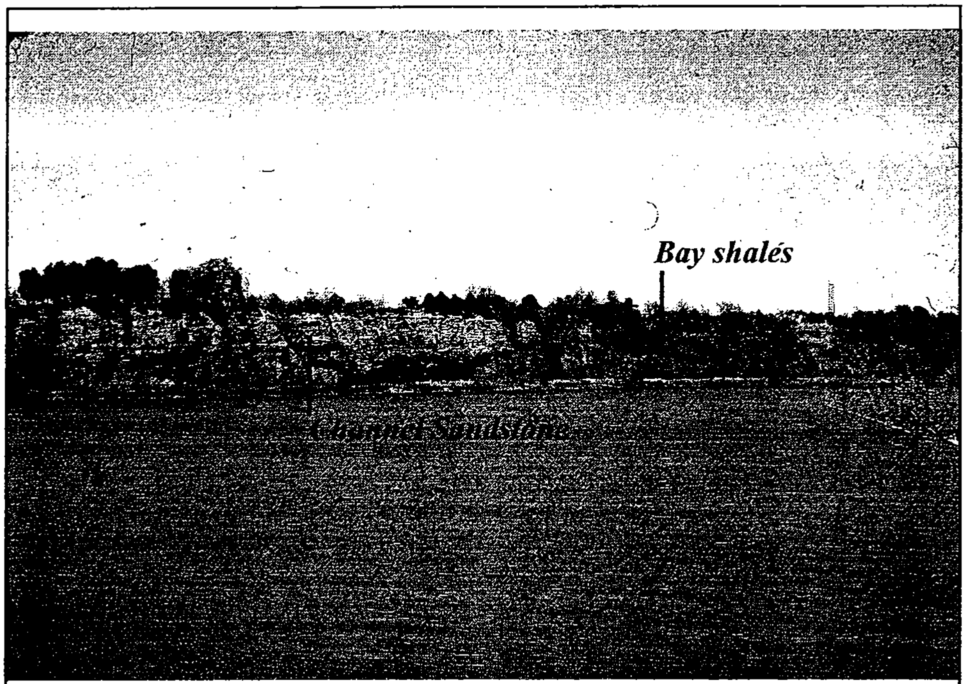


Figure 5-10. Interpretative facies cross-sections of (A) progradational channel mouth bar and (B) distributary channel-fill sand bodies of an elongate, fluvial-dominated delta lobe. Geophysical log profiles are based on bore hole data from the Wilcox (Eocene) Holly Springs delta system of the northern Gulf Coast basin. (Modified from Galloway, 1968.)



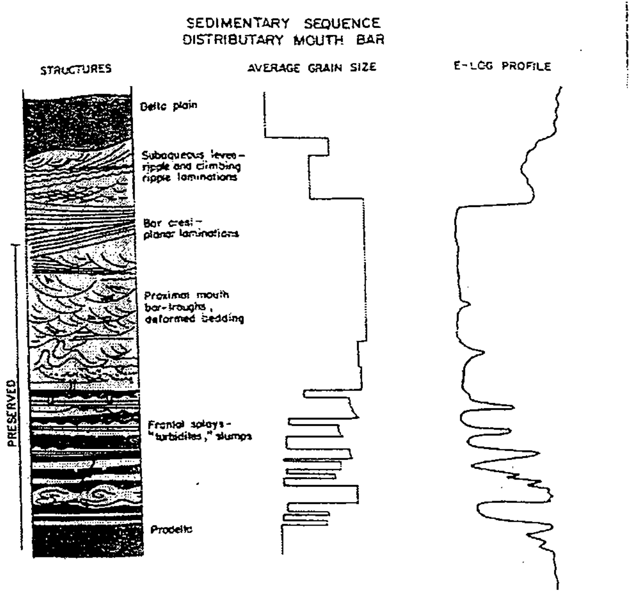
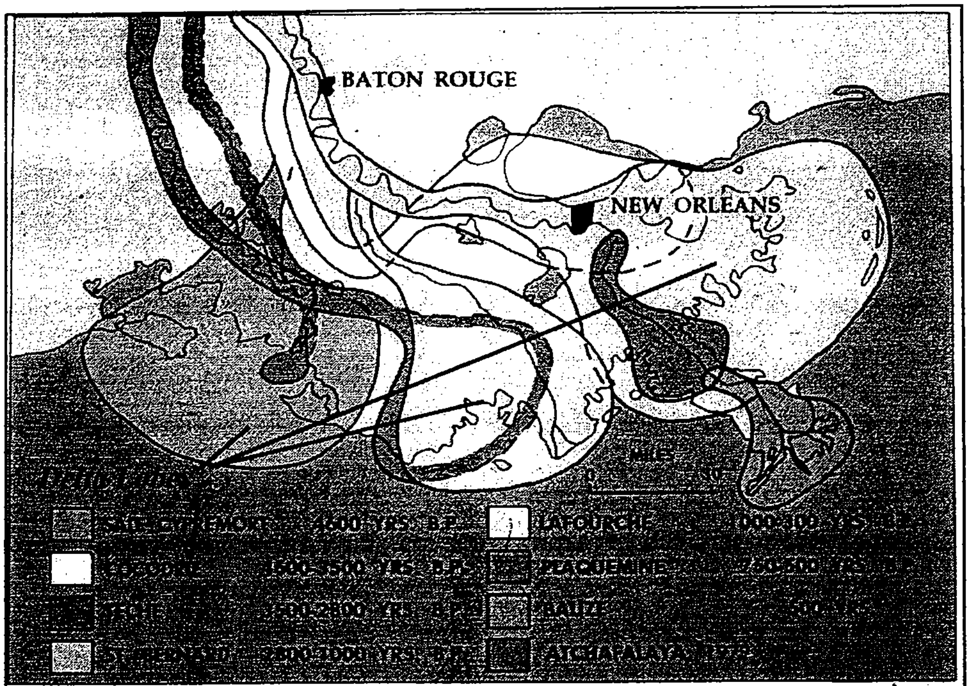
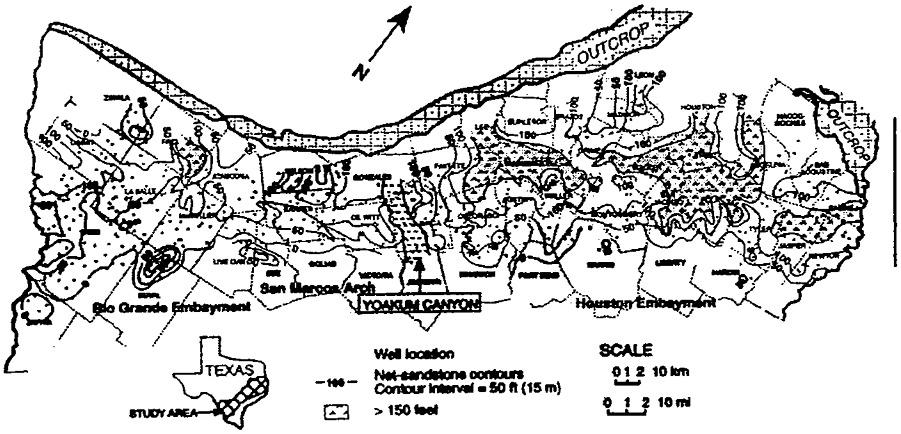


Figure 5-11. Generalized vertical profile through a channel mouth bar sand body. As in fluvial system profiles, sedimentary structures are illustrated schematically, grain size increases to the right on the average grain size plot, and the log profile is drawn to resemble either an S.P. or gamma-ray curve.

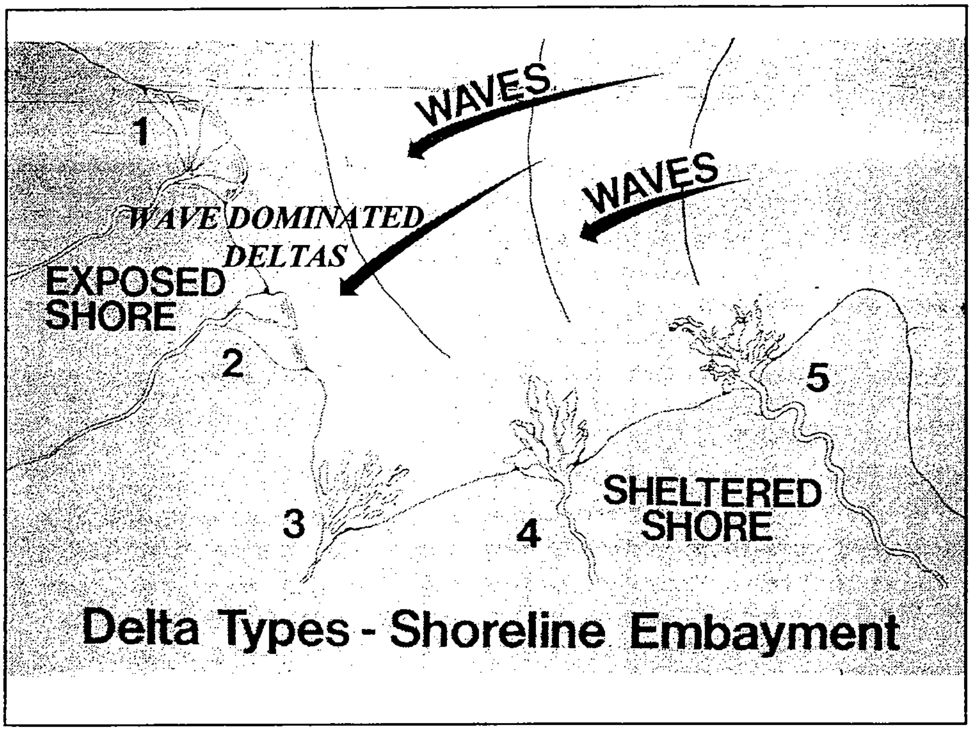


MODIFIED FROM: FISK, KOLB, VAN LOPIK AND OTHERS

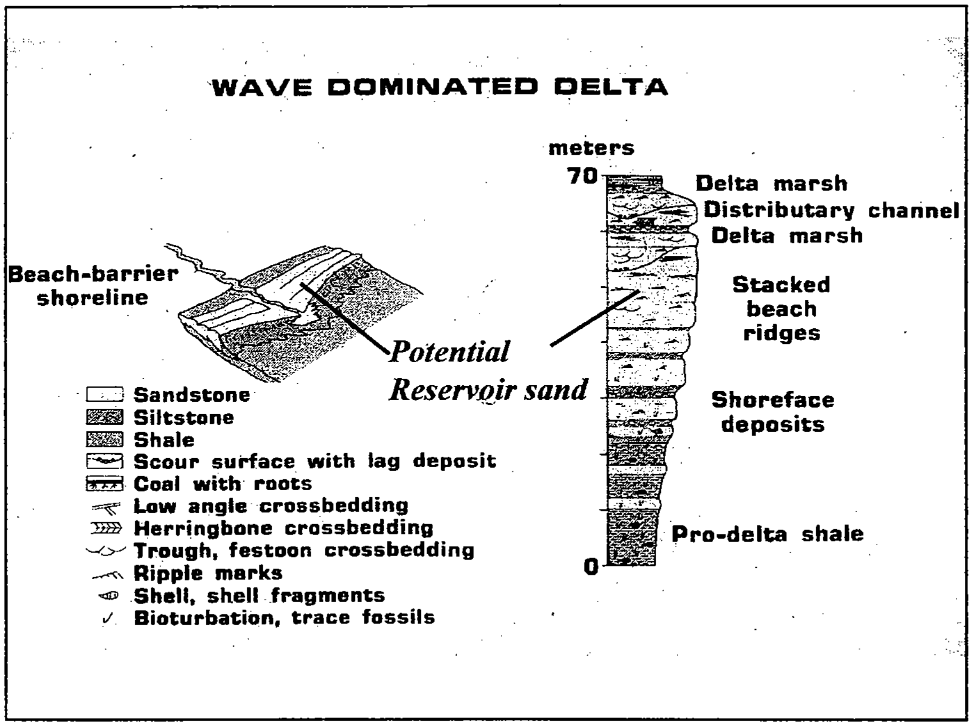


Tertiary subsurface deltaic reservoirs, south Texas (yellow)

Figure 20—Sequence B net-sandstone distribution resembling that of sequence A: dip-dominated trends in the Houston and Rio Grande embayments and strike-oriented pattern in the San Marcos arch. Highest values in the updip area reflect the main fluvial or distributary-channel axes; however, sequence B depocenters have prograded further seaward.

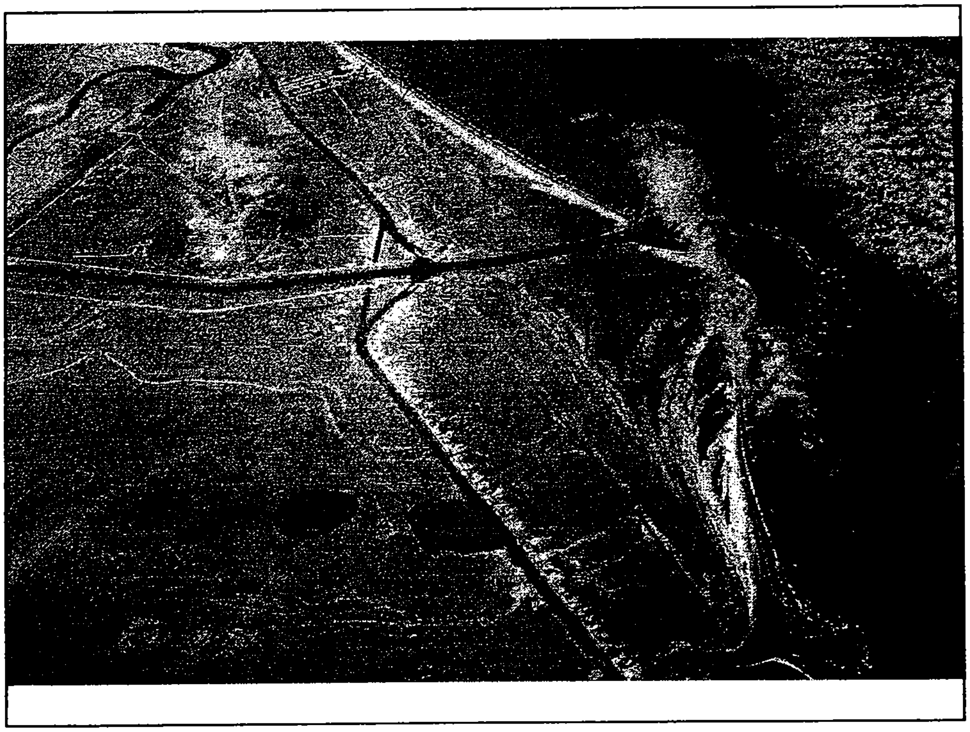


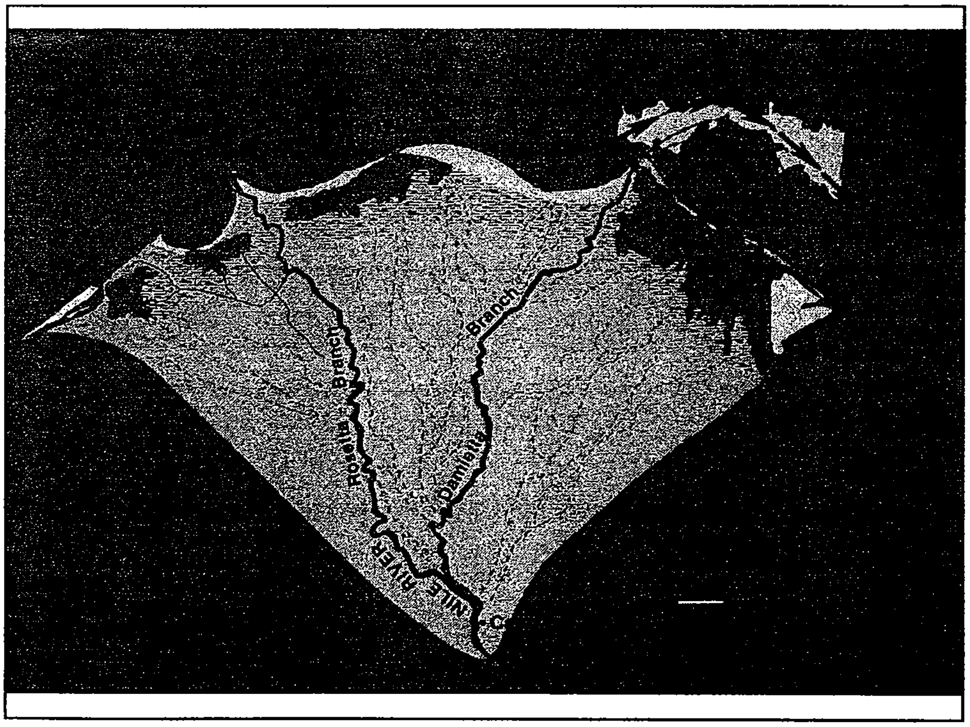
Delta Types - Shoreline Embayment



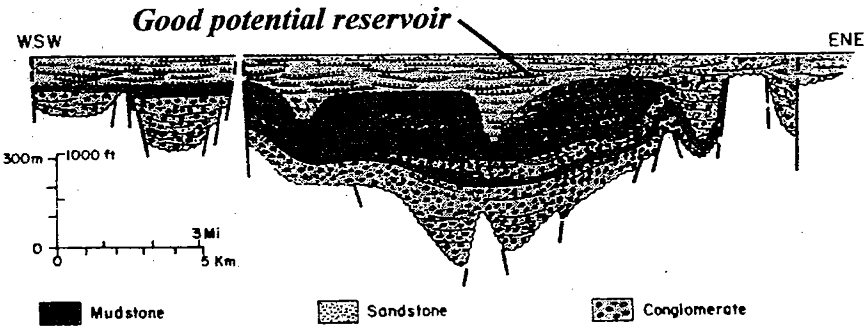
WAVE DOMINATED DELTA

- Sandstone
- Siltstone
- Shale
- Scour surface with lag deposit
- Coal with roots
- Low angle crossbedding
- Herringbone crossbedding
- Trough, festoon crossbedding
- Ripple marks
- Shell, shell fragments
- Bioturbation, trace fossils

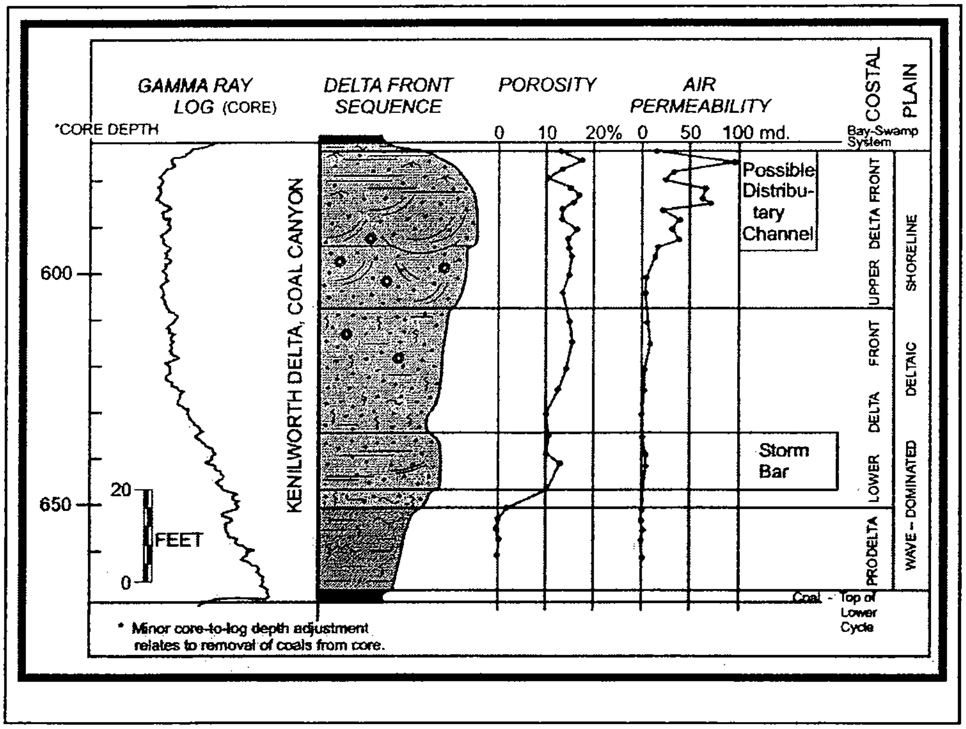


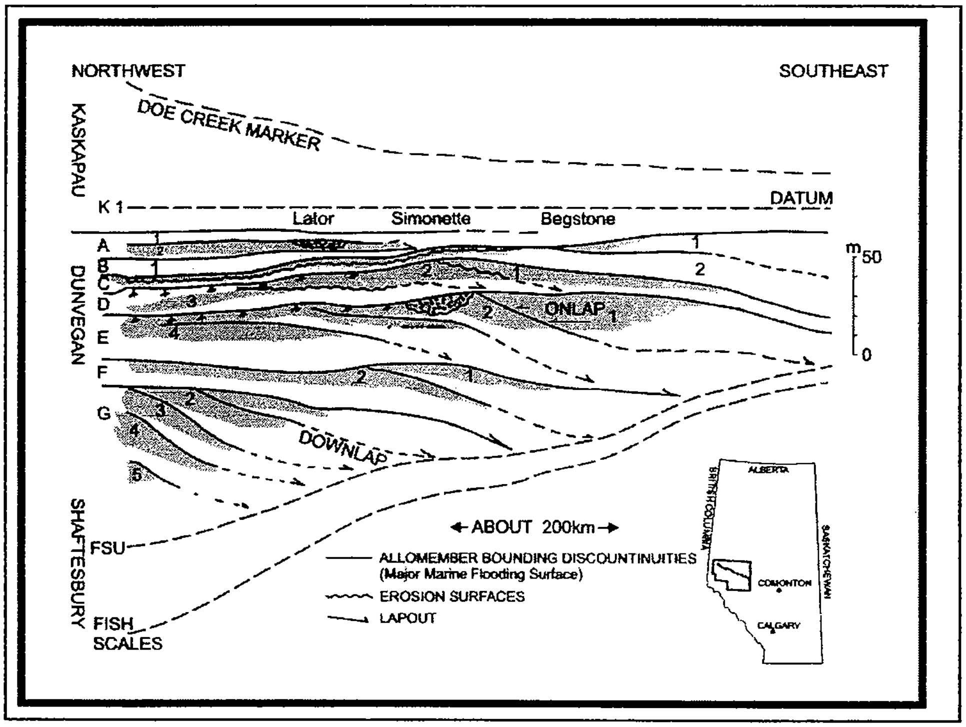

Rosetta Branch
Damietta Branch
NILE RIVER
C

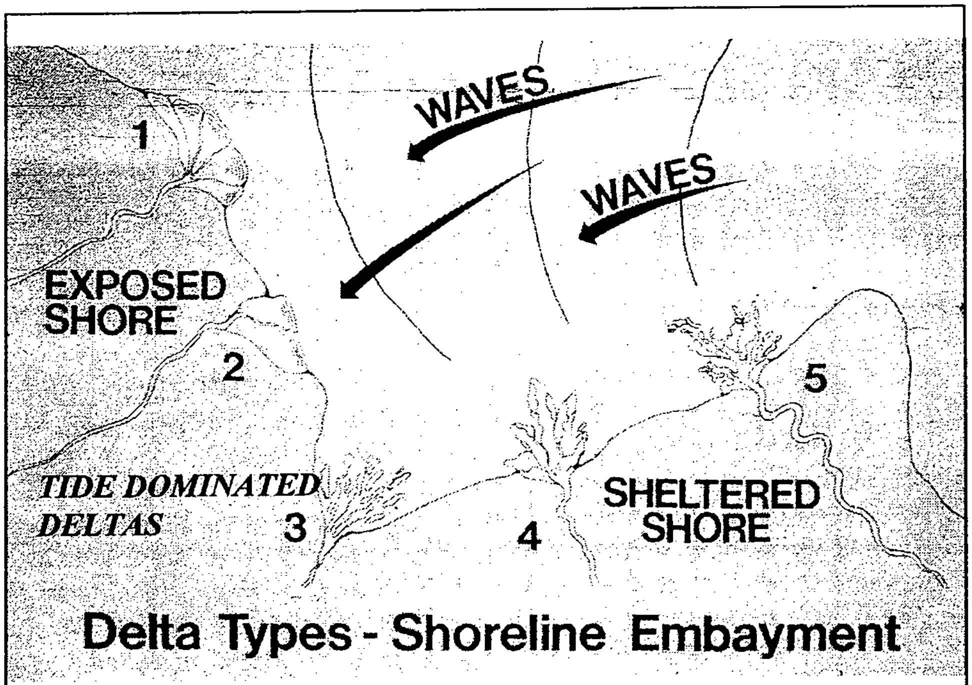
Nile Delta

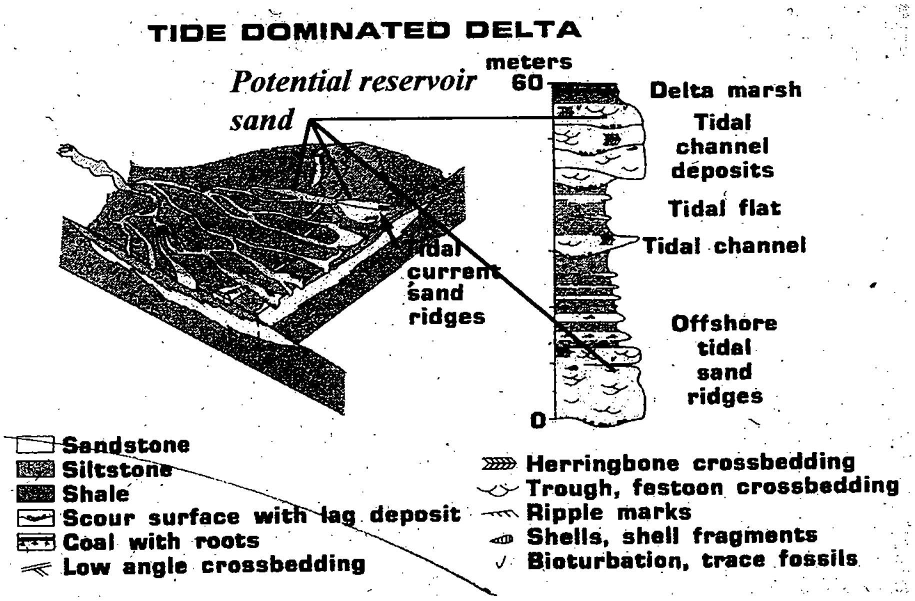


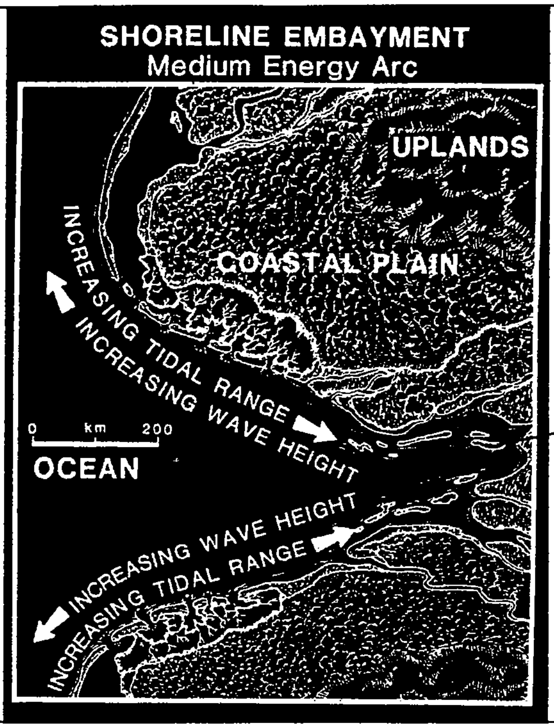
Good potential reservoir


GAMMA RAY LOG (CORE)
DELTA FRONT SEQUENCE
POROSITY
AIR PERMEABILITY
COSTAL PLAIN
*CORE DEPTH
0 10 20%
0 50 100 md.
Bay-Swamp System
600
650
20
0
FEET
KENILWORTH DELTA, COAL CANYON
Possible Distributary Channel
Storm Bar
UPPER DELTA FRONT
LOWER DELTA FRONT
PRODELTA
WAVE - DOMINATED DELTAIC SHORELINE
Coal - Top of Lower Cycle
* Minor core-to-log depth adjustment relates to removal of coals from core.

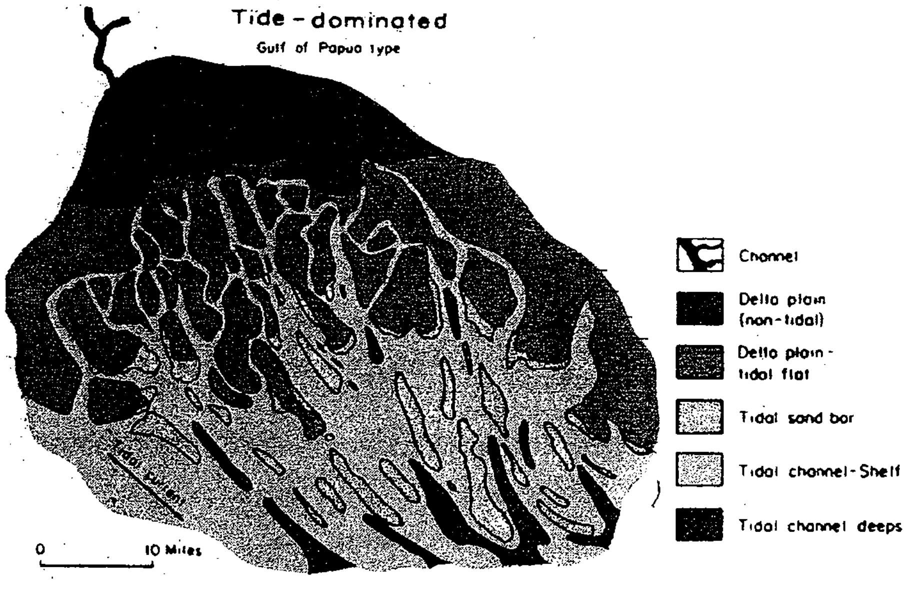

NORTHWEST
SOUTHEAST
KASKAPAU
DOE CREEK MARKER
K 1
DATUM
Lator
Simonette
Begstone
A
B
C
D
E
F
G
DUNVEGAN
ONLAP
DOWNLAP
1
2
3
4
5
m 50
0
SHAFTESBURY
FSU
FISH SCALES
ABOUT 200km
ALLOMEMBER BOUNDING DISCOUNTINUITIES (Major Marine Flooding Surface)
EROSION SURFACES
LAPOUT
ALBERTA
BRITISH COLUMBIA
SASKATCHEWAN
EDMONTON
CALGARY

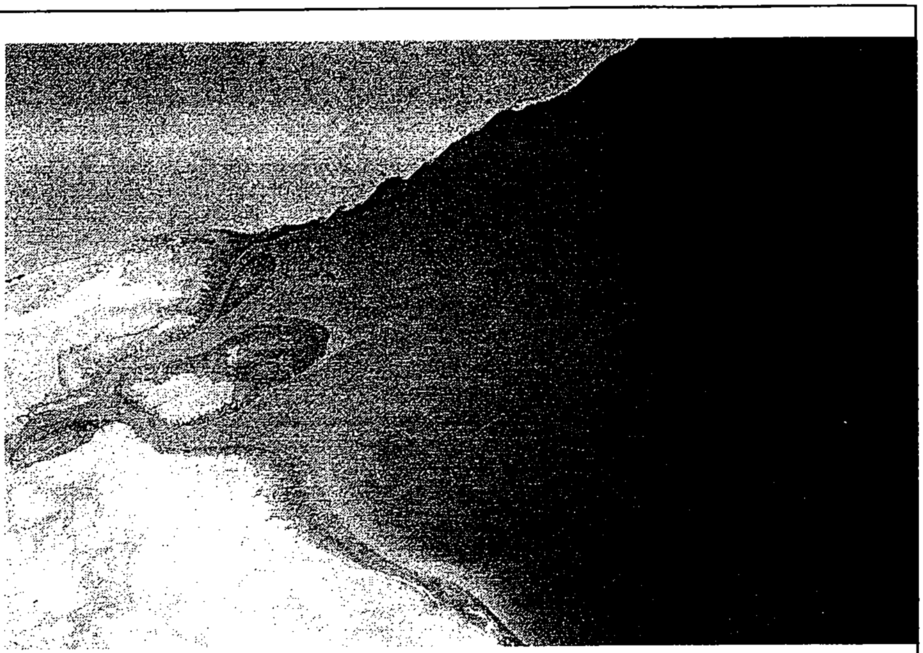

WAVES
WAVES
1
EXPOSED SHORE
2
TIDE DOMINATED DELTAS
3
4
SHELTERED SHORE
5
Delta Types - Shoreline Embayment

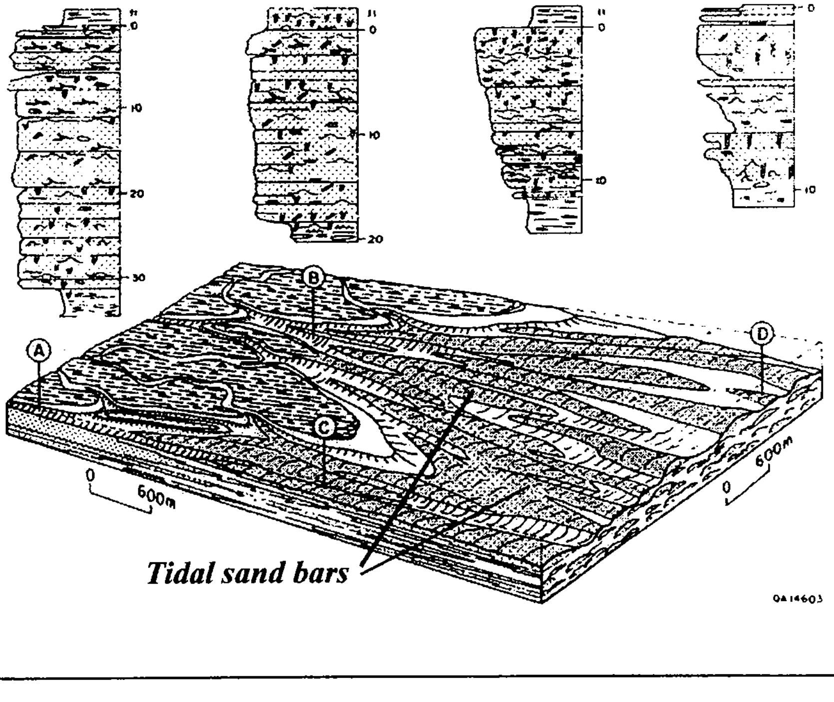

TIDE DOMINATED DELTA
Potential reservoir sand
Tidal current sand ridges
meters
60
0
Delta marsh
Tidal channel deposits
Tidal flat
Tidal channel
Offshore tidal sand ridges
Sandstone
Siltstone
Shale
Scour surface with lag deposit
Coal with roots
Low angle crossbedding
Herringbone crossbedding
Trough, festoon crossbedding
Ripple marks
Shells, shell fragments
Bioturbation, trace fossils



Tidal Sand bars






ft
0
10
20
30
ft
0
10
20
ft
0
10
0
10
A
B
C
D
0
600m
0
600m
Tidal sand bars
QA14603

Tide-Dominated Deltas

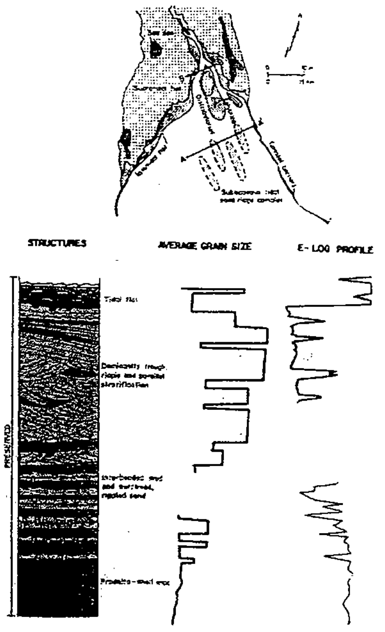


Figure 5-28. Generalized vertical profile through a tidal current sand ridge based on sedimentary features of the Colorado subaqueous delta-front platform.

Characteristics of tidal sand-ridge sandstones

Thickness:	Range 3-12 ft. average 6 ft.
Basal contact:	Transitional with marine shales.

Texture and Composition

Grain size:	Upward-coursening from siltstone/very fine-grained sandstone at the base to upper fine-grained sandstone at the top.
Sorting:	Well to very well.
Clay interbeds:	Very common and gradually decreasing toward the top. Their relative content defines the upward-coursening, thickening trend.
Clay clasts and wood fragments:	Common in the upper half.
Shell clasts:	Mainly in the sandier levels of the upper part. Frequently in high concentrations at the top.

Sedimentary Structures

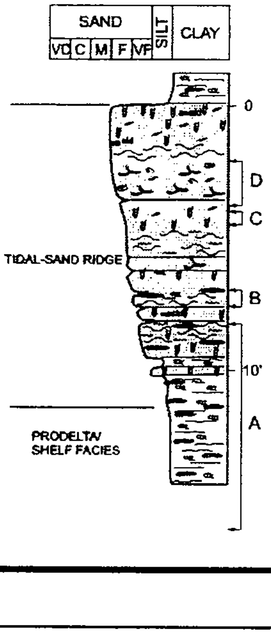
Wavy lamination and ripples are dominant in the lower two thirds of the facies.

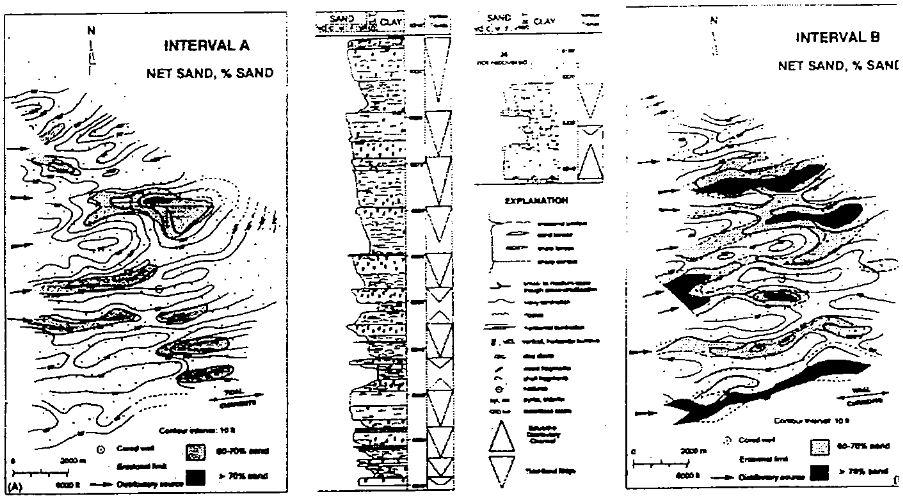
Small-scale trough cross-stratification is usually present in the upper one-third facies.

Burrows

Most common within the lower half or at the very top of the facies. Frequently muddy sandstones are homogenized by bioturbation. Ophiomorpha traces are common in sand-rich levels.

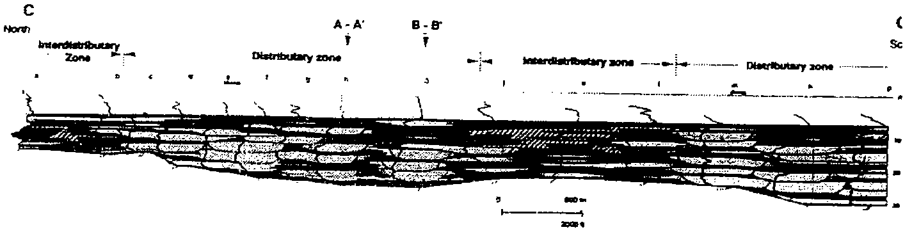
TIDAL SAND-RIDGE AND PRODELTA/SHELF FACIES



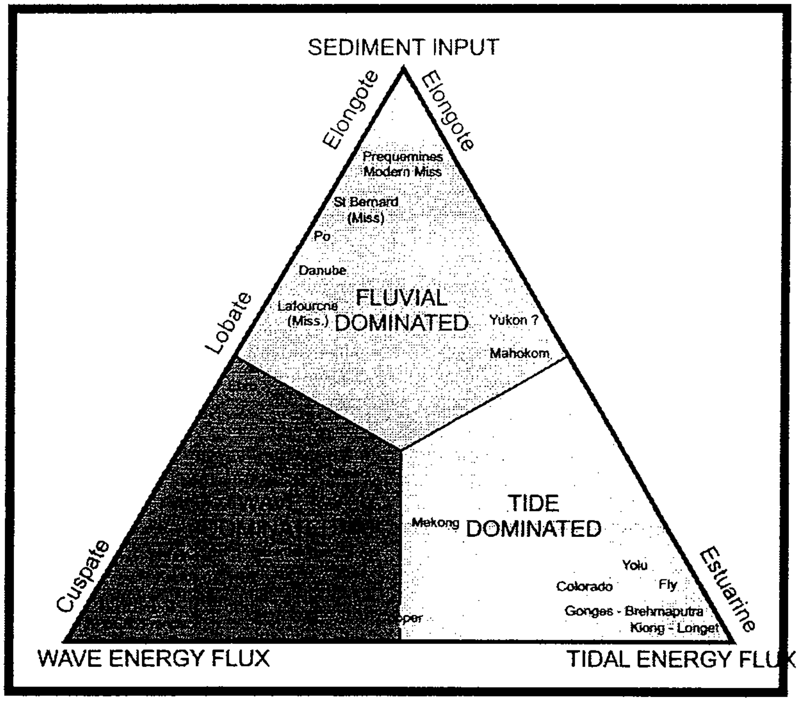


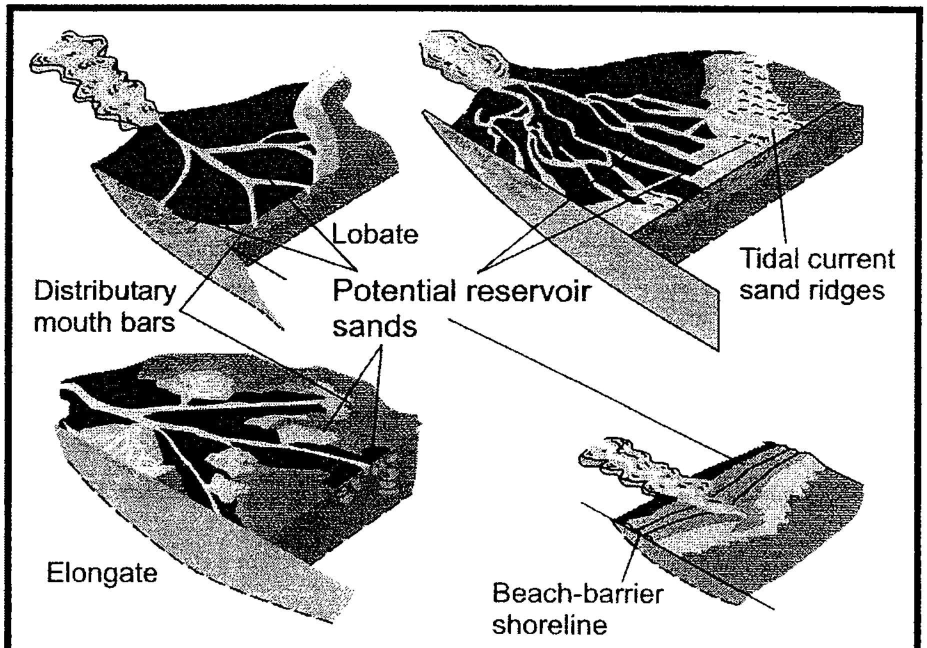
Maguregui and Tyler

Evolution of tide-dominated deltaic sandstones



[illegible]





(Modified from Reading, 1986, Sedimentary Environments and Facies p. 117)

CONCLUSIONS

- ***DELTAS ARE COMPLEX SEDIMENT BODIES***

- ***DIFFERENT DELTA TYPES HAVE DIFFERENT TYPES OF SAND BODIES WITH DIFFERENT TRENDS***

- ***IT IS IMPORTANT TO UNDERSTAND WHICH DELTA TYPE YOUR RESERVOIR IS IN IF YOU WANT TO MAXIMIZE OR IMPROVE PRODUCTION AND RESERVOIR MANAGEMENT***

APPLIED RESERVOIR CHARACTERIZATION FOR THE INDEPENDENT OPERATOR: WITH EMPHASIS ON COMPARTMENTALIZED RESERVOIRS AND ROUTINE TECHNIQUES FOR DETECTING COMPARTMENTS

UNIT 1: INTRODUCTION TO RESERVOIR CHARACTERIZATION

UNIT 2: EXAMPLES OF COMPARTMENTALIZED RESERVOIRS

UNIT 3: GEOLOGIC CONTROLS ON POROSITY AND PERMEABILITY

UNIT 3A: SEISMIC POROSITY DETECTION IN A CARBONATE RESERVOIR

UNIT 4: FLOW UNIT DETERMINATION & CHARACTERIZATION

UNIT 5: BASICS OF SEQUENCE STRATIGRAPHY

UNIT 6: FLUVIAL DEPOSITS AND RESERVOIRS

UNIT 7: EOLIAN DEPOSITS AND RESERVOIRS

UNIT 8: SHOREFACE DEPOSITS AND RESERVOIRS

UNIT 9: DELTAIC DEPOSITS AND RESERVOIRS

*UNIT 10: DEEP-WATER (TURBIDITE) DEPOSITS AND RESERVOIRS

UNIT 11: BOREHOLE IMAGE LOGS AND APPLICATIONS

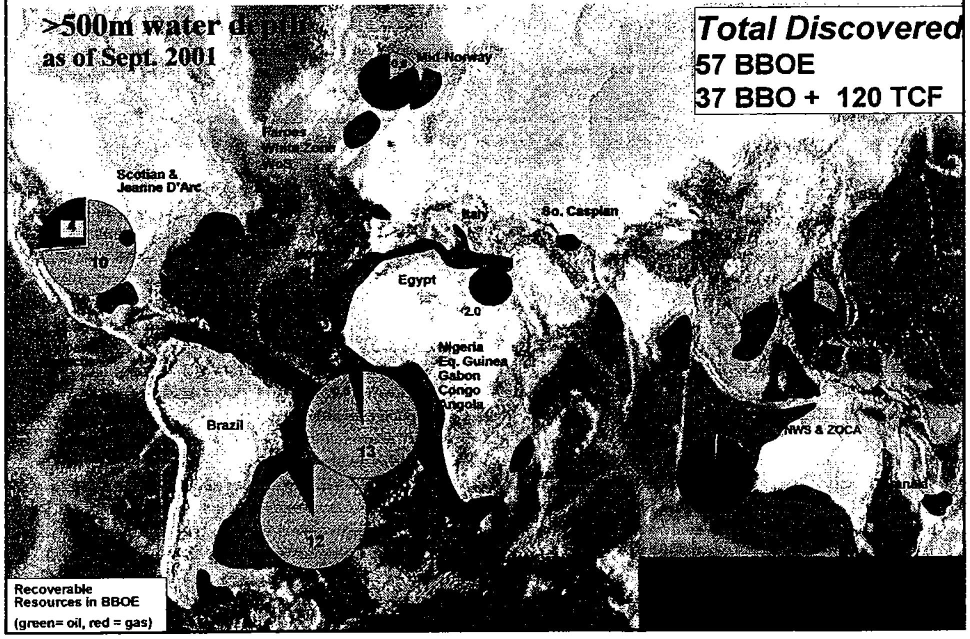
UNIT 12: DIPMETER LOGS AND APPLICATIONS

UNIT 13: STRUCTURALLY COMPARTMENTALIZED RESERVOIRS

KEY REFERENCES TO INDIVIDUAL UNITS

DEEPWATER (TURBIDITE) DEPOSITS & RESERVOIRS

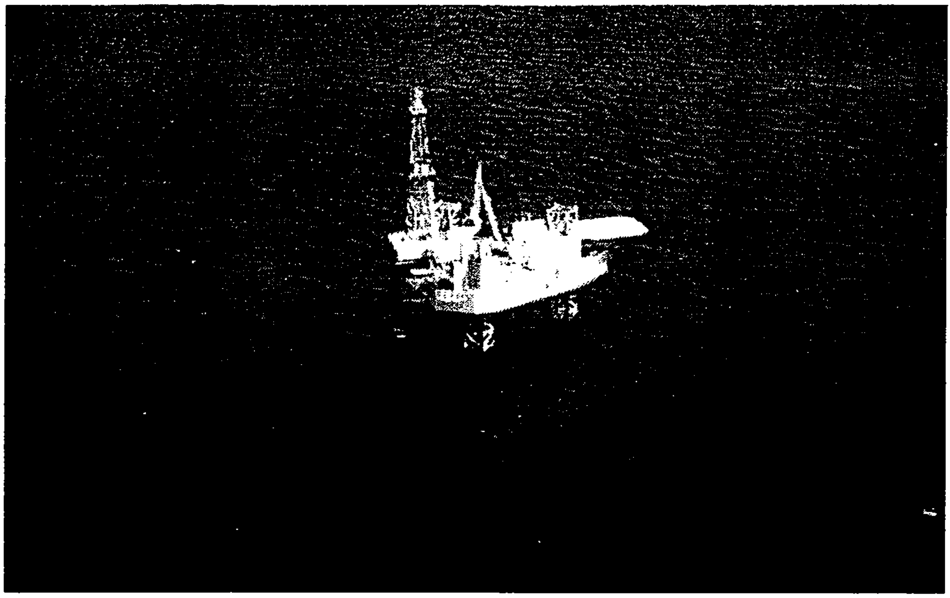
Deepwater Discovered Reserves



>500m water depth,
as of Sept. 2001

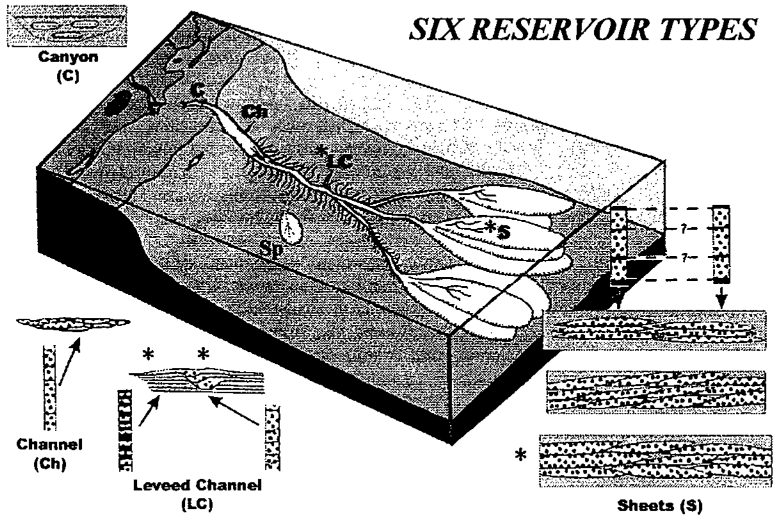
Total Discovered
57 BBOE
37 BBO + 120 TCF

Recoverable Resources in BBOE
(green= oil, red = gas)



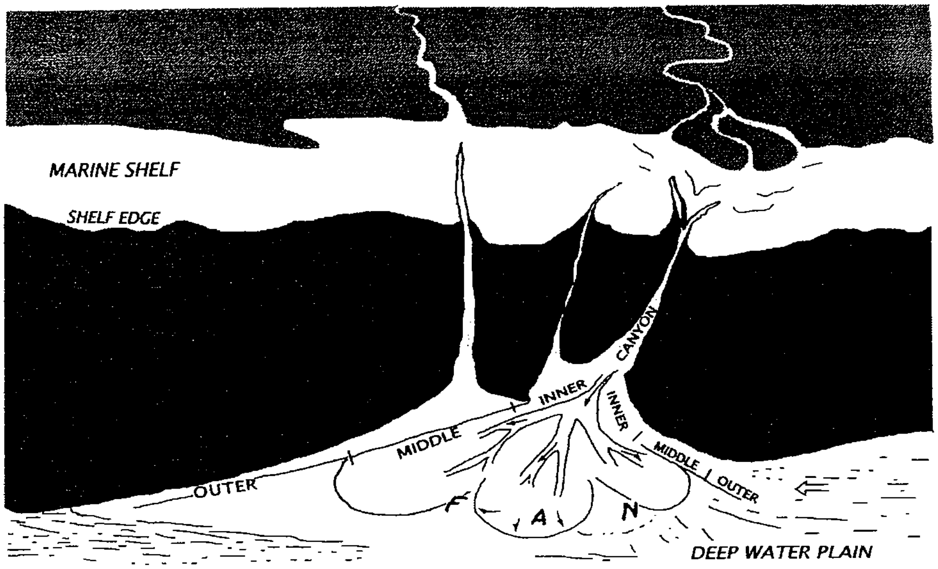
GEOLOGIC DEFINITION: Clastic sediments transported beyond the shelf edge into deep water by sediment gravity flow processes and deposited on the continental slope and in the basin. They are later buried and become part of a basin fill: Engineering and geologic 'deep water' are usually the same.

SIX RESERVOIR TYPES



* Reservoirs we'll look at today

Modified from Bouma (2000)



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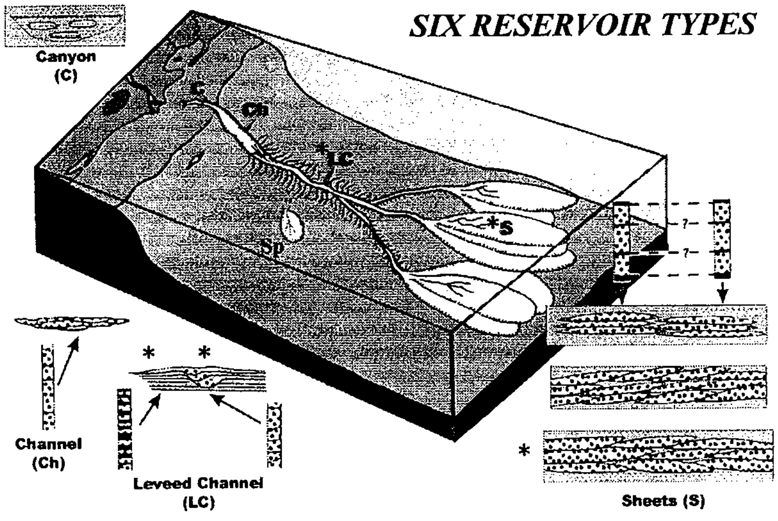
SIX RESERVOIR TYPES



* Reservoirs we'll look at today

Modified from Bouma (2000)

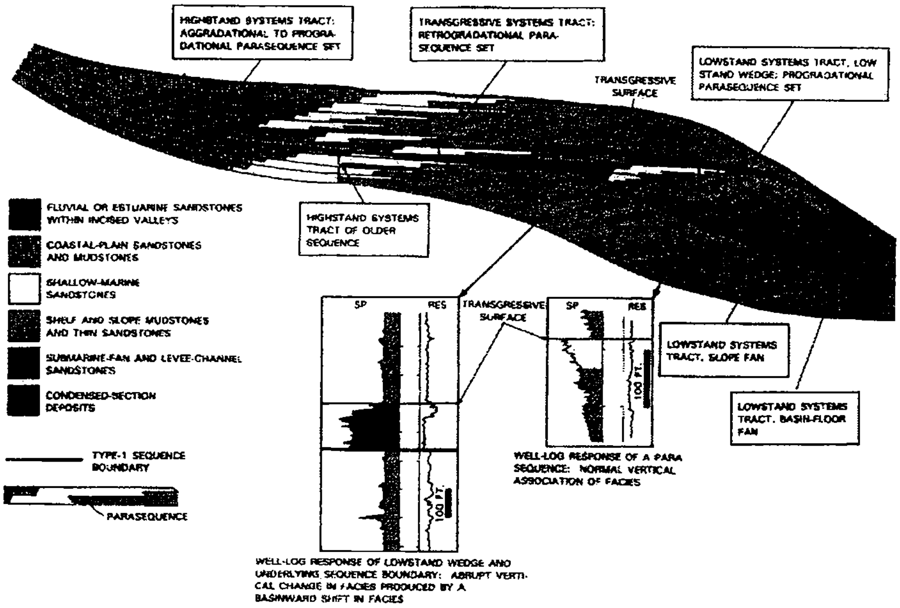
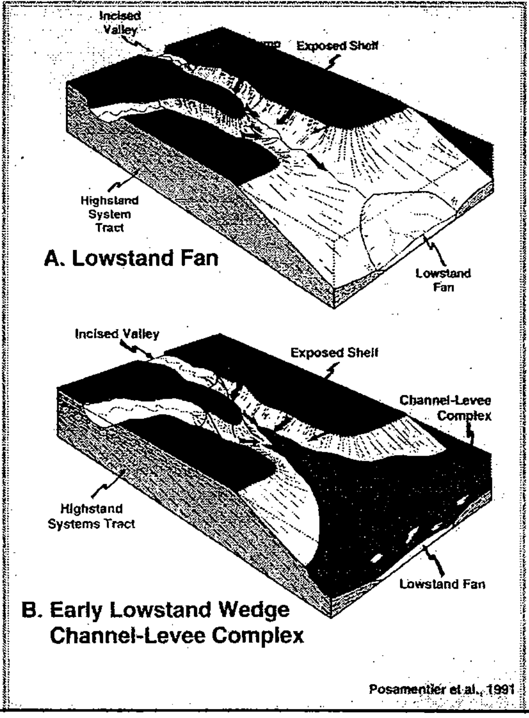


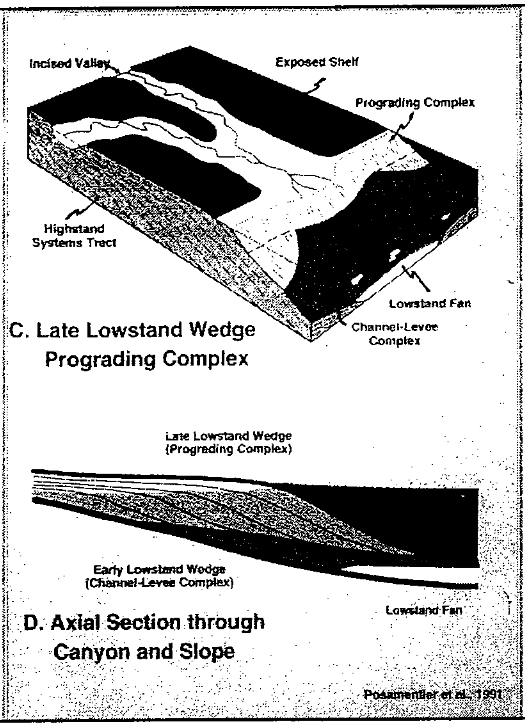
Figure 19—Stratal patterns in a type-1 sequence deposited in a basin with a shelf break.



A. Lowstand Fan

B. Early Lowstand Wedge Channel-Levee Complex

Posamentier et al., 1991



C. Late Lowstand Wedge Prograding Complex

D. Axial Section through Canyon and Slope

Posamentier et al. 1991

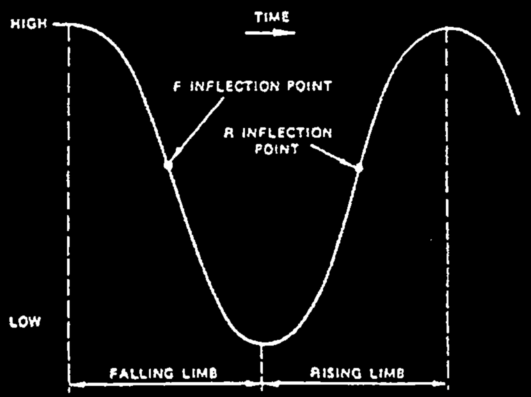


Figure 1. Elements of eustatic change. Maximum rates of rise and fall coincide with R- and F-inflection points. From Posamentier and others, 1988.
Reprinted by permission of SEPM.

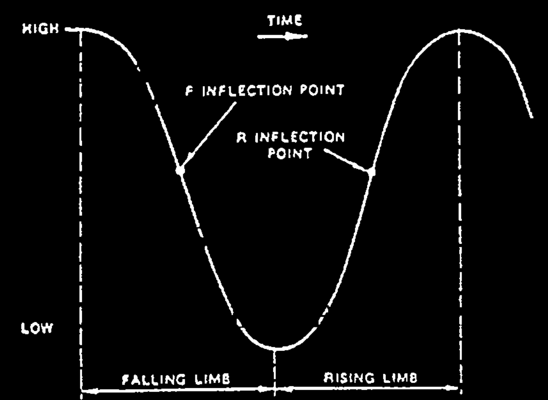
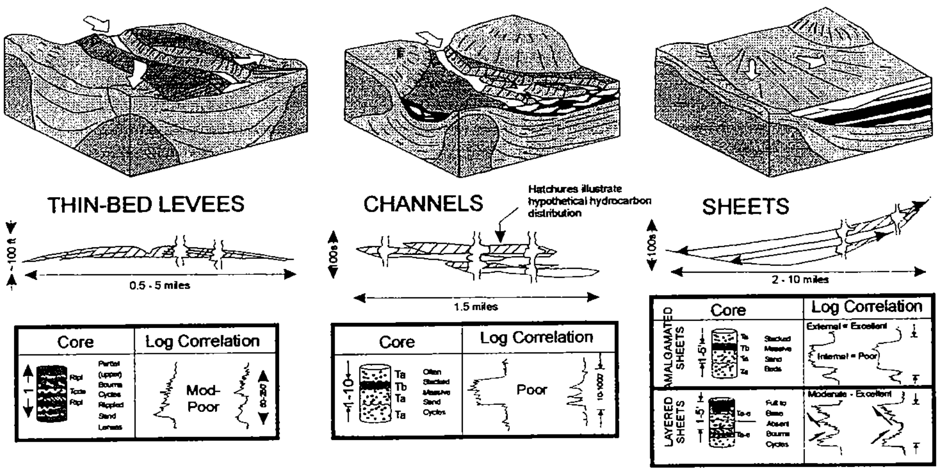


Figure 1. Elements of eustatic change. Maximum rates of rise and fall coincide with R- and F-inflection points. From Posamentier and others, 1988. Reprinted by permission of SEPM.

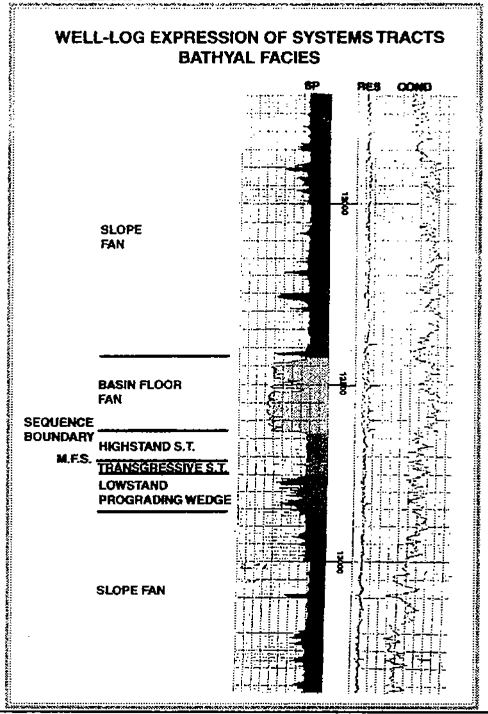


-Seismic Facies: "Gull-wing" to Subparallel, Poor to Fair Continuity
-Log Profile: Subdued, Serrate (to Fining-up)
-Log Correlatability: Moderate to Poor
-Thinly Bedded/ Laminated Sands/Silts (<4" beds)
-Insignificant Amalgamation

-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)



WELL-LOG EXPRESSION OF SYSTEMS TRACTS
BATHYAL FACIES

RESERVOIR PERFORMANCE ISSUES WITH DIFFERENT SANDSTONE TYPES

•*SHEET SANDSTONES*

- **-GOOD RESERVOIRS**
- **-GOOD LATERAL CONTINUITY**
- **-GOOD RESERVOIR QUALITY**
- **-SANDSTONES SEPARATED BY CONTINUOUS SHALES; CAN GIVE RISE TO COMPARTMENTS & MULTIPLE FLUID CONTACTS**

•*CHANNEL SANDSTONES*

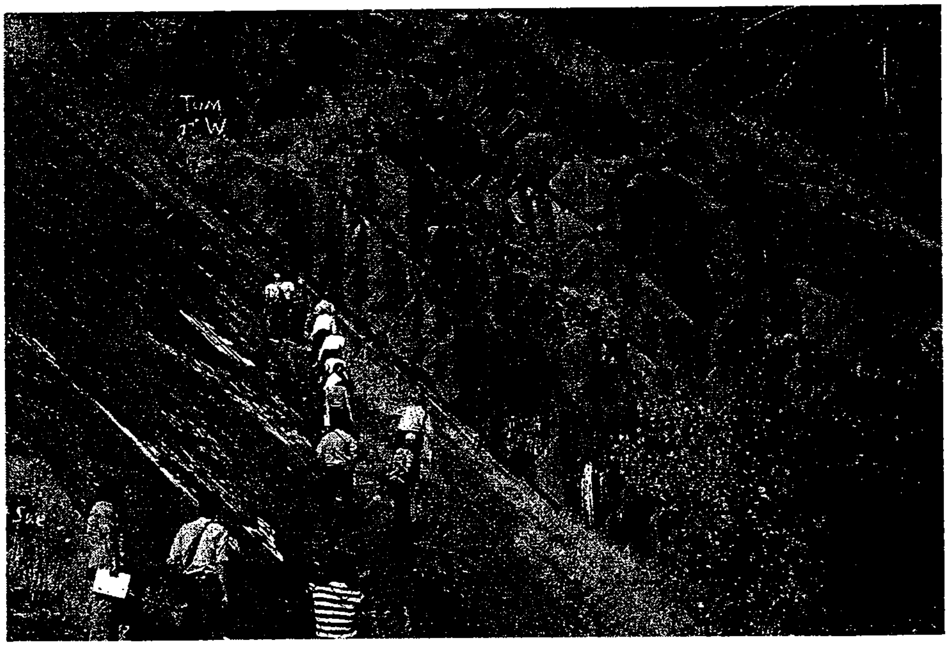
- **-INTERNALLY COMPLEX**
- **-UNPREDICTABLE INTERNAL CONTINUITY & CONNECTIVITY; CAN GIVE RISE TO COMPARTMENTS & MULTIPLE FLUID CONTACTS**

•*CHANNEL-LEVEE/OVERBANK DEPOSITS*

- **-THIN-BEDDED, LOW RESISTIVITY, LOW CONTRAST ‘ PAY’**
- **-CONTINUITY & CONECTIVITY ARE VARIABLE**
- **-PRESSURE COMMUNICATION BETWEEN CHANNEL & LEVEES??**
  - **-SOMETIMES YES & SOMETIMES NO**
- **-SOMETIMES SANDSTONE-, AND SOMETIMES SHALE-FILLED CHANNELS**
- **-LEVEE WEDGE RESERVOIRS CAN BE ISOLATED FROM EACH OTHER & FROM CENTRAL CHANNEL-FILL; GIVES RISE TO COMPARTMENTS & MULTIPLE FLUID CONTACTS**

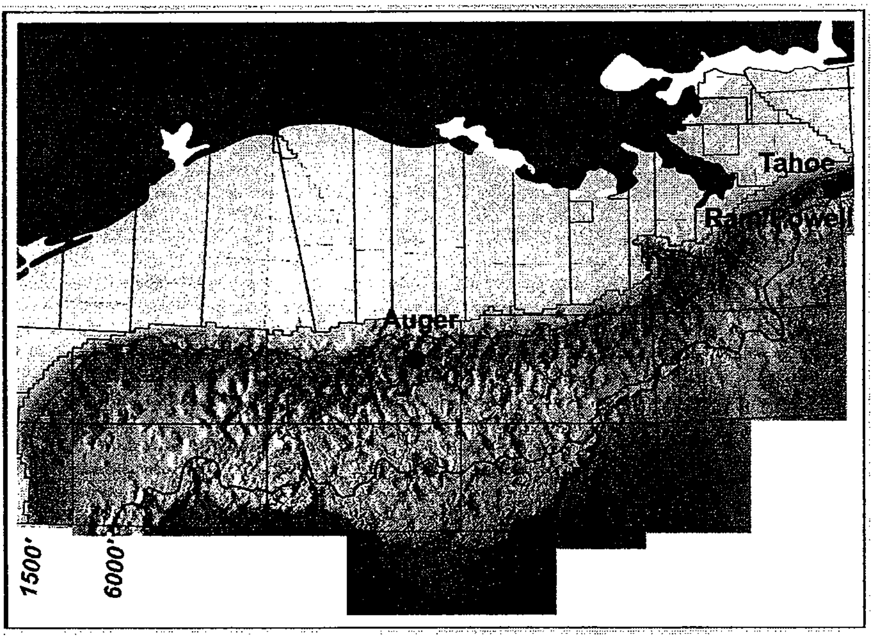
SHEET SANDSTONE EXAMPLES

- •*S Sand, Auger Field; Gulf of Mexico* (Kendrick, 1998)
  - -Since 1994, >200MMBOE produced
  - -layered/amalgamated sheet sands across basin
  - -oil-bearing zones above water-bearing zones
- •*4500' Sand, Garden Banks 236; Gulf of Mexico* (Fugitt et al., 2000)
  - -Since 6/94, 93BCFG produced
  - -layered/amalgamated sheet sandstones
  - -shaley intervals subdivide sandy intervals into different production zones
  - -strong water drive
- •*Marlin, Viosca Knoll; Gulf of Mexico* (Clemenceau et al., 2000)
  - -amalgamated sheet sandstones
  - -limited vertical connectivity due to laterally continuous shales
- •*Magnus; North Sea* (Leonard et al., 2000)
  - -1.2BBOOIP
  - -Sandstones separated by 1-5m thick shale
- •*Andrew Field; North Sea* (Leonard et al., 2000)
  - -292MMBOOIP
  - -Well performance strongly influenced by shales, which impact gas migration toward producing wells
- •*Long Beach Unit; S. California* (Slatt et al., 1993)
  - -3.8BBOOIP
  - -Laterally continuous shales extend across fault blocks

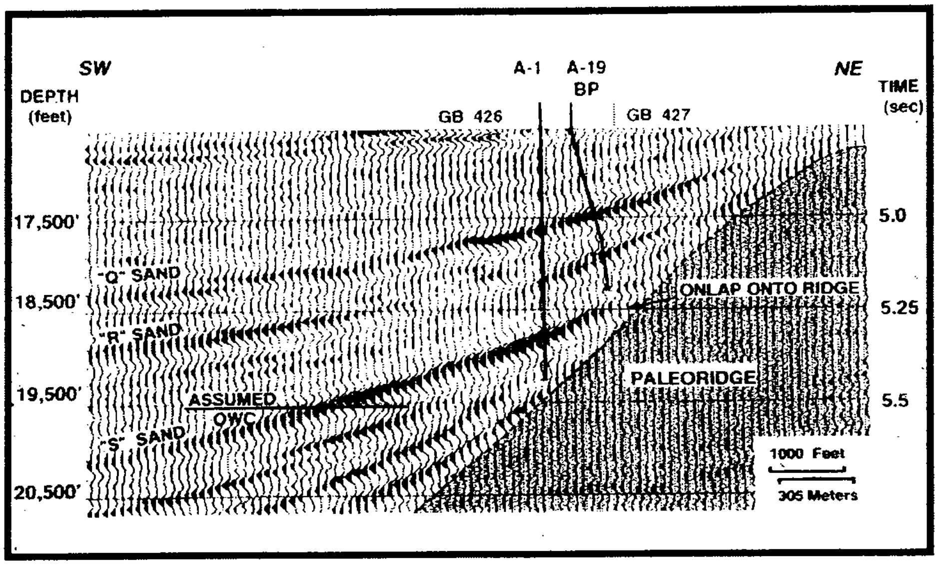


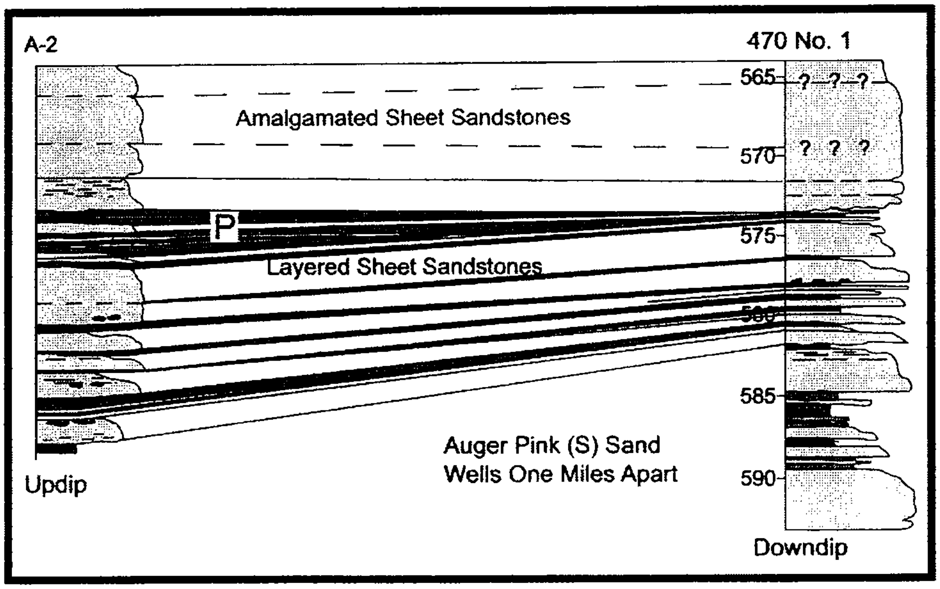
Stevens Sandstone, California

Jackfork Sandstone, DeGray Spillway, Arkansas

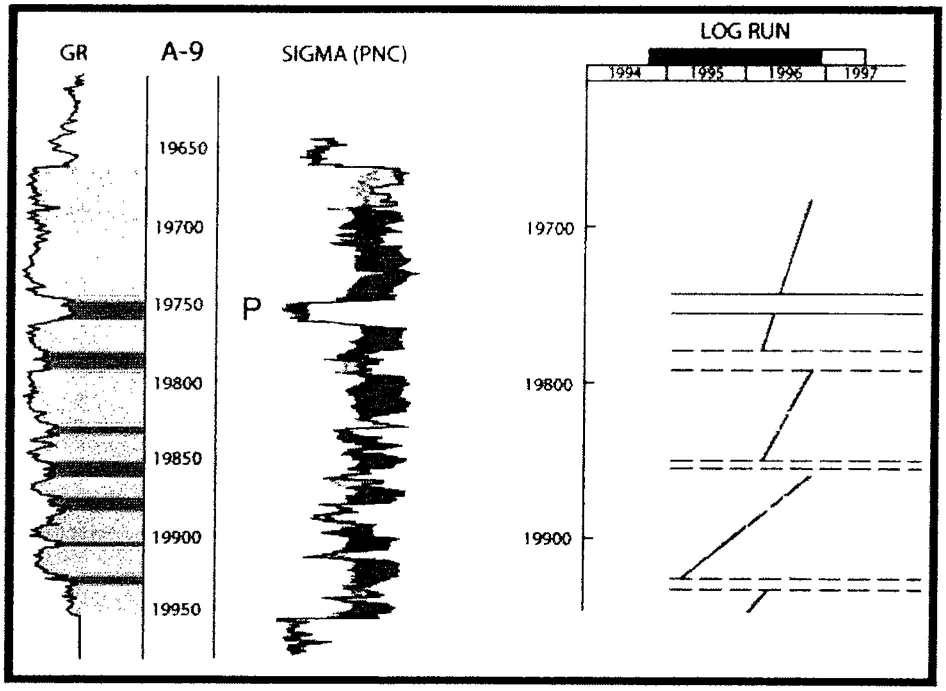


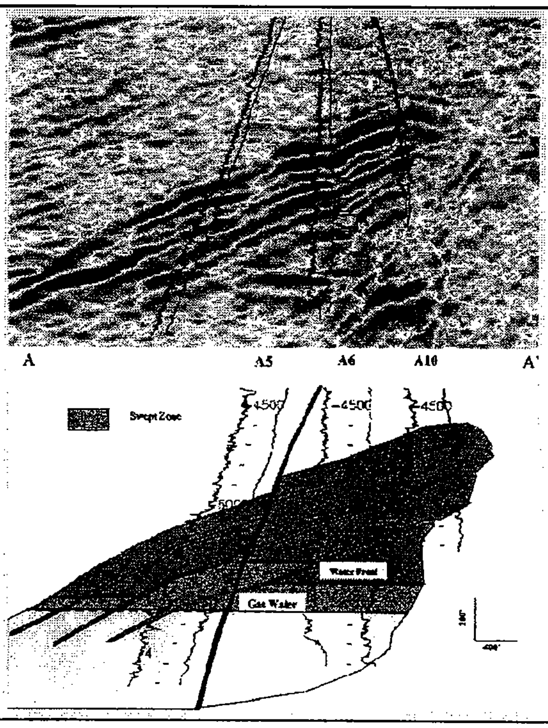
(Kendrick, 2000)





Auger Pink (S) Sand
Wells One Miles Apart





4500' Sand,
Garden
Banks

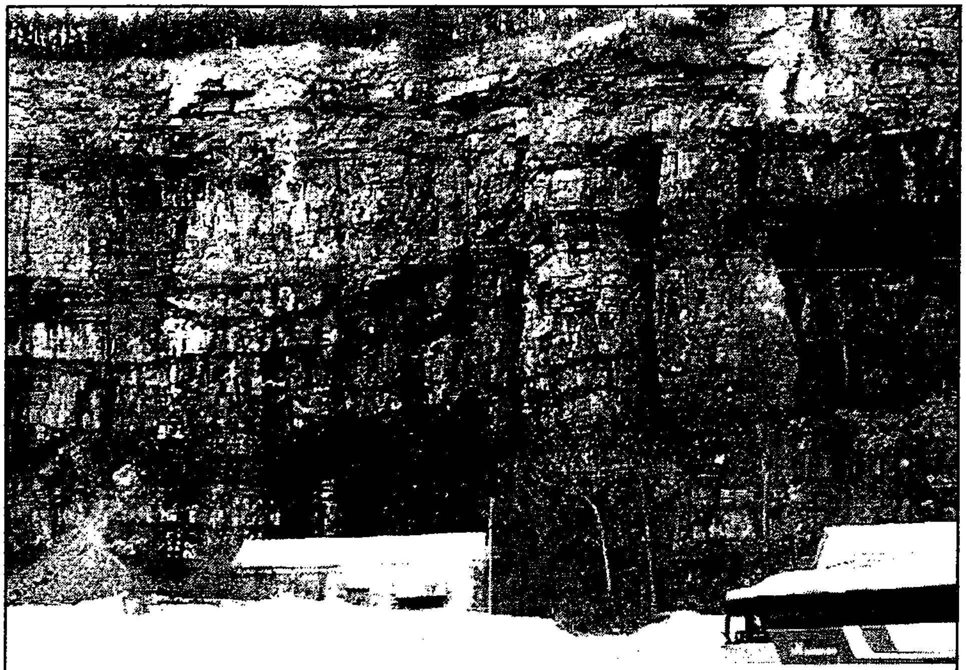
(Fugitt et al.
2000)

CHANNEL-FILL SANDSTONE EXAMPLES

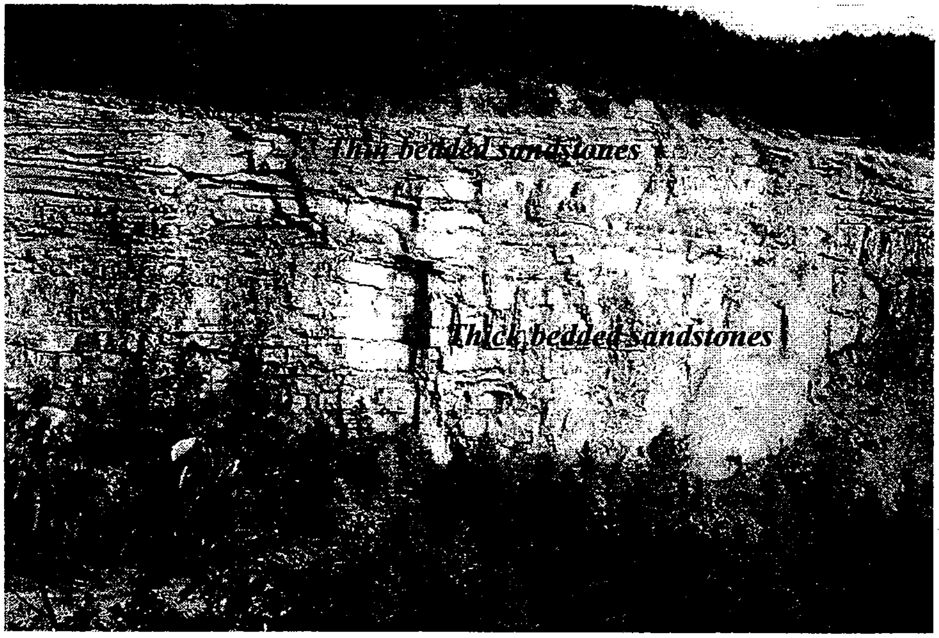
- ***N Sand, Ram Powell, Gulf of Mexico*** **(Kendricks, 2000)**
  - **-Cumulative production is 12MMBE**
  - **-Variable thickness over short distances**
  - **-Numerous perched water levels**
  - **-Reservoir is composed of multiple, laterally offset stacked, lenticular channel-fill sandstones incised into slope shales**

- ***8500' Sand, Garden Banks 236, Gulf of Mexico*** **(Fugitt et al., 2000)**
  - **-128BCFG produced through 4/98**
  - **-Good vertical connectivity, but lateral continuity of sand is variable**
  - **-Multiple shales, but shales are not laterally continuous**
  - **-Multiple perched water contacts**
  - **-Due to complexities, recovery efficiency would be less if the reservoir were oil-bearing**

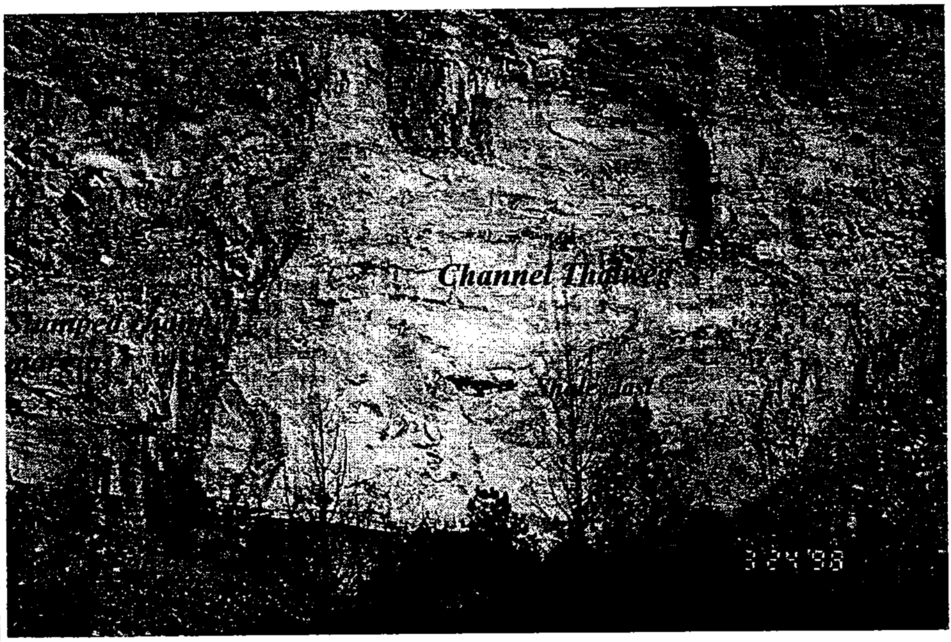
Jackfork Sandstone, Big Rock Quarry, Arkansas



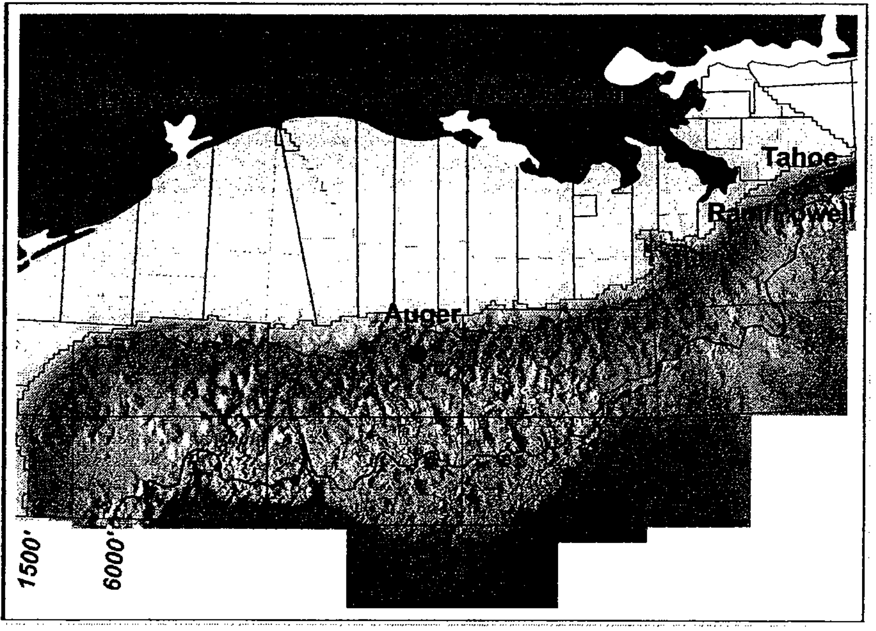
Cut-and-fill structures. Most cuts are mud-lined



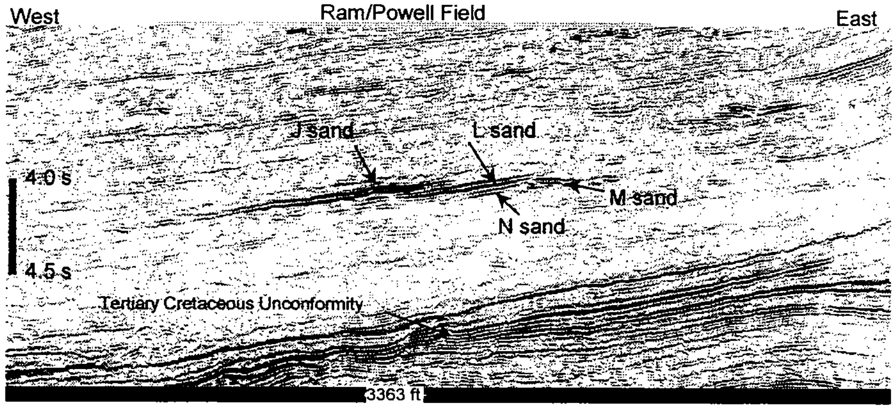
Levee Wedge **Slumped Channel margin Margin** **Channel Thalweg**



(Intra-canyon channel fill and adjacent (left) channel-margin slump

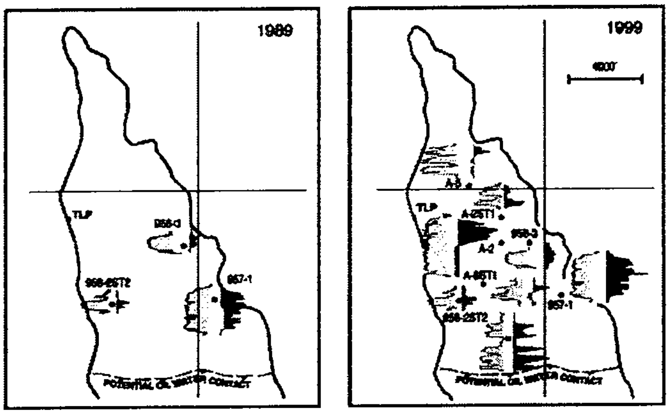


(Kendrick, 2000)

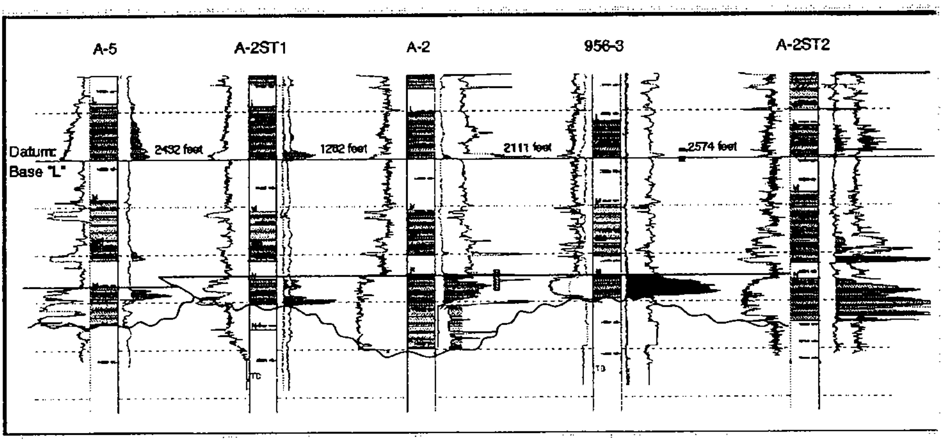


(Clemenceau et al., 2000)

Ram Powell 'N' Sand

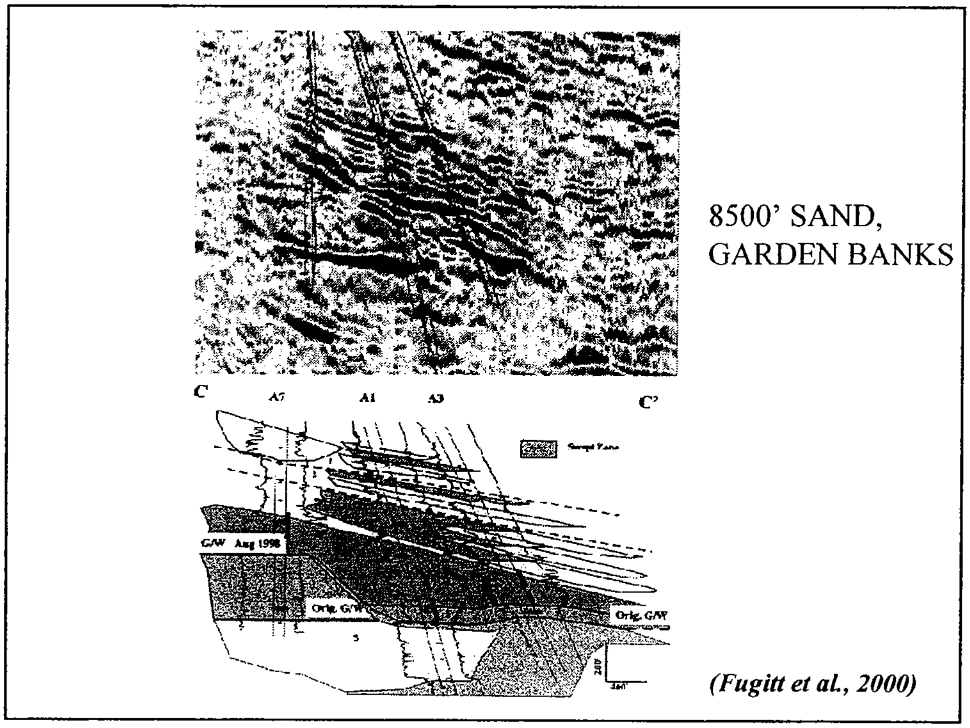


(Kendrick, 2000)



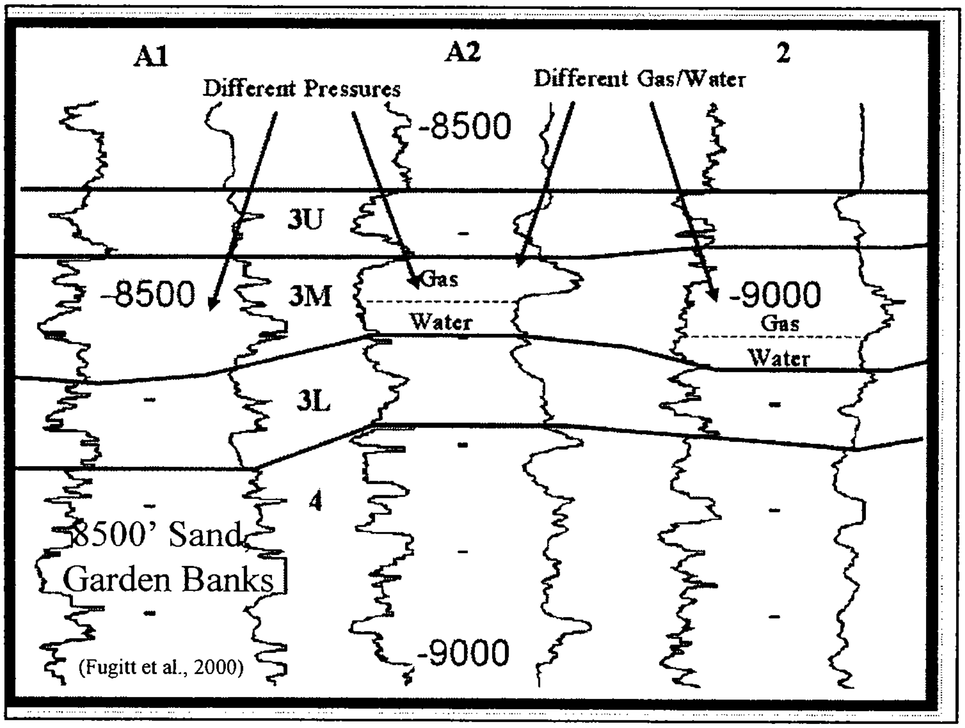
Ram-Powell N Sand

(Kendrick, 2000)



8500' SAND,
GARDEN BANKS

(Fugitt et al., 2000)

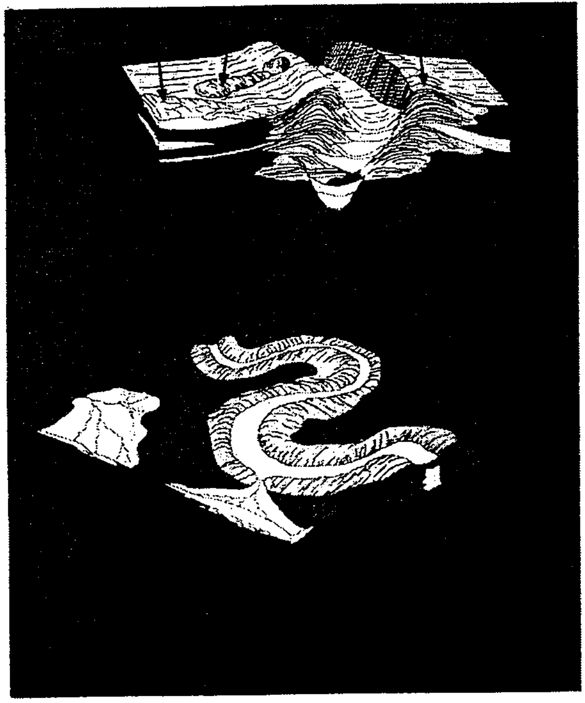


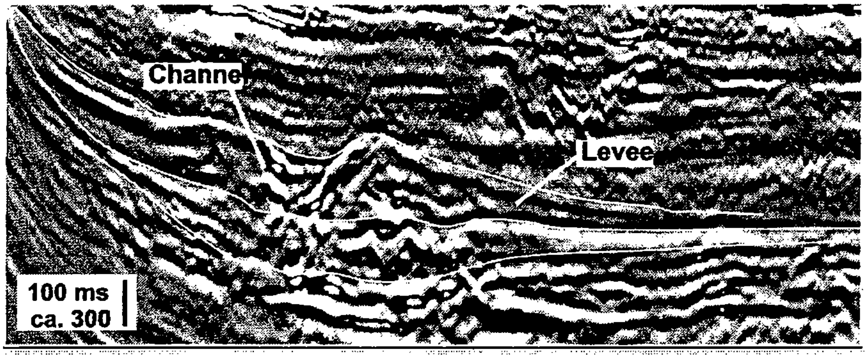
8500' Sand,
Garden Banks

(Fugitt et al., 2000)

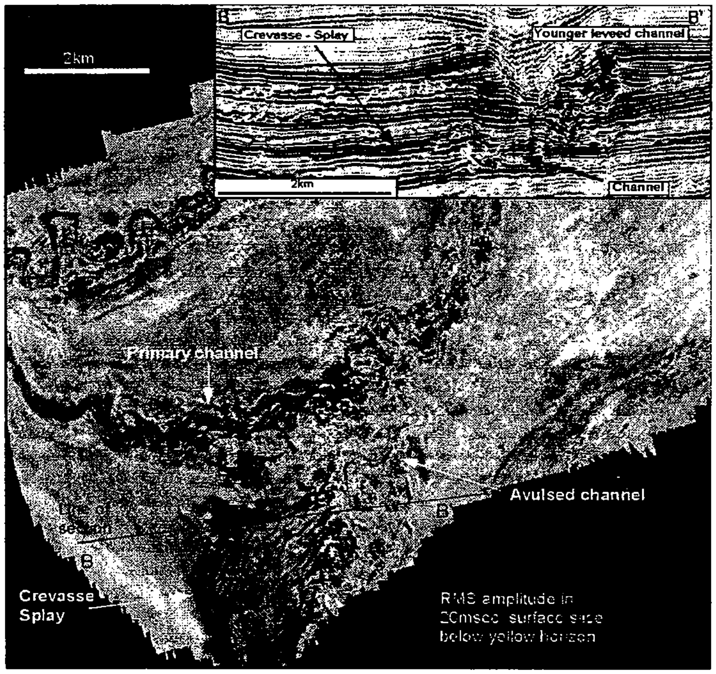
CHANNEL LEVEE/OVERBANK EXAMPLES

- **_Ram/Powell, L Sand, Gulf of Mexico_ (Clemenceau et al., 2000)**
  - **500MMBOESTOOIP**
  - **Reservoir is thin-bedded levell/overbank facies**
  - **Single 2,500ft. Horizontal well in proximal levee facies peaked at 8.8MBOPD and 108MMCFGD**
  - **Good lateral continuity and pressure communication across entire 4000 acre reservoir**
- **_M4.1 Sand, Tahoe, Gulf of Mexico_ (Kendrick, 2000)**
  - **>17MMBE gas and condensate**
  - **Differential pressure depletion and fluid contacts between west and east levees**
- **_P Sand, Mahogany, Gulf of Mexico (Camp, 1998)_**
  - **Peak production of 19,900BOPD and 31MMCFGD**
  - **Upper P sand forms two wedge shaped, thin-bedded units that thin away from a shale-filled channel**
  - **Better reservoir quality in proximal levee facies**



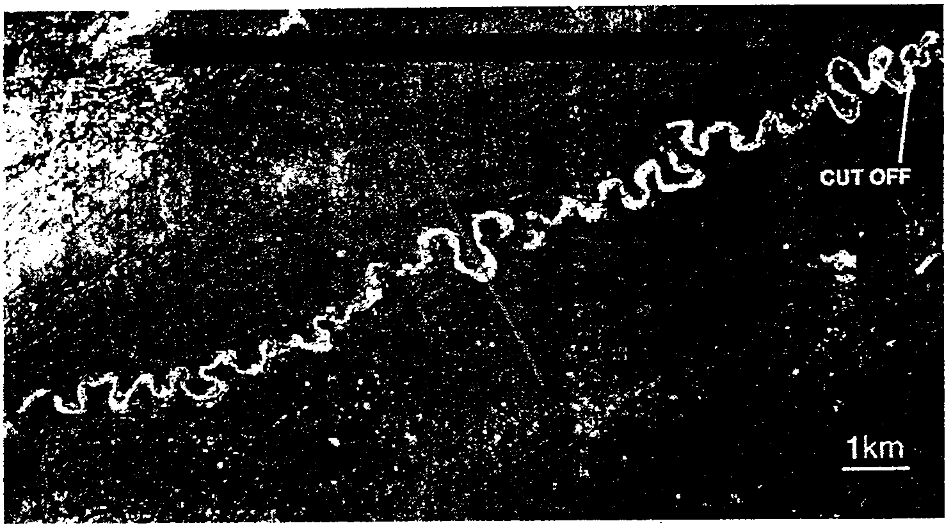


(Shanley et al., 2000)



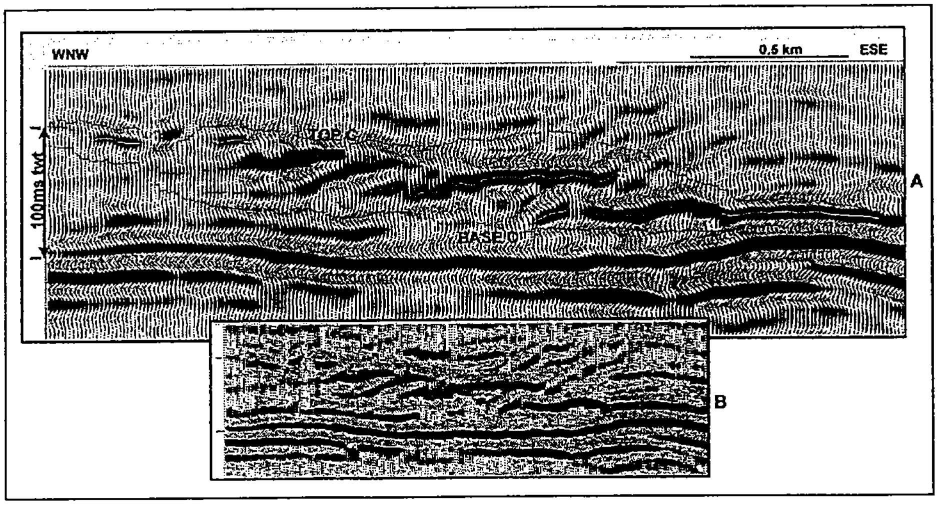
(Mayall et al., 2000)

3D SEISMIC HORIZON SLICE



Offshore Angola *(Provided by Kolla)*

3D Seismic line, offshore Angola

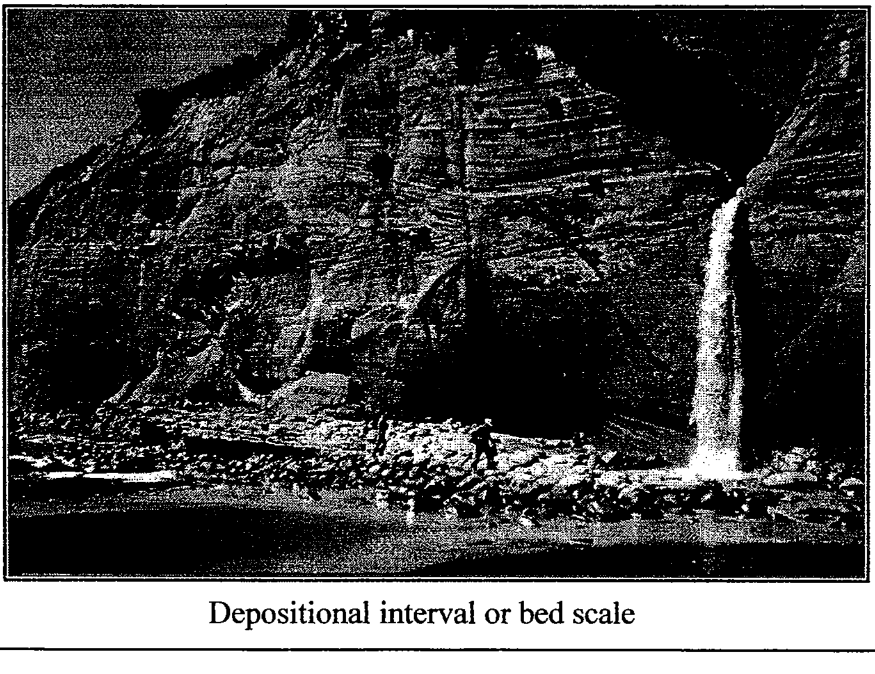


Black = positive seismic reflection
Purple = negative seismic reflection

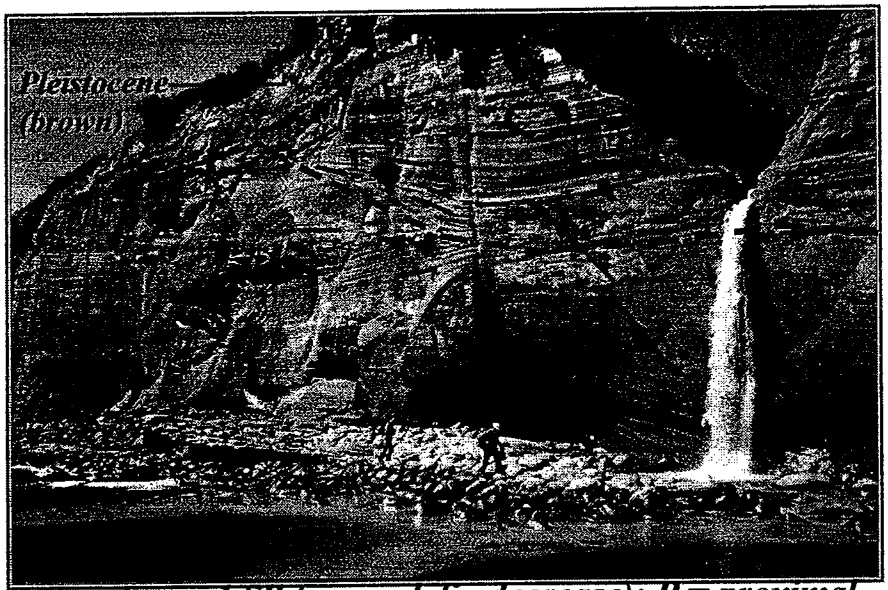
Kolla et al., 2001

Miocene Mt. Messenger Formation, Taranaki Basin, New Zealand: *Cliff is 250m high and several km long*

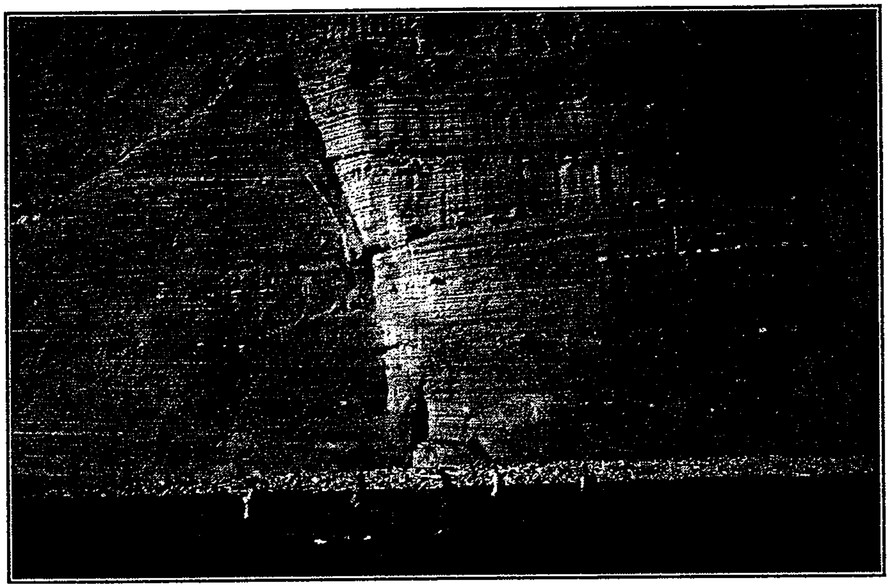
PHOTOMOSAICS FROM HELICOPTER; WELLS; CORES; LOGS; HIGH-RESOLUTION SHALLOW SEISMIC; MEASURED SECTIONS

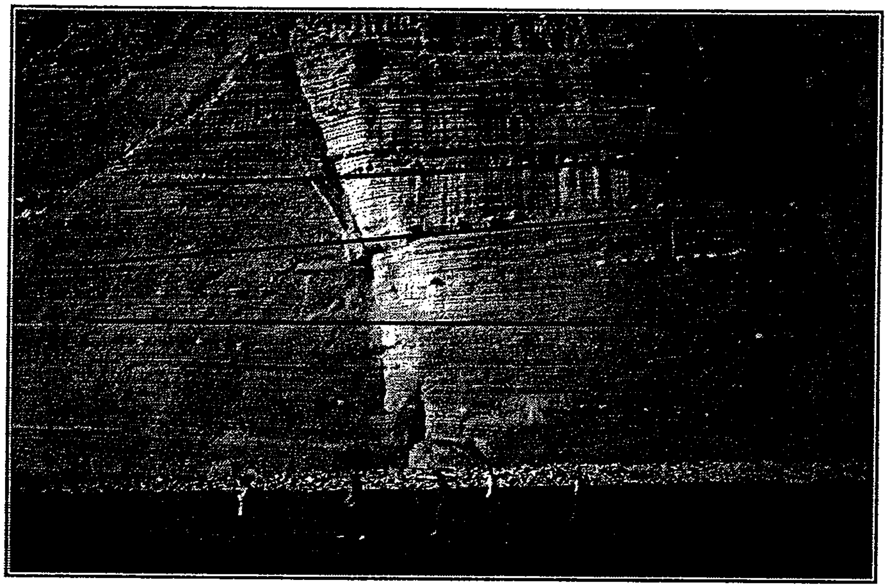


Depositional interval or bed scale



C = channel fill (upward dip decrease); P = proximal levee (high & variable angle dips); D = distal levee;





Distal levee bed sets (lower & uniform dip angles)

LEVEE FACIES

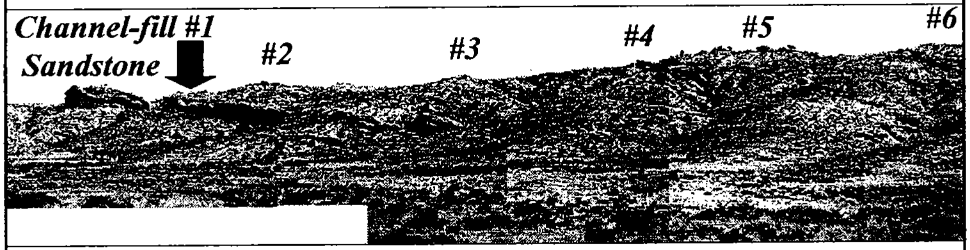
Proximal levee:	Higher net sand; thin bedded; cut-and-fill; mud-lined scours; climbing ripples; good connectivity; high angle and variable dips of beds.
Distal levee	Lower net sand; thin bedded; interbedded sand/silt; good continuity; low angle and uniform dips of beds
Channel margins:	Complex: slumps,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

Cretaceous Lewis Shale, Wyoming
"Bashful outcrops"

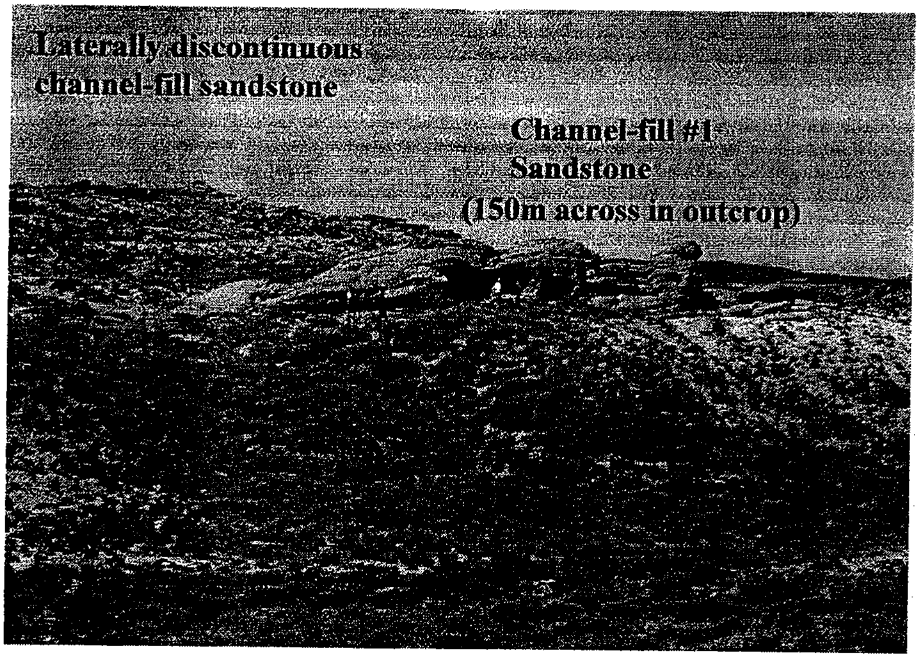
S1 and S2 are continuous Lewis sheet sandstones
CC is Lewis leveed channel complex on Spine I
F is shallow marine Fox Hills

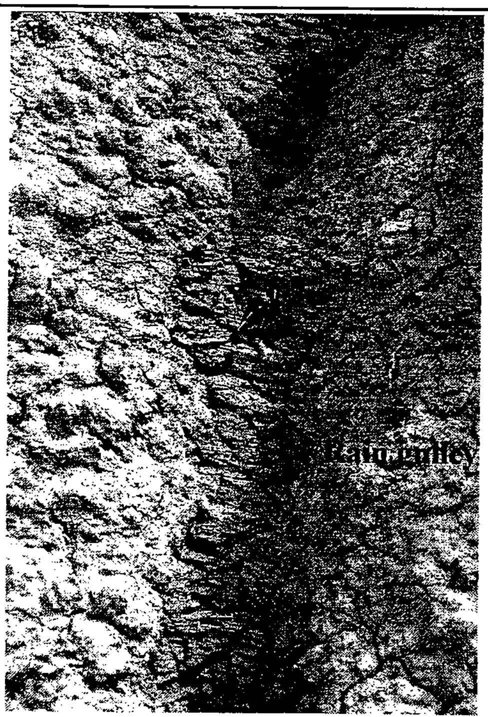
Spine I

(yellow line is app. 450m on ground; 120m of strat. section) **Well-------**

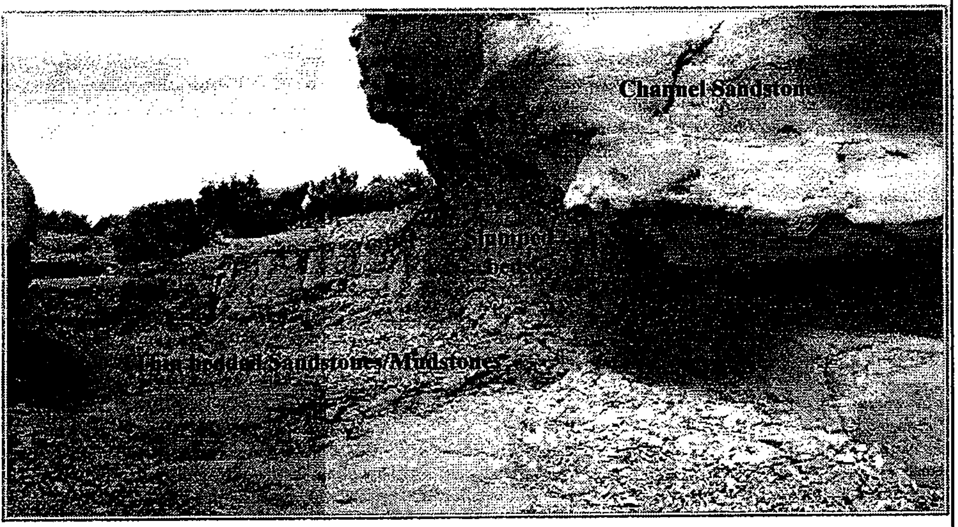


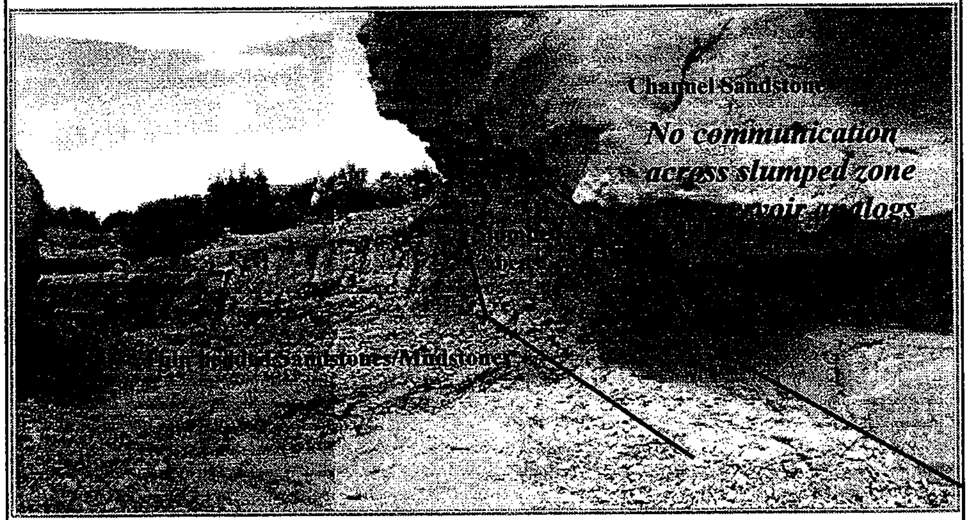
10 Channel-fill sandstones, <u>each separated by shale/mudstone breaks</u>: i.e. discontinuous reservoirs; not so easy to develop as sheet sandstone reservoirs !!

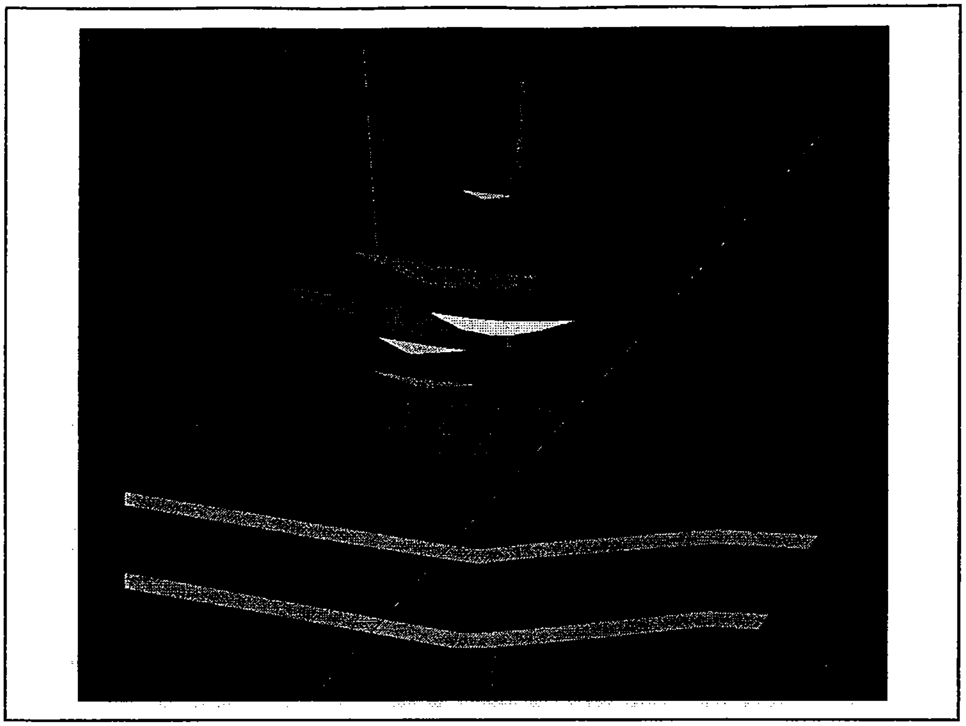


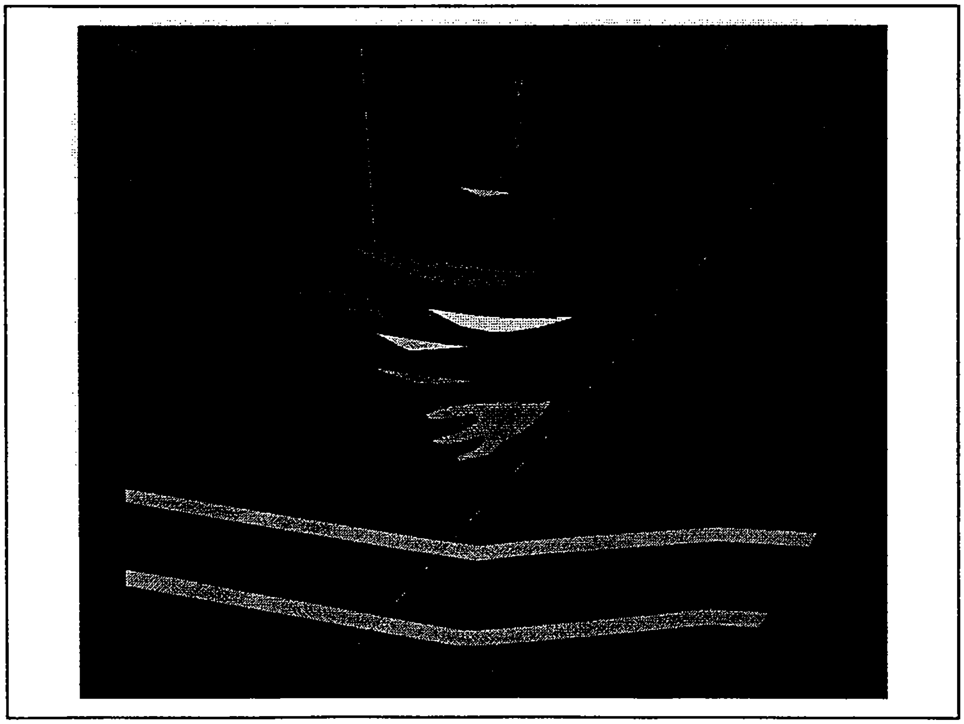


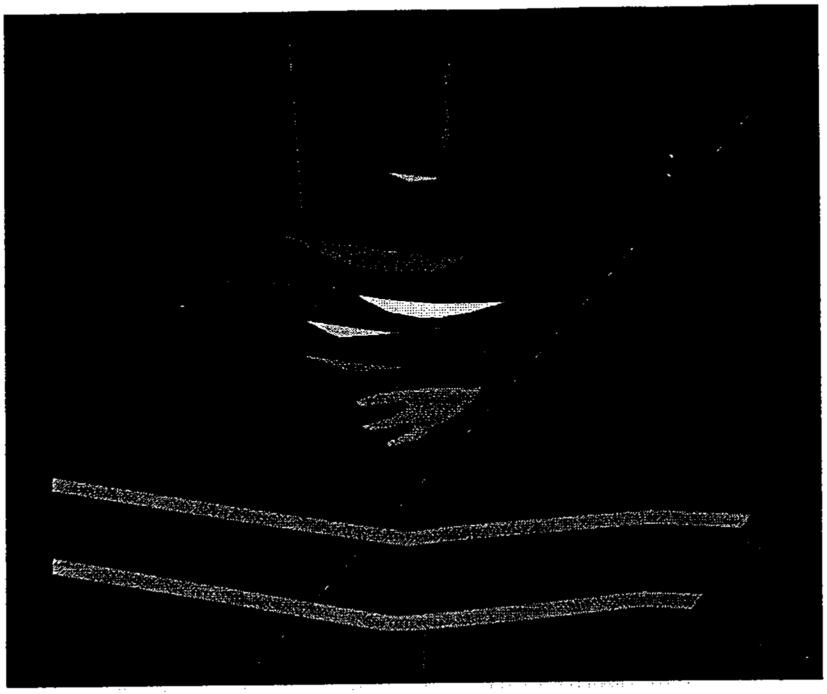
Thin-bedded, extra-channel or levee facies


Channel Sandstone
Slumped beds
Thin-bedded Sandstones/Mudstones

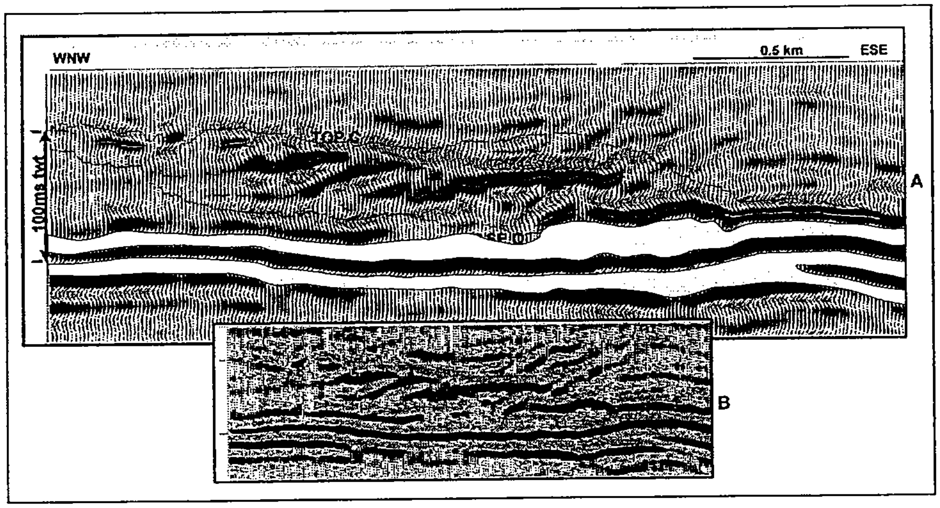

Channel Sandstone
No communication
across slumped zone
Thin-bedded Sandstones/Mudstones







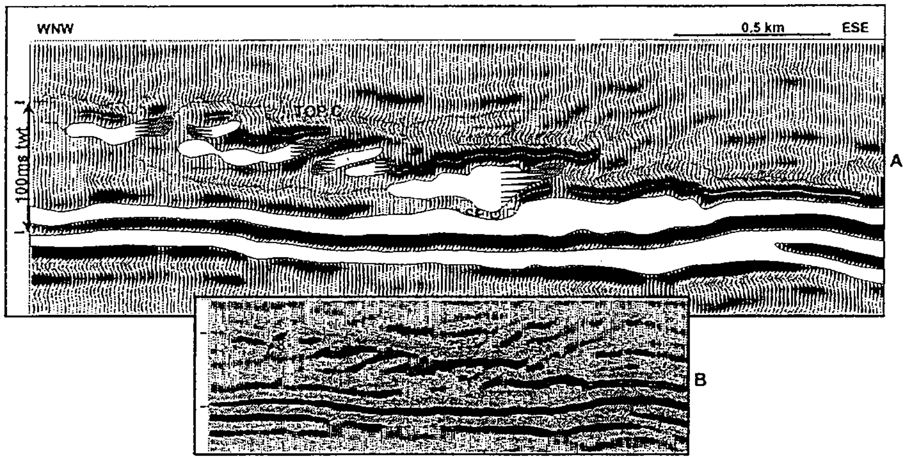
3D Seismic line, offshore Angola



Black = positive seismic reflection
Purple = negative seismic reflection

Kolla et al., 2001

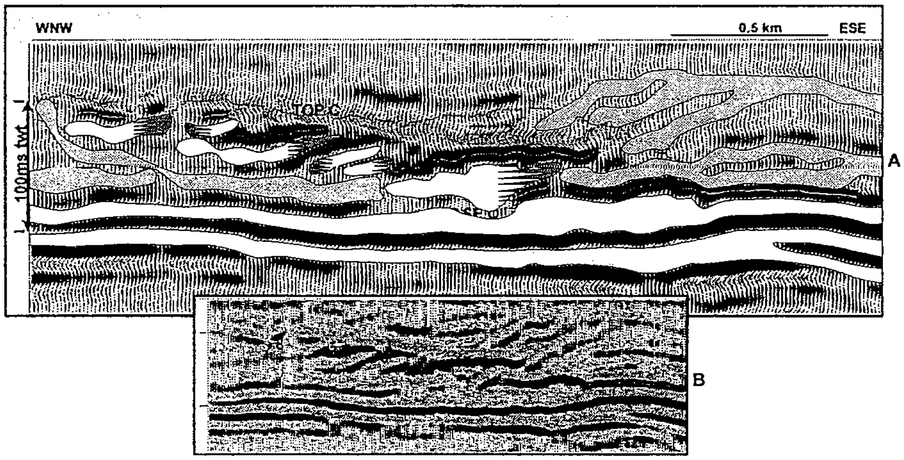
3D Seismic line, offshore Angola



Black = positive seismic reflection
Purple = negative seismic reflection

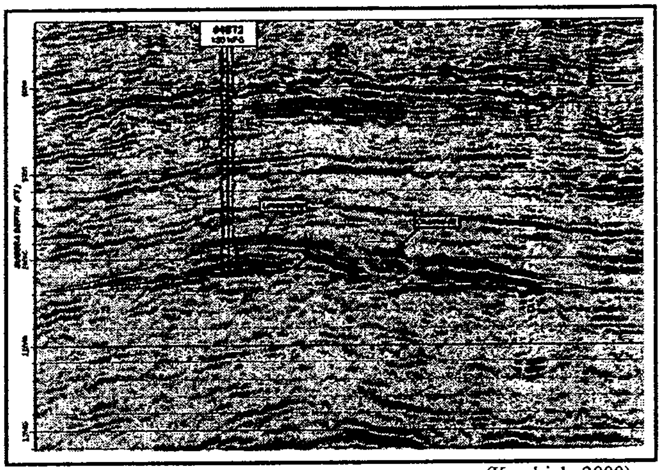
Kolla et al., 2001

3D Seismic line, offshore Angola



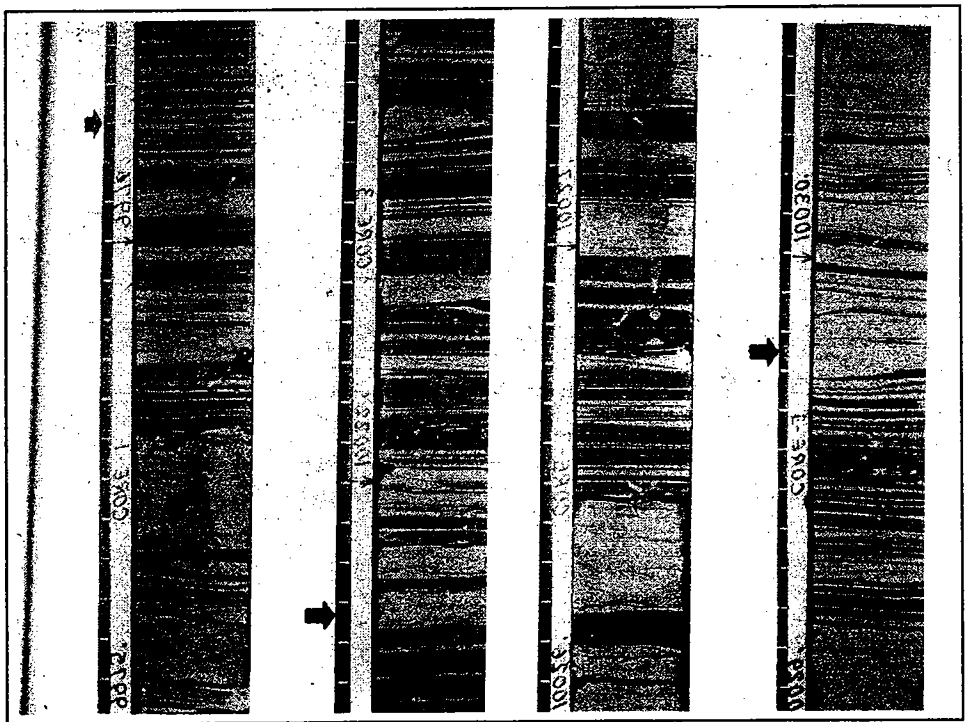
Black = positive seismic reflection
Purple = negative seismic reflection

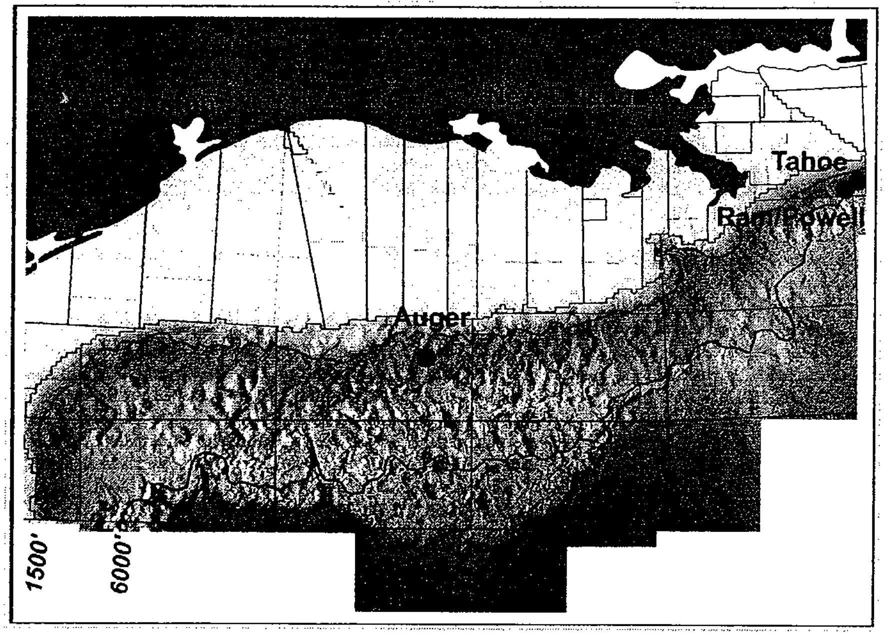
Kolla et al., 2001



(Kendrick, 2000)

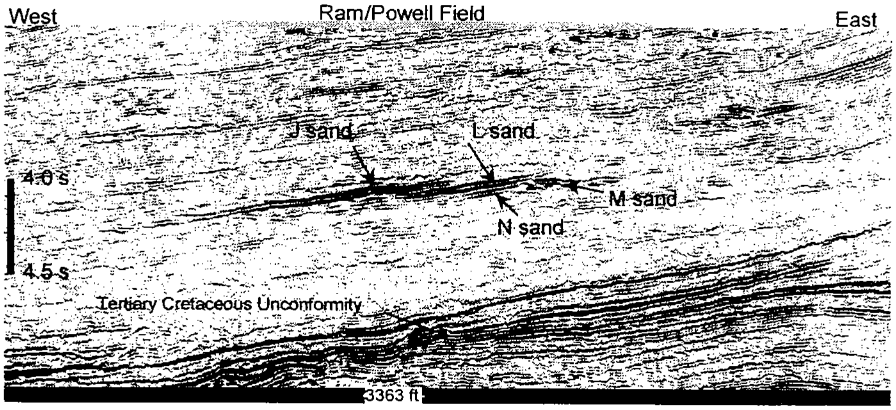
Tahoe Field





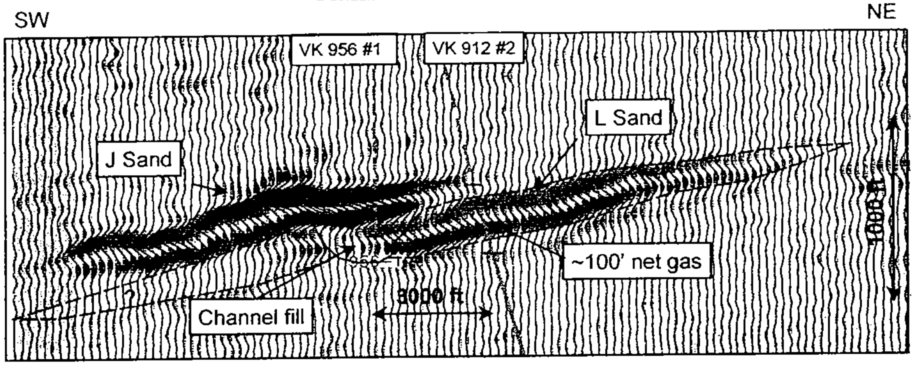
(Kendrick, 2000)

L Sand, Ram/Powell Field, Gulf of Mexico: comprises channel, proximal, & distal levee facies.



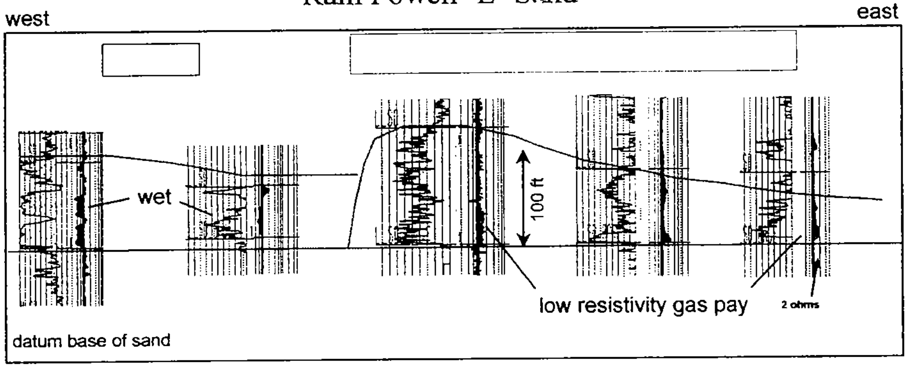
(Clemenceau et al., 2000)

Ram Powell 'L' Sand



(Clemenceau et al., 2000)

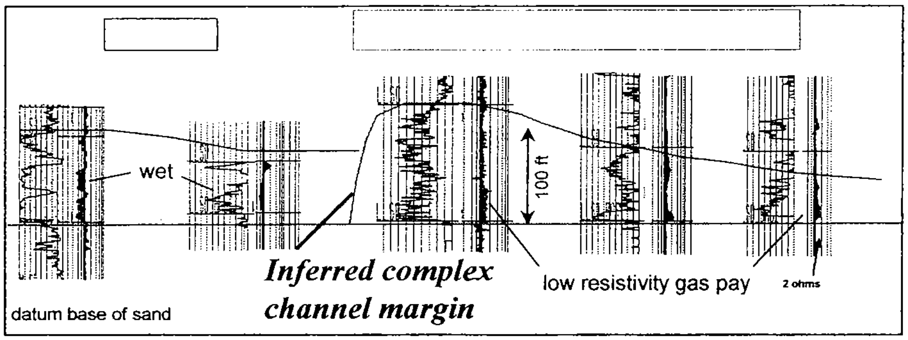
Ram Powell 'L' Sand



(Clemenceau et al, 2000)

Ram Powell 'L' Sand

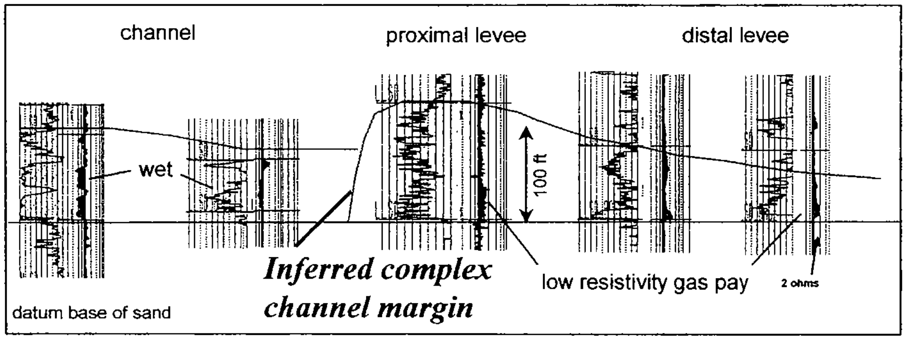
west east



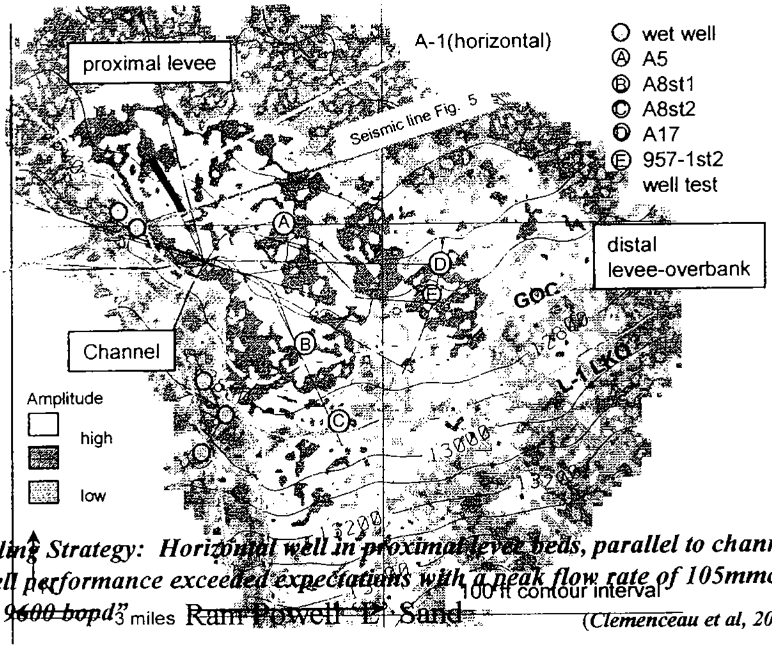
(Clemenceau et al, 2000)

Ram Powell 'L' Sand

west east



(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*)

SUMMARY

- **DEEP WATER (TURBIDITE) RESERVOIRS ARE COMPLEX**

- **THREE MAIN TYPES OF RESERVOIRS (ARCHITECTURAL ELEMENTS):**
  - **-SHEETS**
  - **-CHANNEL-FILL**
  - **-LEVEE/OVERBANK**

- **MULTIPLE FLUID CONTACTS AND COMPLEX PRESSURE REGIMES FOR EACH TYPE, BUT DIFFERENT REASONS FOR MULTIPLE CONTACTS & PRESSURES**

- **THEREFORE IT IS IMPORTANT TO UNDERSTAND THE ARCHITECTURE OF THE SPECIFIC RESERVOIR OF INTEREST**

- **BECAUSE OF DIFFERENT PRODUCTION ISSUES WITH EACH TYPE:**
  - **-WELL SPACING**
  - **–HORIZONTAL, SLANT, OR VERTICAL WELL**
  - **-WELL ORIENTATION**
  - **-ANTICIPATED FLOW RATES**

- **OUTCROPS PROVIDE AN EXCELLENT MEANS OF IMPROVING UNDERSTANDING OF RESERVOIR ARCHITECUTRE; GIVEN THE PROPER SCALES, OUTCROPS PROVIDE THE ONLY MEANS OF OBTAINING SUB-SEISMIC SCALE CONTINUITY & CONNECTIVITY INFORMATION**

APPLIED RESERVOIR CHARACTERIZATION FOR THE INDEPENDENT OPERATOR: WITH EMPHASIS ON COMPARTMENTALIZED RESERVOIRS AND ROUTINE TECHNIQUES FOR DETECTING COMPARTMENTS

UNIT 1: INTRODUCTION TO RESERVOIR CHARACTERIZATION

UNIT 2: EXAMPLES OF COMPARTMENTALIZED RESERVOIRS

UNIT 3: GEOLOGIC CONTROLS ON POROSITY AND PERMEABILITY

UNIT 3A: SEISMIC POROSITY DETECTION IN A CARBONATE RESERVOIR

UNIT 4: FLOW UNIT DETERMINATION & CHARACTERIZATION

UNIT 5: BASICS OF SEQUENCE STRATIGRAPHY

UNIT 6: FLUVIAL DEPOSITS AND RESERVOIRS

UNIT 7: EOLIAN DEPOSITS AND RESERVOIRS

UNIT 8: SHOREFACE DEPOSITS AND RESERVOIRS

UNIT 9: DELTAIC DEPOSITS AND RESERVOIRS

UNIT 10: DEEP-WATER (TURBIDITE) DEPOSITS AND RESERVOIRS

***UNIT 11: BOREHOLE IMAGE LOGS AND APPLICATIONS**

UNIT 12: DIPMETER LOGS AND APPLICATIONS

UNIT 13: STRUCTURALLY COMPARTMENTALIZED RESERVOIRS

KEY REFERENCES TO INDIVIDUAL UNITS

APPLICATIONS OF BOREHOLE IMAGE LOGS

BOREHOLE IMAGE AND DIPMETER LOGS

- PROVIDES ELECTRICAL/ACOUSTIC IMAGE OF BOREHOLE WALL

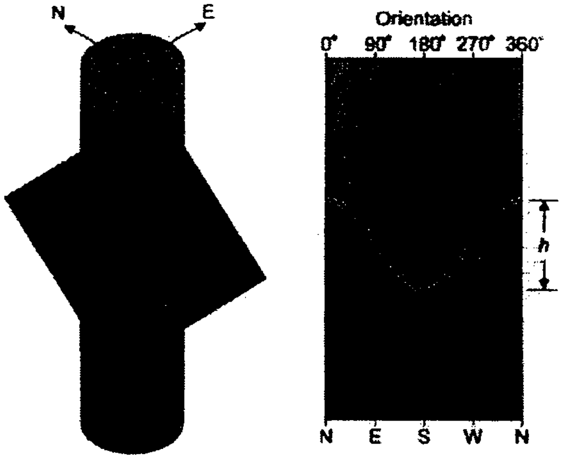
- WATER-BASED OR SYNTHETIC MUDS REQUIRED
  - OBMI Log (^{TM} Schlumberger)
- FIRST USED TO OBSERVE FAULTS AND FRACTURES

- NOW USED FOR SEDIMENTARY/STRATIGRAPHIC INTERPRETATION; PROVIDES INFORMATION ON BEDDING AND STRATIFICATION STYLES, BED CONTINUITY AWAY FROM WELLBORE, ETC.

- DIPMETER DATA CAN BE USED FOR CORRELATION AND INTERPRETATION PURPOSES

Vertical resolution of various logging tools. Modified from Allen et al (1988). * = Trademark of Schlumberger

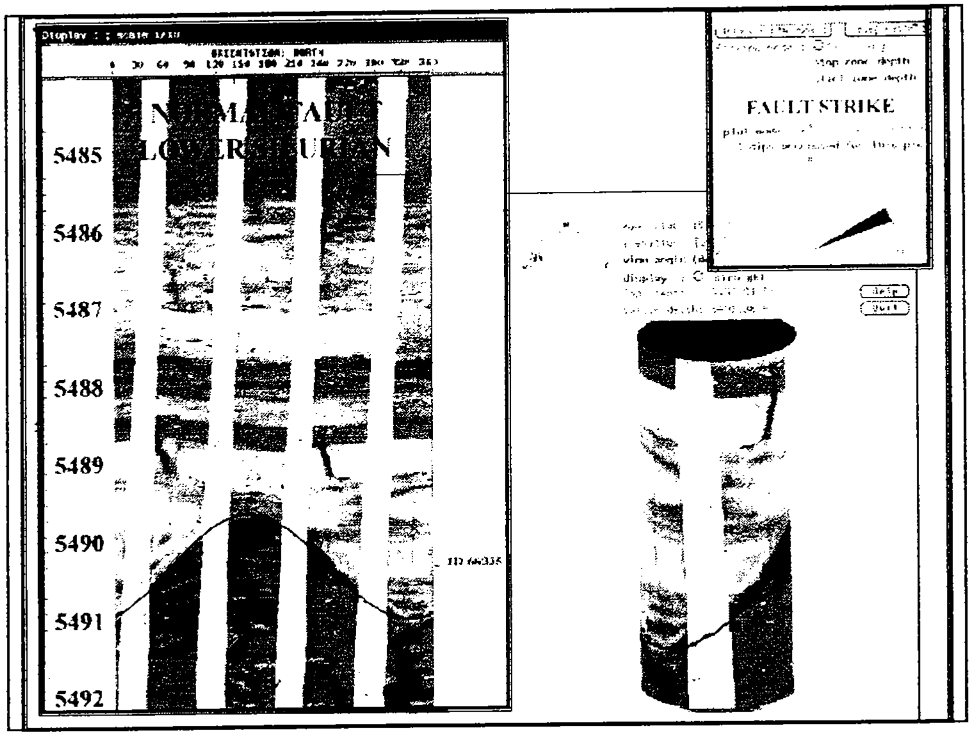
Tool	Abbreviation	Intrinsic Vertical Resolution
Formation MicroScanner	FMS*	0.2 in/5 mm
Formation Microimager	FMU*	0.2 in/5 mm
Strat. High Res. Dipmeter	SHDT*	0.4 in/10 mm
High Resolution Dipmeter	HDT*	0.5 in/13 mm
Microspherically Focused Log	MSFL*	2-3 in/5-7.6 cm
Medium Induction Log	ILM*	5-6 ft/1.5 m
Deep Induction Log	ILD*	7-8 ft/2 m
Spontaneous Potential	SP*	5 ft/1.5 m
Density Log	LDT*	15 in/38 cm
Photoelectric Log	PE*	2 in/5 cm
Neutron Log	CNL*	15 in/38 cm
Gamma Ray	GR*	8-12 in/20-31 cm
Sonic Log	BHC*	24 in/61 cm

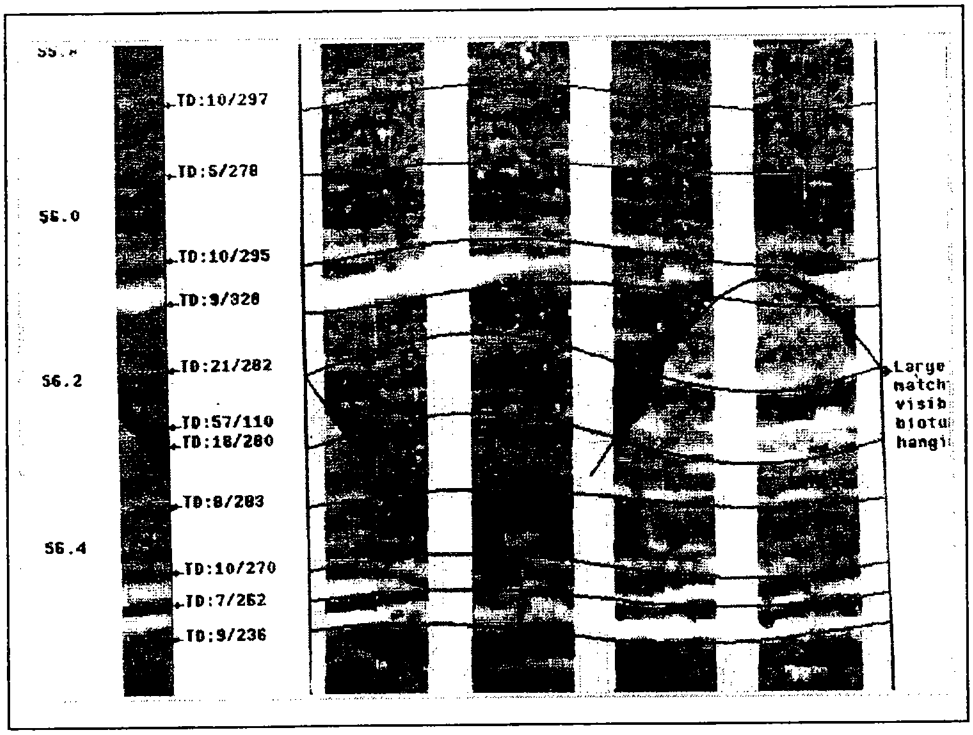


Dip azimuth is trough of sinusoid

Dip Angle = $\tan^{-1}(h/d)$

Planar feature intersecting a well bore and borehole imaging log of the feature (modified from Zemanek et al. 1970).


ORIENTATION: NORTH
0 30 60 90 120 150 180 210 240 270 300 330 360
NORMAL FAULT
LOWER SILURIAN
5485
5486
5487
5488
5489
5490
5491
5492
TD 66/335
stop zone depth
start zone depth
FAULT STRIKE
view angle
display
Help
Quit


55.8
56.0
56.2
56.4
TD:10/297
TD:5/278
TD:10/295
TD:9/328
TD:21/282
TD:57/110
TD:18/280
TD:8/283
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TD:7/262
TD:9/236
Large
match
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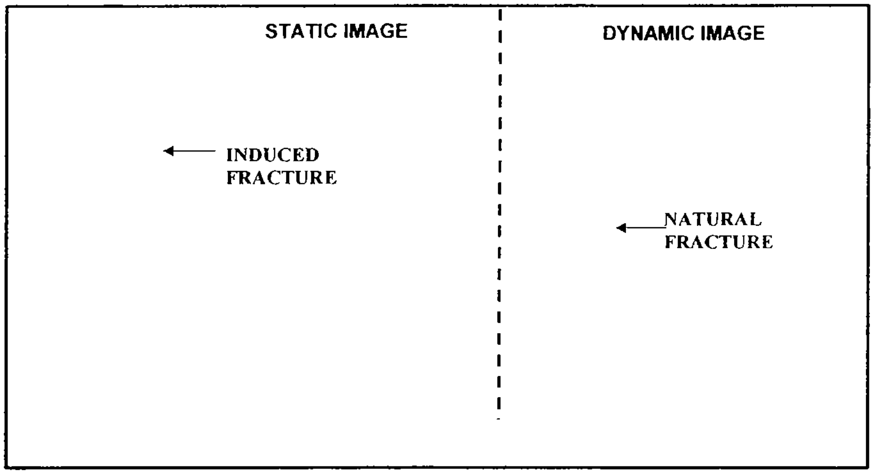
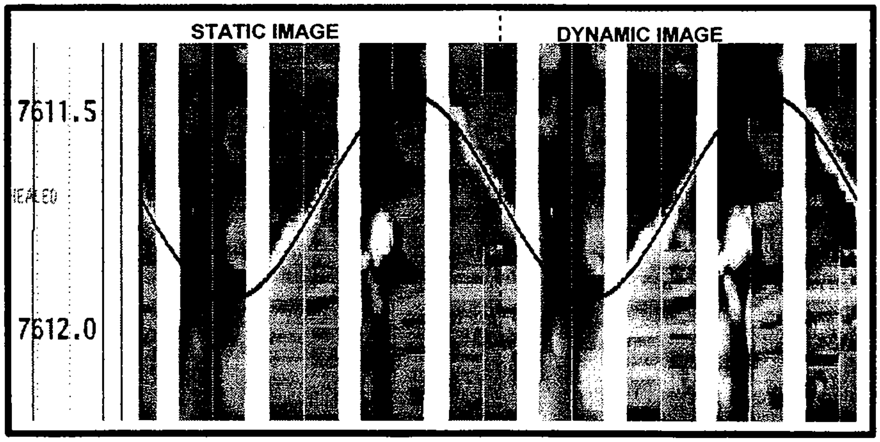
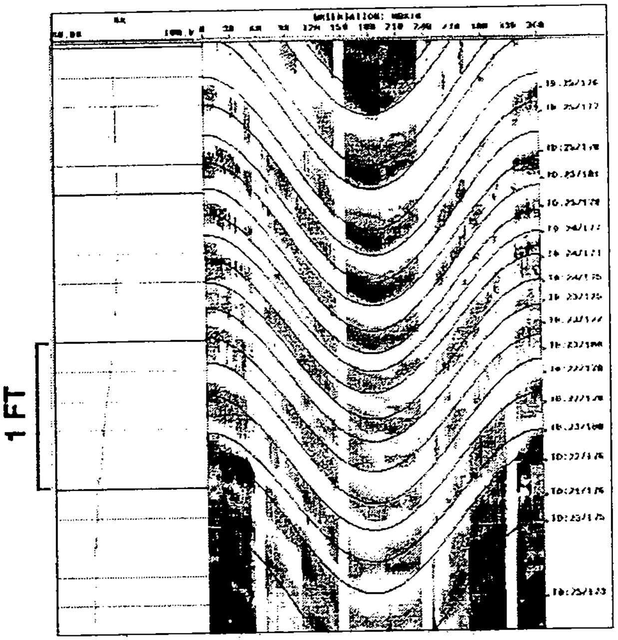


Figure 3.17 Image of induced fractures in the Pilgrim Federal well. The dip of the induced fracture is more vertical compared with the natural fracture. Depth is in ft.

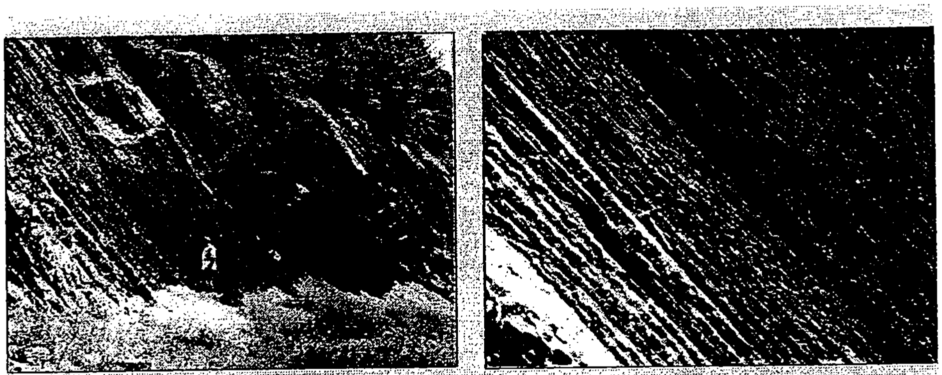


Calcite-filled fracture

THIN BEDS



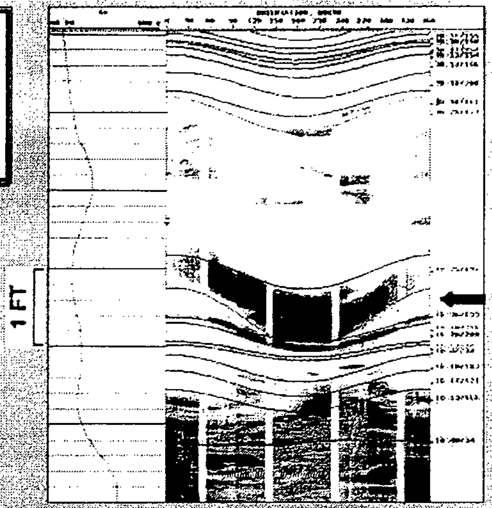
(Slatt et al., 1994)



Thin bedded low-density turbidity current deposits.

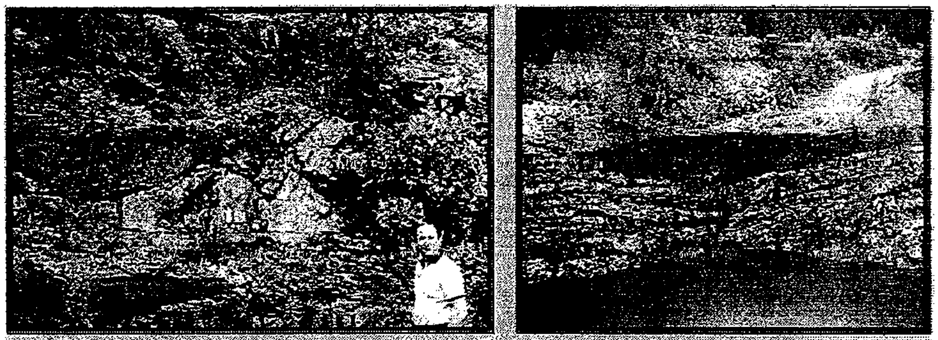
(Slatt et al., 1994)

SHALE-FILLED DEPRESSION



Shale-filled depression (arrow) above sandstone beds.

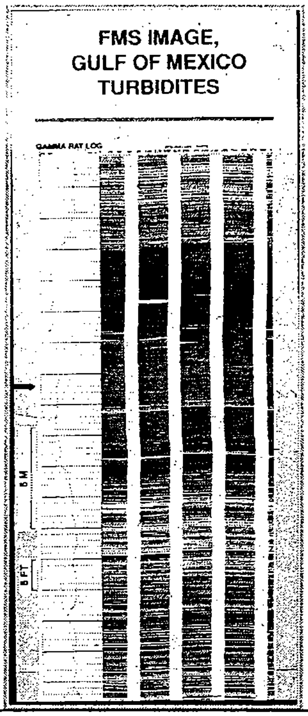
(Slatt et al., 1994)



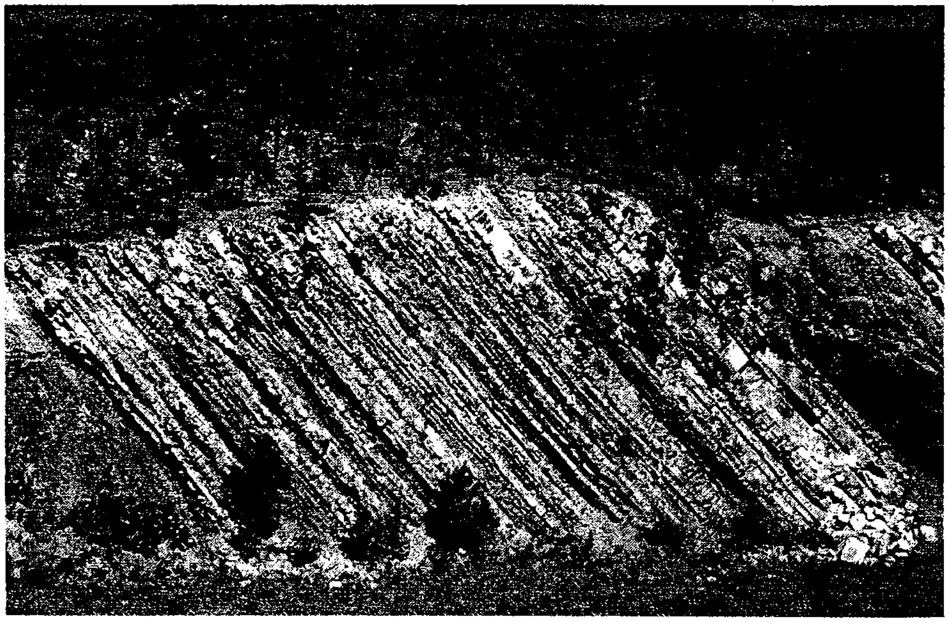
Shale-filled topographic depression interpreted as a slump scar on the upper surface of a sandstone bed. The shale has been resedimented into the depression.

(Slatt et al., 1994)

(Slatt et al., 1994)



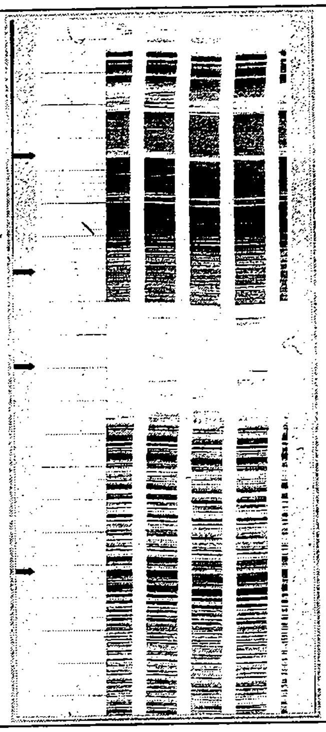
(Slatt et al., 1994)



Jackfork Sandstone, DeGray Spillway, Arkansas

General borehole image characteristics of sheet sandstones

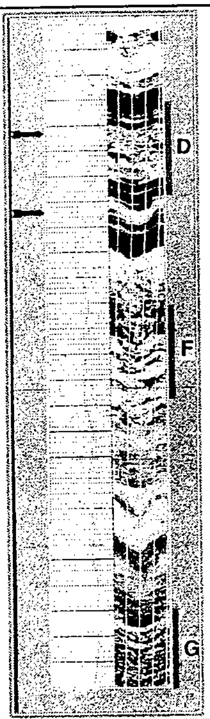
"Layered"



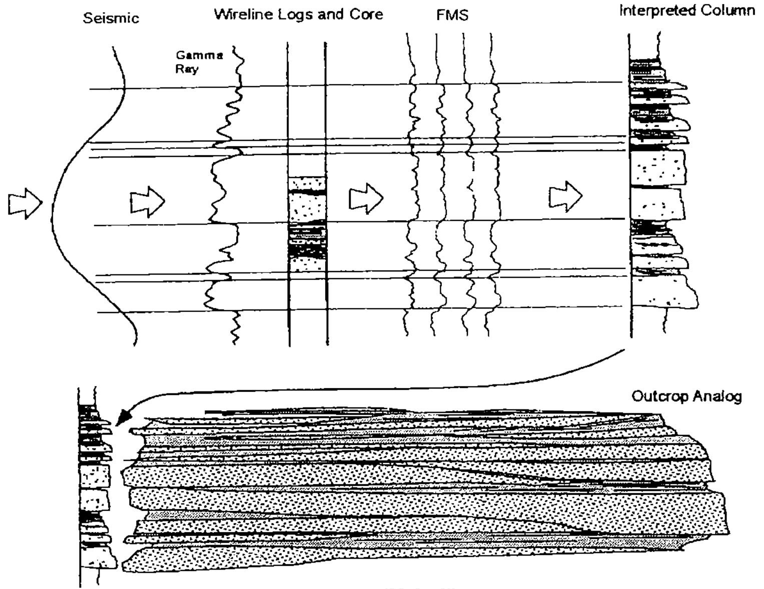
(Slatt et al., 1994)

General borehole image characteristics of channel-fill sandstones

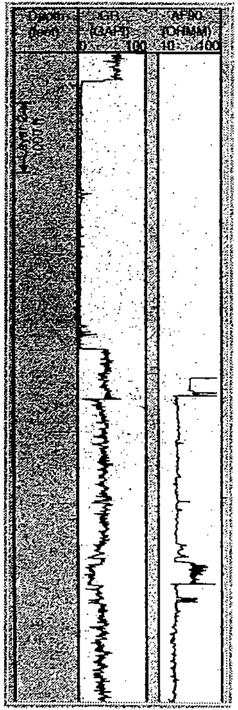
"Chaotic"



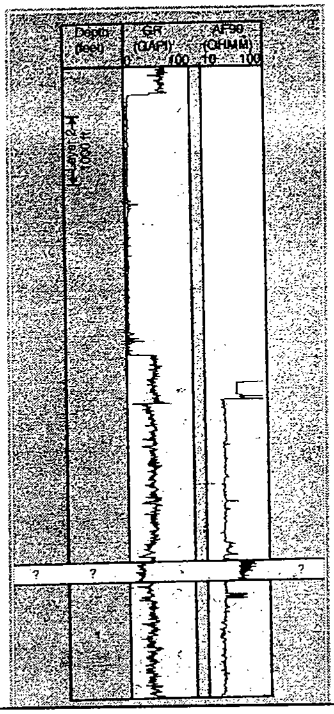
(Slatt et al., 1994)



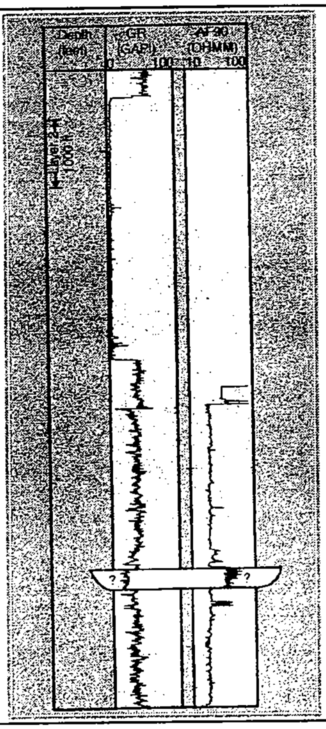
(Mahaffie et al., 1994)



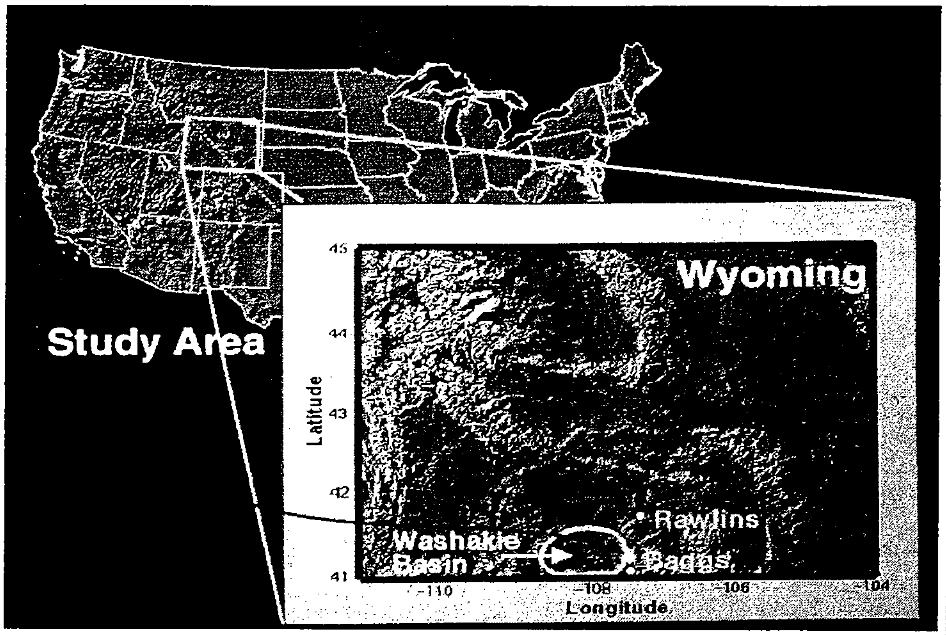
Sheet or channel-fill sandstone????



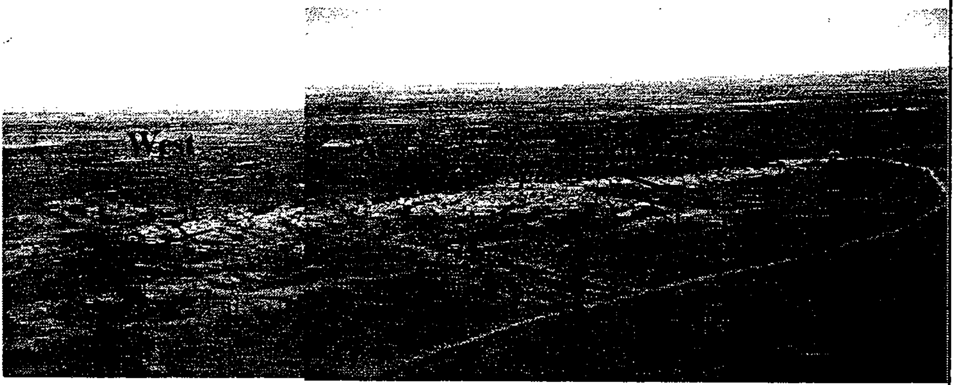
Sheet???



Channel-fill???



Cretaceous Lewis Shale, Wyoming
"Bashful outcrops"



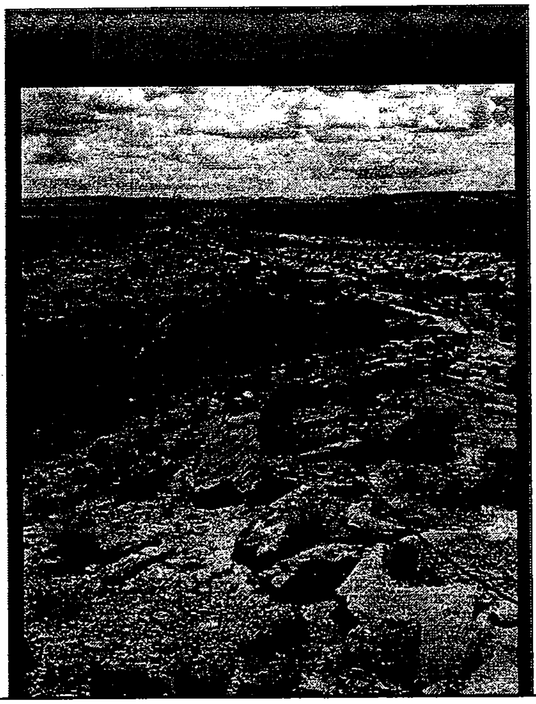
S1 and S2 are continuous Lewis sheet sandstones
CC is Lewis leveed channel complex on Spine I
F is shallow marine Fox Hills

Cretaceous Lewis Shale, Wyoming

S1 and S2 are continuous Lewis sheet sandstones
CC is Lewis leveed channel complex on Spine I
F is shallow marine Fox Hills

Sheet Sandstones:* *Laterally <u>continuous</u> for miles: i.e. good potential reservoir facies; <u>individual sandstone intervals are separated by shales.</u>

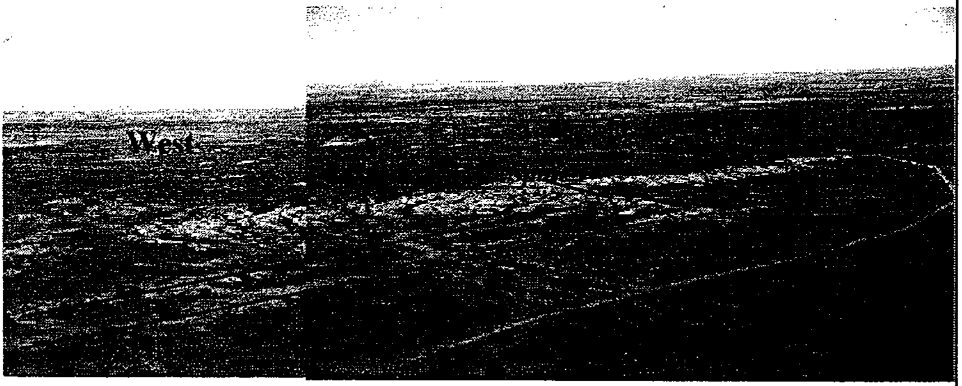
(Witton, 1999)



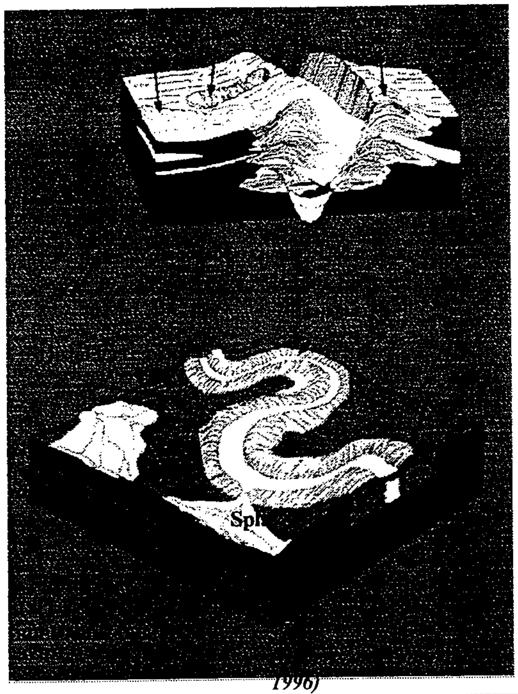
Cretaceous Lewis Shale, Wyoming

S1 and S2 are continuous Lewis sheet sandstones
CC is Lewis leveed channel complex on Spine I
F is shallow marine Fox Hills

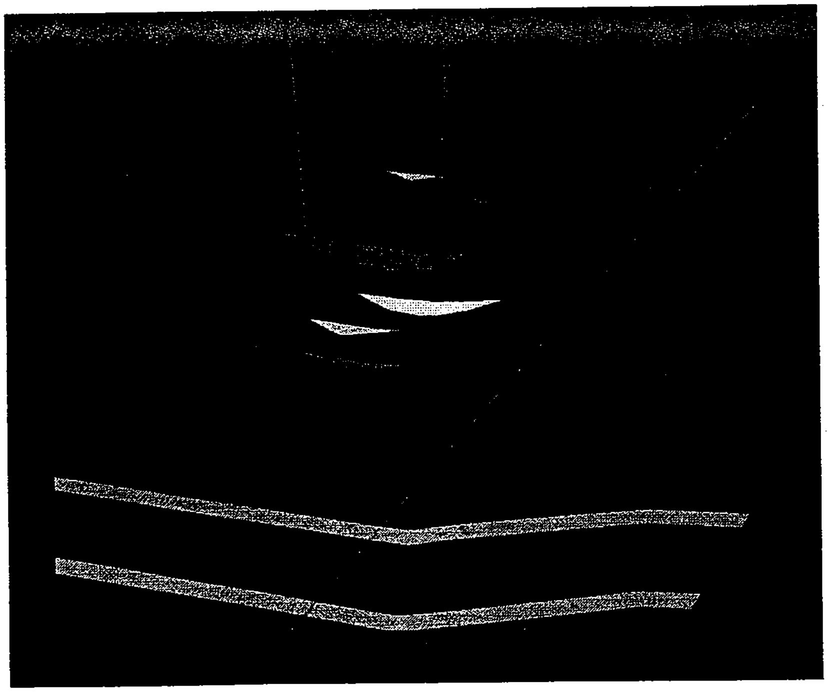
Cretaceous Lewis Shale, Wyoming

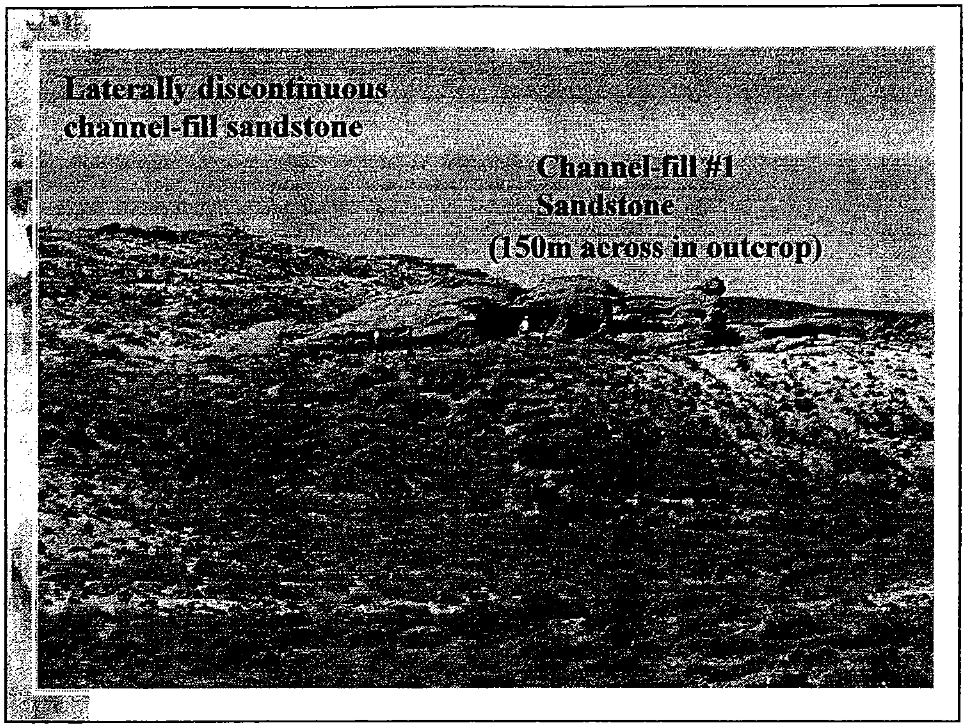


S1 and S2 are continuous Lewis sheet sandstones
CC is Lewis leveed channel complex on Spine I
F is shallow marine Fox Hills

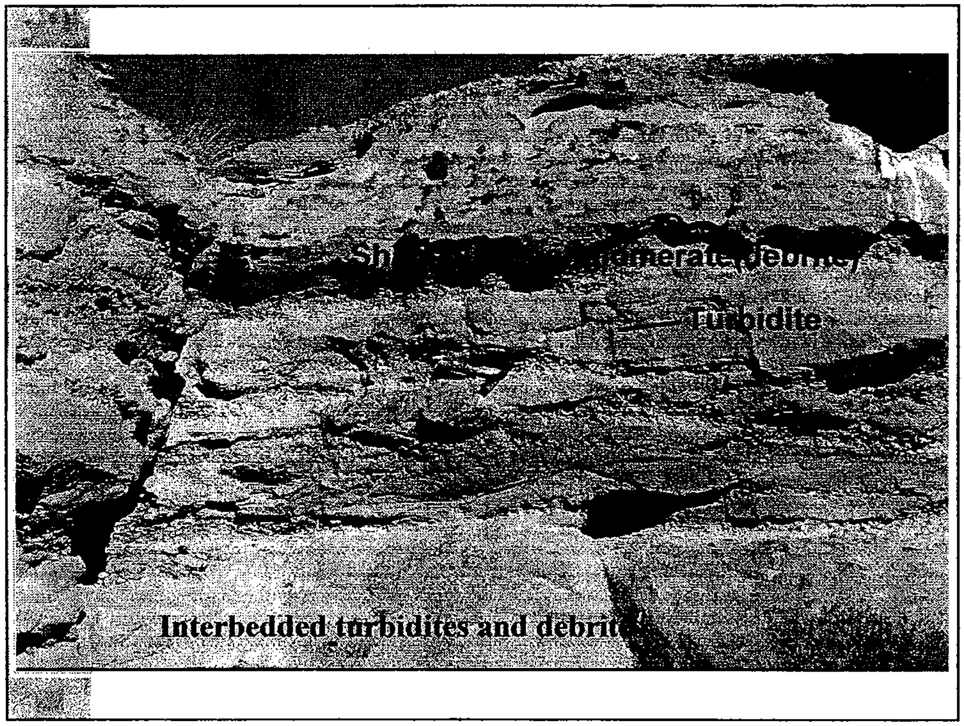


1996)

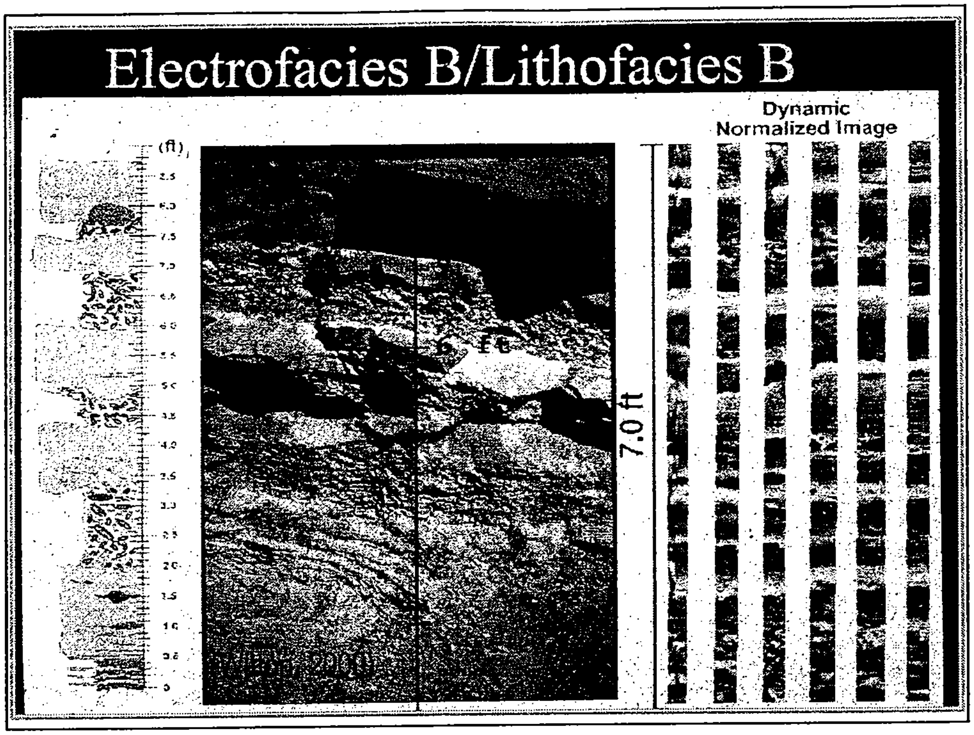




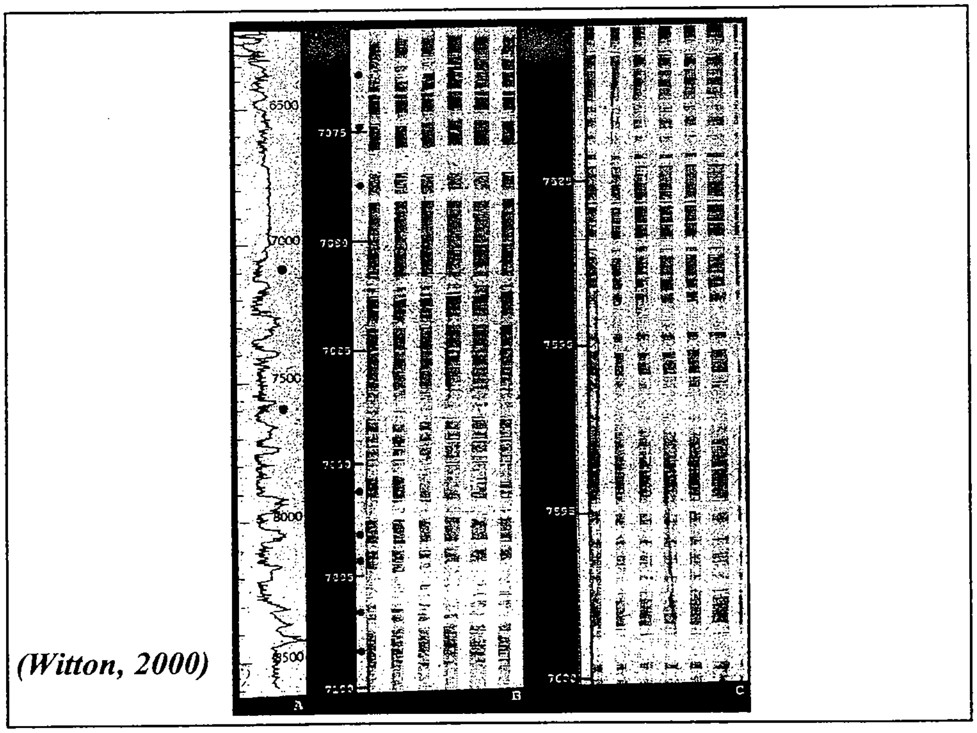
Laterally discontinuous channel-fill sandstone



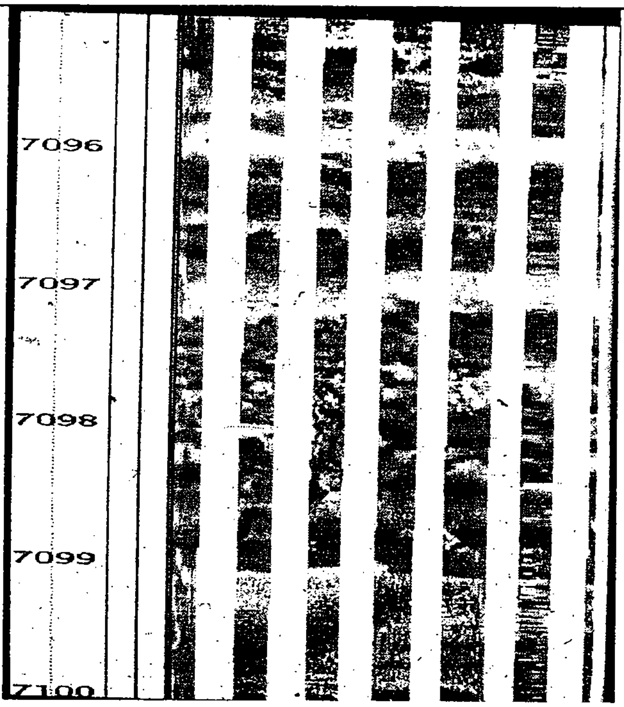
Interbedded turbidites and debrites



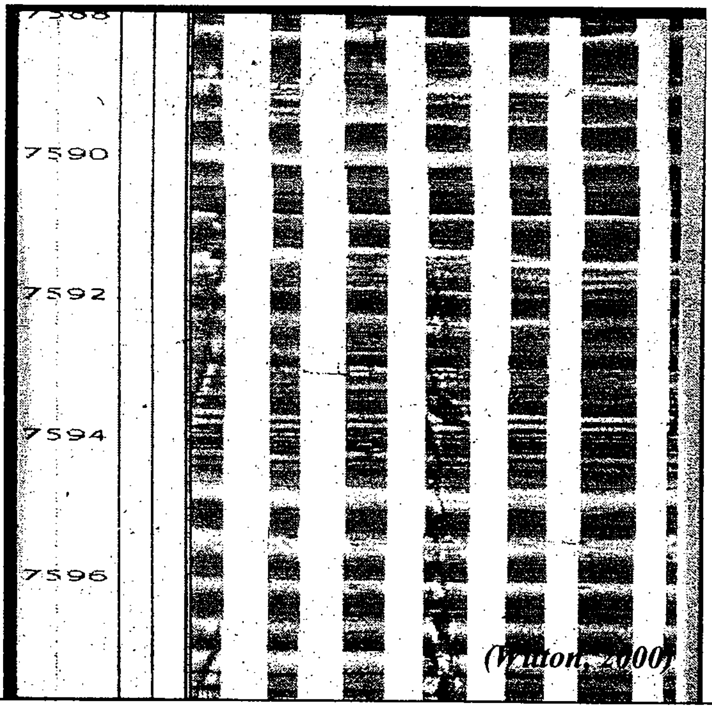
Electrofacies B/Lithofacies B



(Witton, 2000)



(Witton, 2000)



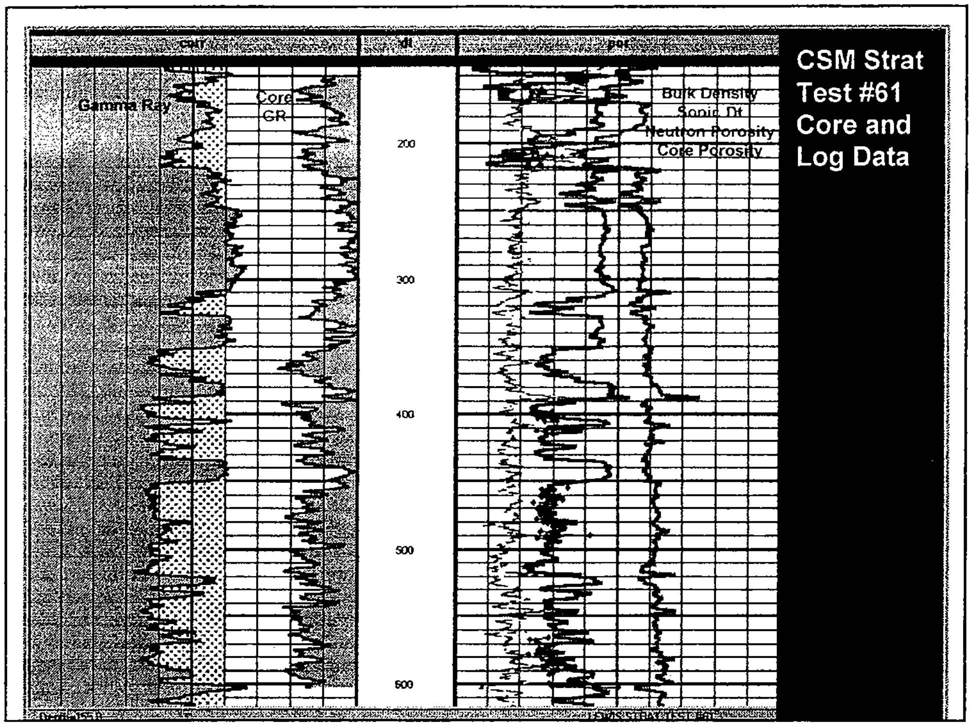
(Witton, 2000)

DIFFERENTIATING SHEET FROM CHANNEL SANDSTONES

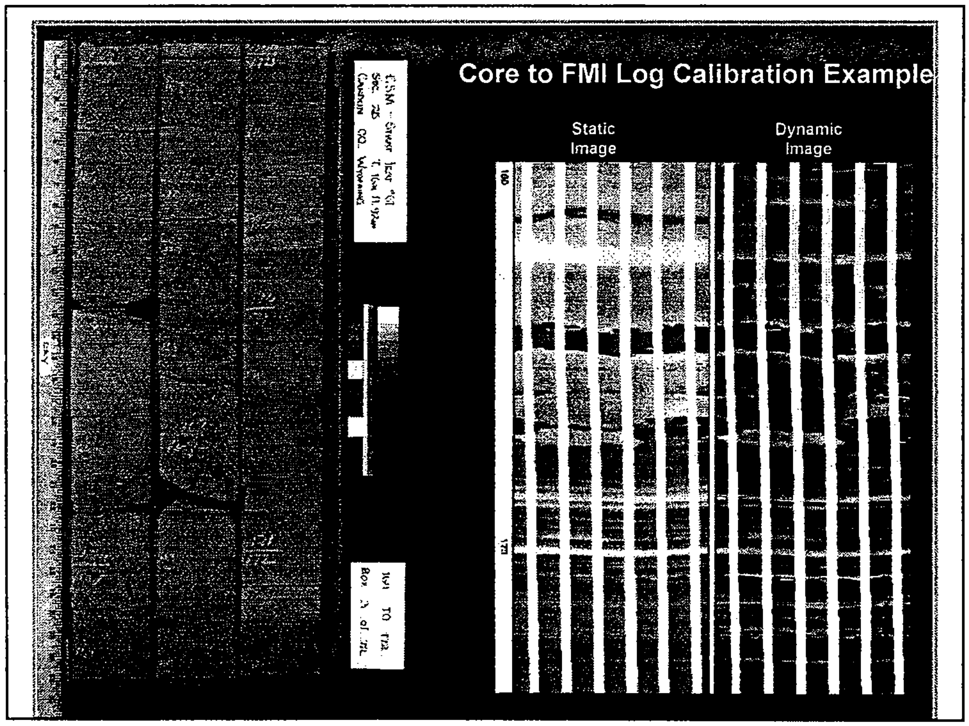
(Subseismic scale)

- PRESENCE OR ABSENCE OF COMMON SHALE RIP-UP CLASTS IN SANDSTONES
- SCOUR- vs. FLAT-BASED SANDSTONES
- INTERBEDDED DEBRITES AND TURBIDITES vs. TURBIDITES
- BOREHOLE IMAGE/CORE FEATURES
  - -Above features:
  - -Small scale continuities vs. discontinuities
  - -Vertical bed thickness/orientation trends
    (Hurley techniques)

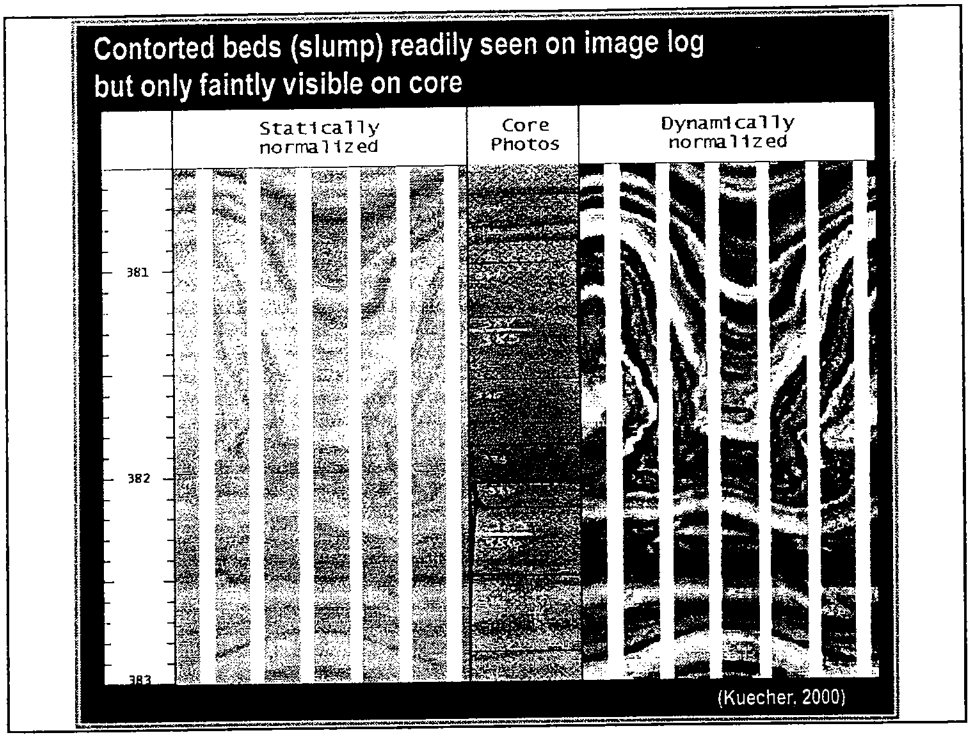
Behind-outcrop drilling for logs and core



CSM Strat Test #61 Core and Log Data

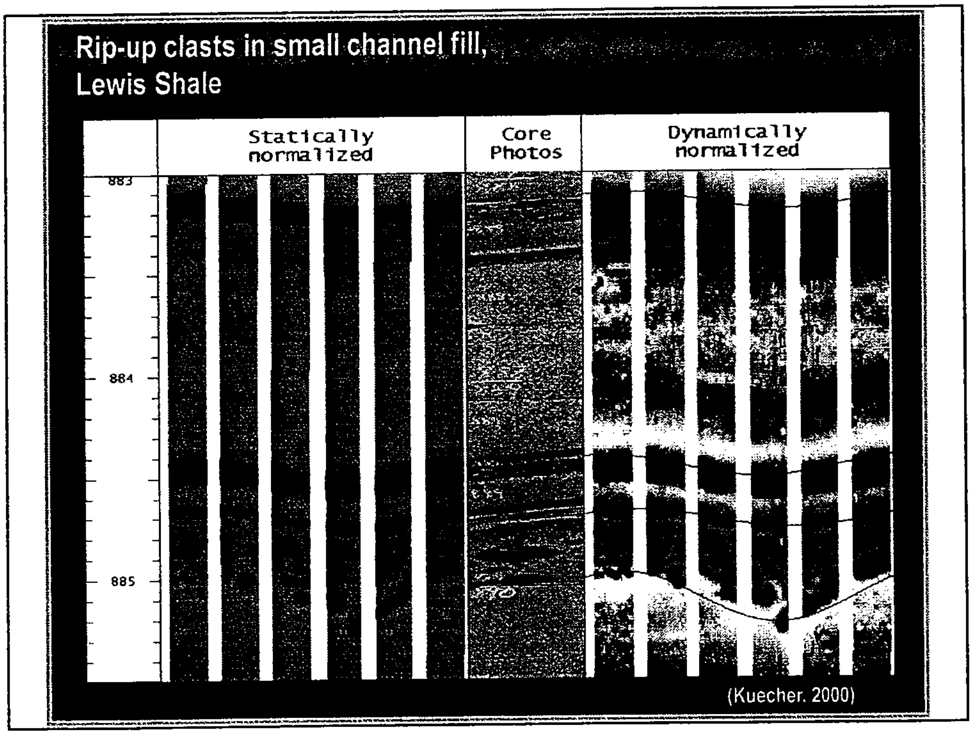


Core to FMI Log Calibration Example



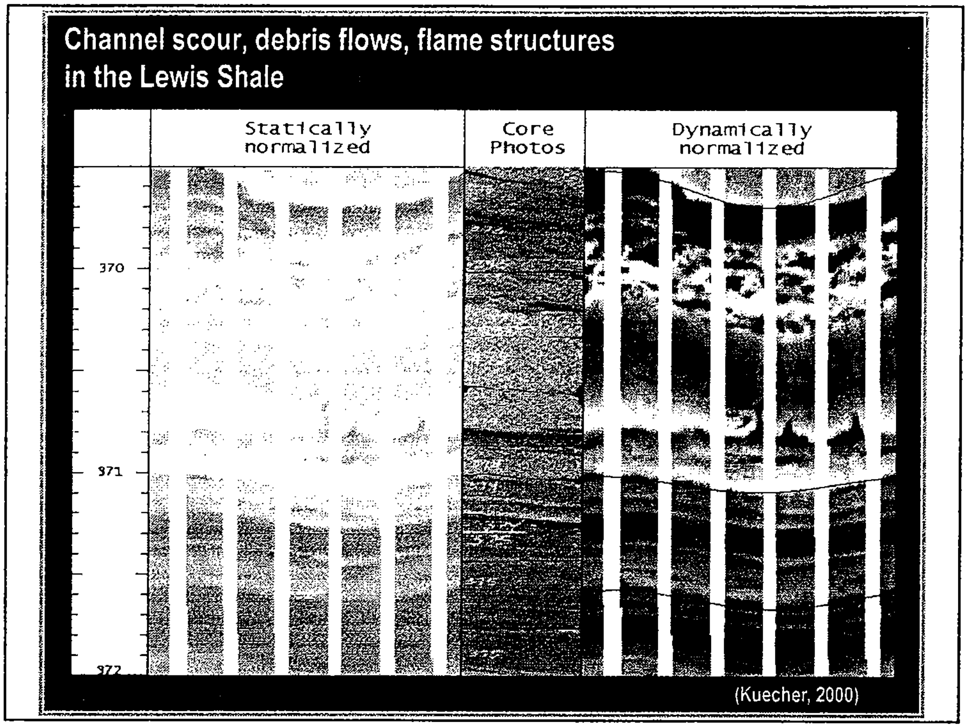
Contorted beds (slump) readily seen on image log but only faintly visible on core

(Kuecher, 2000)



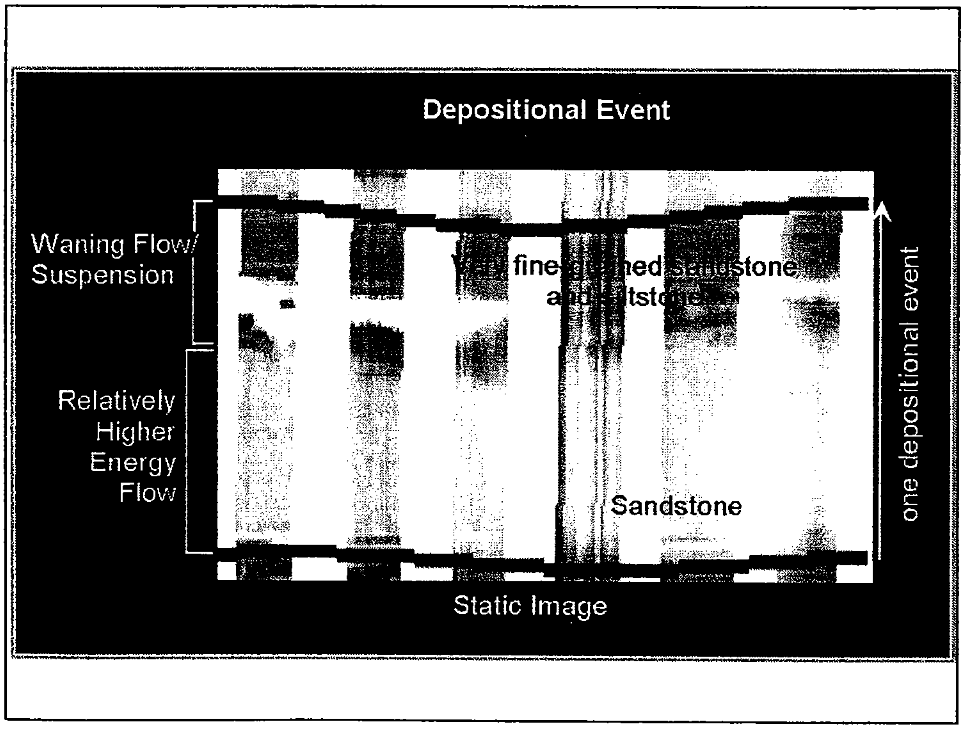
Rip-up clasts in small channel fill, Lewis Shale

(Kuecher, 2000)



Channel scour, debris flows, flame structures in the Lewis Shale

(Kuecher, 2000)



Depositional Event

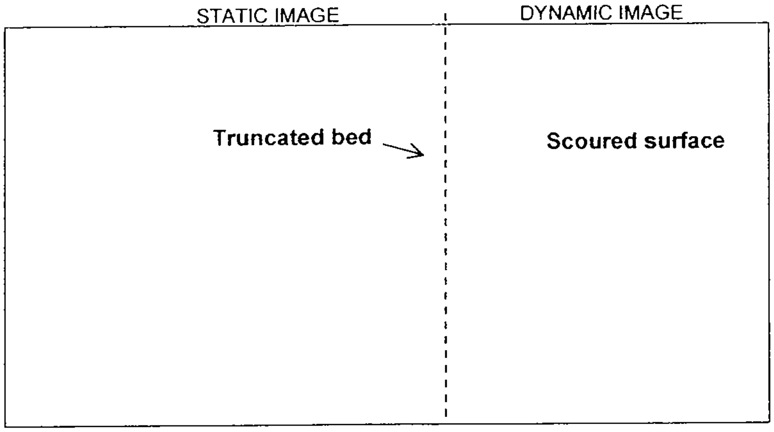


Figure 3.9 Image of a scoured surface in the Iverson well. The underlying bed was truncated by the scoured surface. Depth is in ft.

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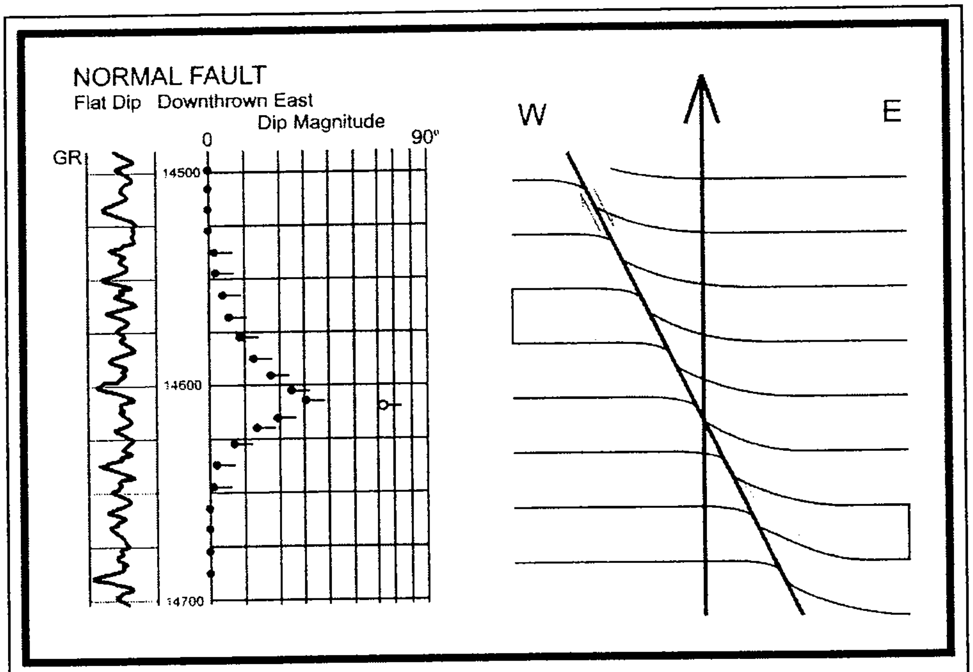
UNIT 11: BOREHOLE IMAGE LOGS AND APPLICATIONS

*UNIT 12: DIPMETER LOGS AND APPLICATIONS

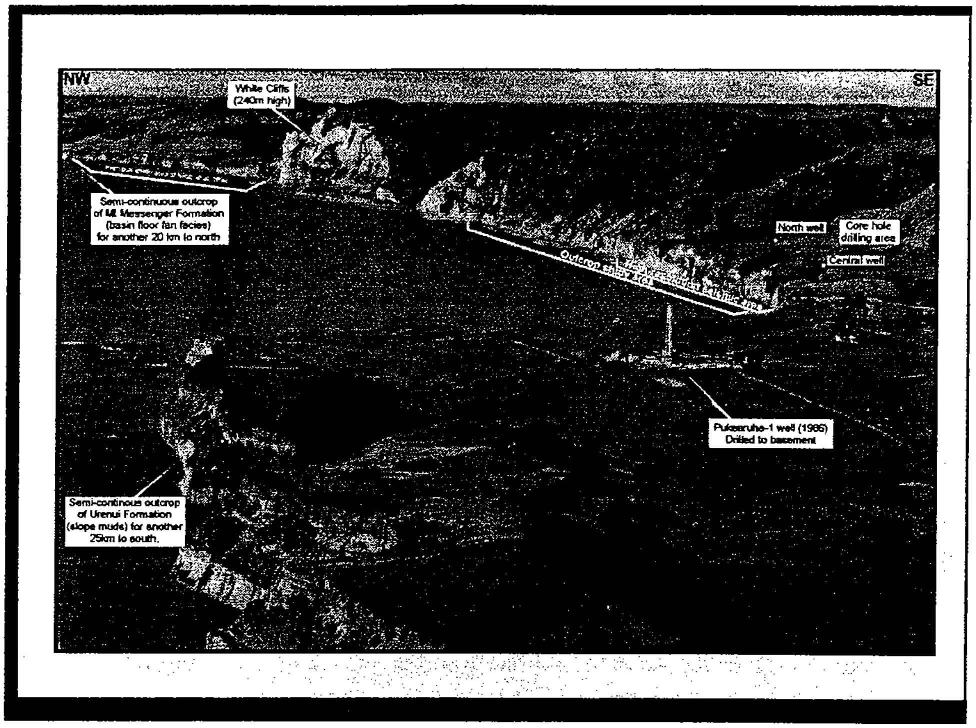
UNIT 13: STRUCTURALLY COMPARTMENTALIZED RESERVOIRS

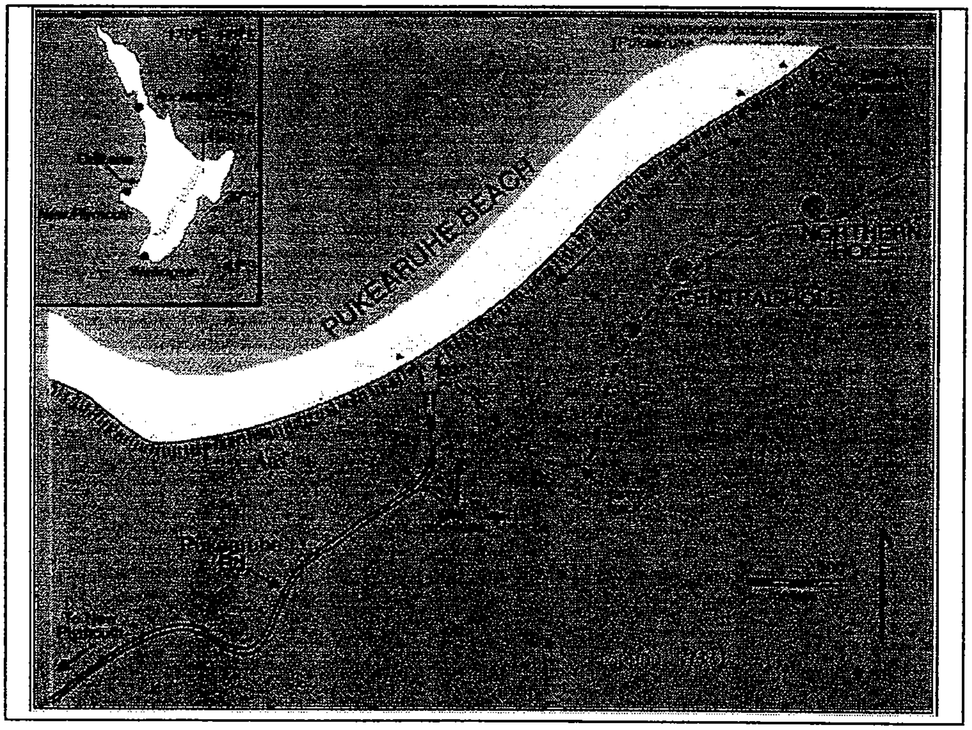
KEY REFERENCES TO INDIVIDUAL UNITS

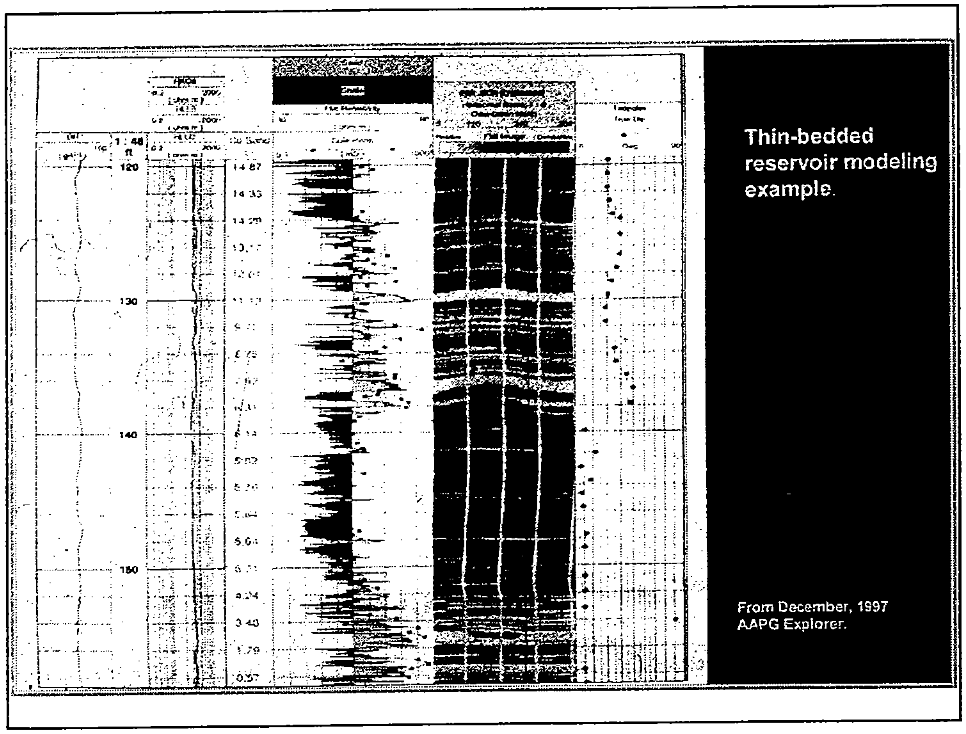
APPLICATIONS OF DIPMETER LOGS


NORMAL FAULT

Flat Dip Downthrown East

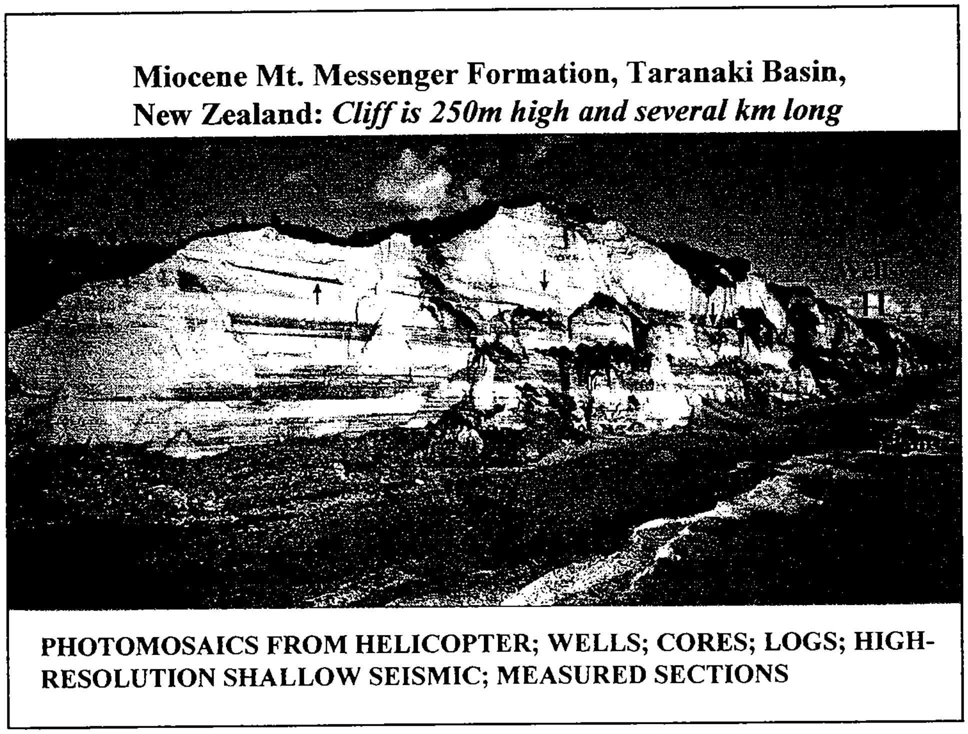

NW
SE
White Cliffs (240m high)
Semi-continuous outcrop of Mt Messenger Formation (basin floor fan facies) for another 20 km to north
Outcrop study area
North well
Core hole drilling area
Central well
Pukearuhe-1 well (1986) Drilled to basement
Semi-continous outcrop of Urenui Formation (slope muds) for another 25km to south.


PUKEARUHE BEACH



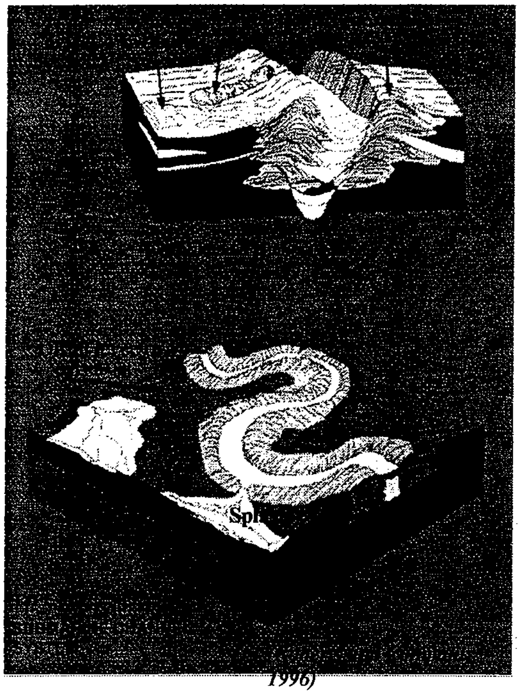
Thin-bedded reservoir modeling example.

From December, 1997 AAPG Explorer.

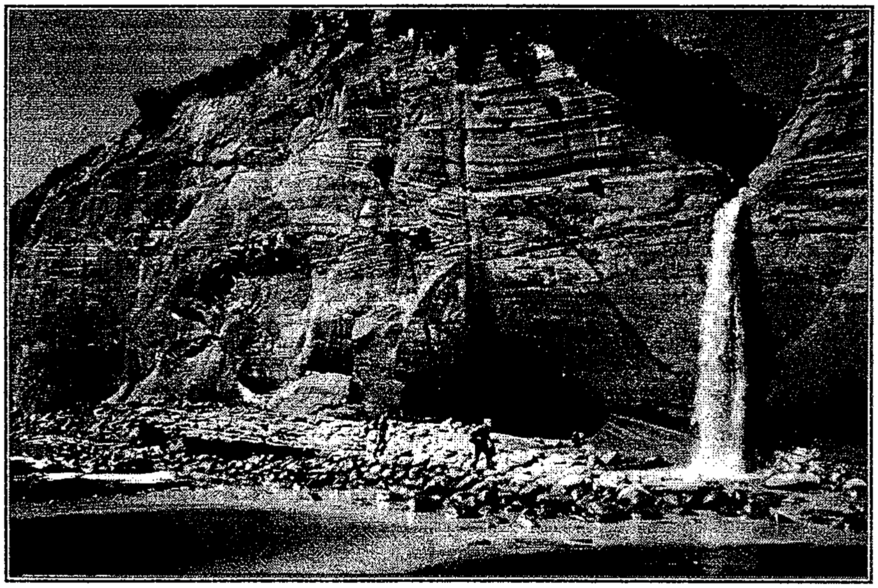


Miocene Mt. Messenger Formation, Taranaki Basin, New Zealand: *Cliff is 250m high and several km long*

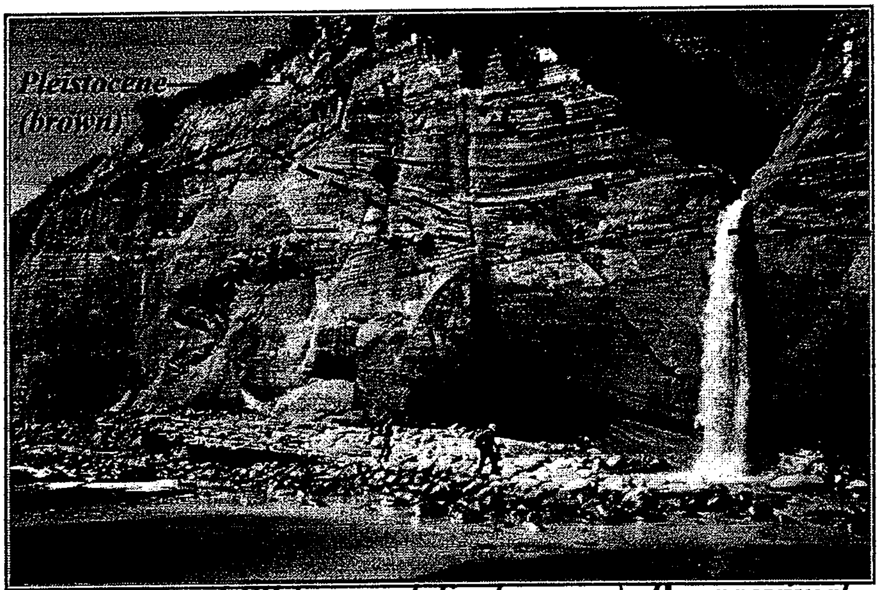
PHOTOMOSAICS FROM HELICOPTER; WELLS; CORES; LOGS; HIGH-RESOLUTION SHALLOW SEISMIC; MEASURED SECTIONS



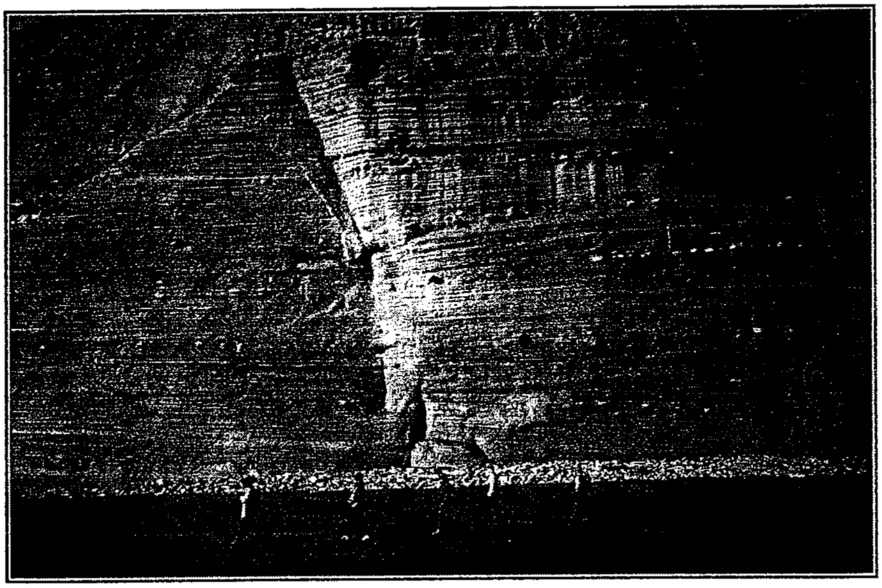
1996)

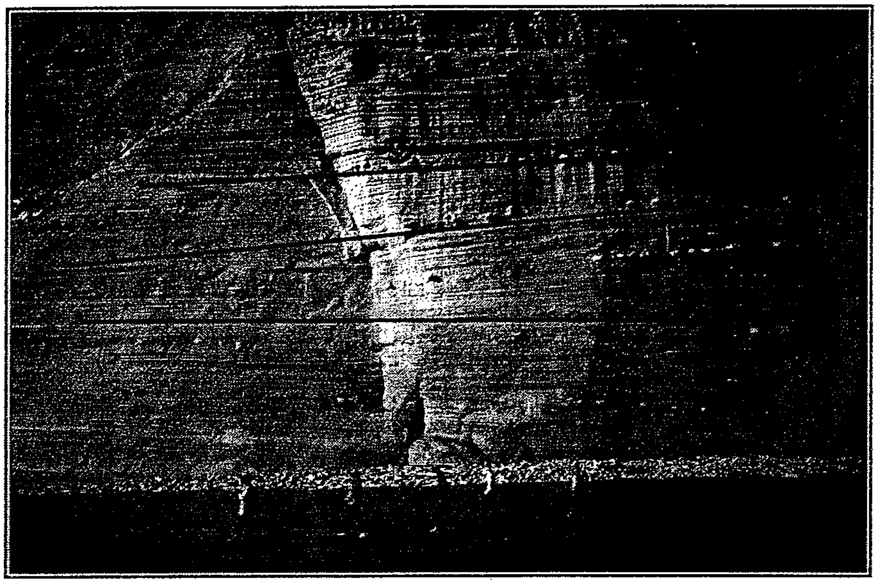


Depositional interval or bed scale



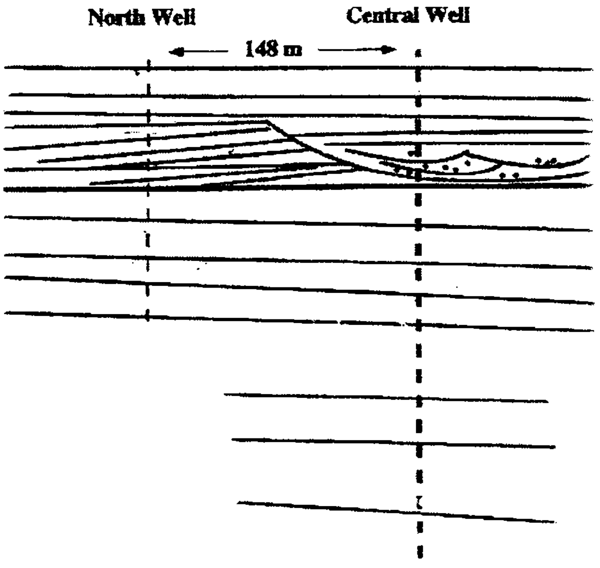
C = channel fill (upward dip decrease); P = proximal levee (high & variable angle dips); D = distal levee;





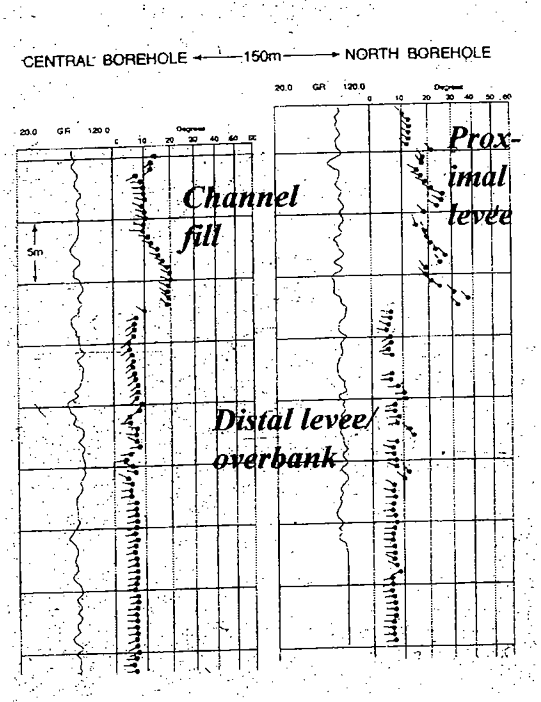
Distal levee bed sets (lower & uniform dip angles)

Bedding Style Model



(Spang, 1998)

Behind-outcrop dipmeter logs (by Schlumberger)



Channel fill

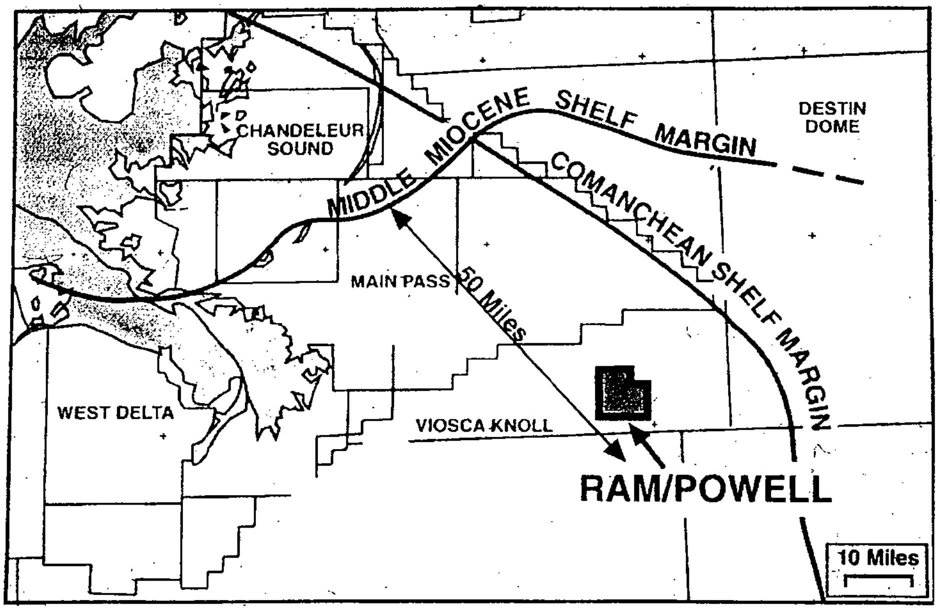
Proximal levee

Distal levee/ overbank

(Slatt et al., 1998)

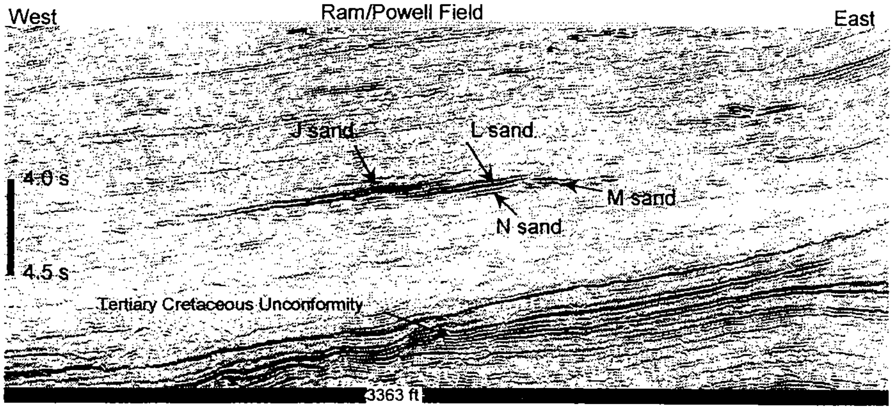
LEVEE FACIES

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



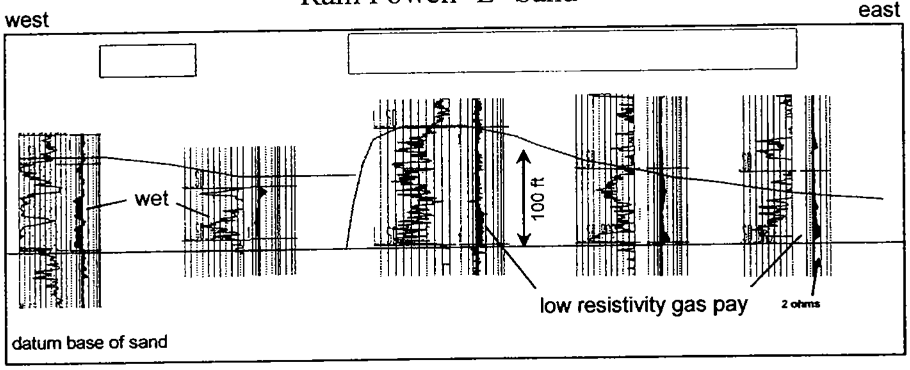
(Clemenceau et al., 1995)

L Sand, Ram/Powell Field, Gulf of Mexico: comprises channel, proximal, & distal levee facies.



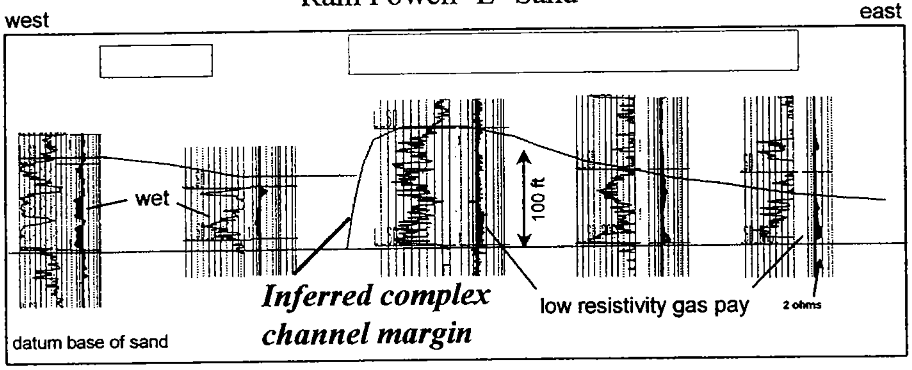
(Clemenceau et al., 2000)

Ram Powell ‘L’ Sand



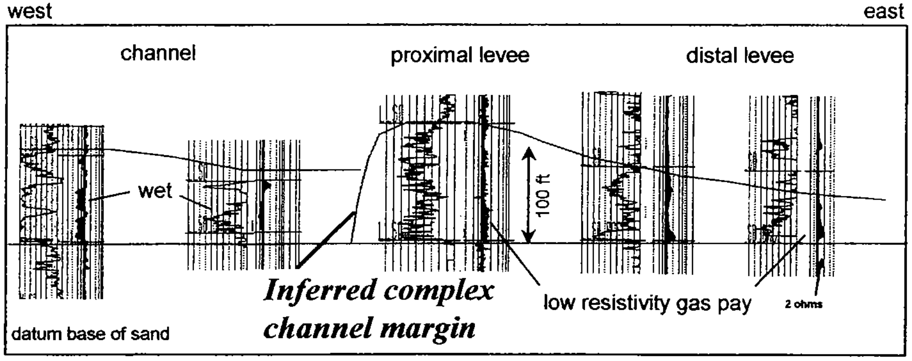
(Clemenceau et al, 2000)

Ram Powell ‘L’ Sand

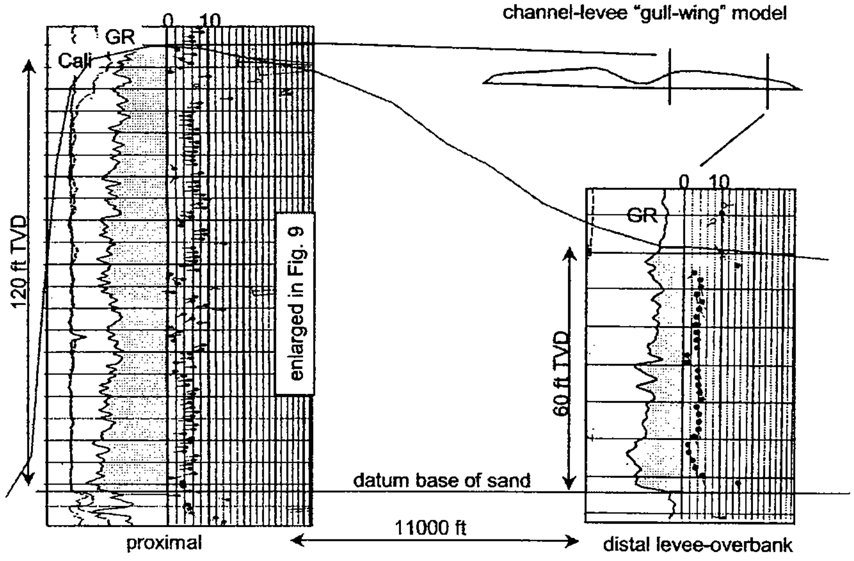


(Clemenceau et al, 2000)

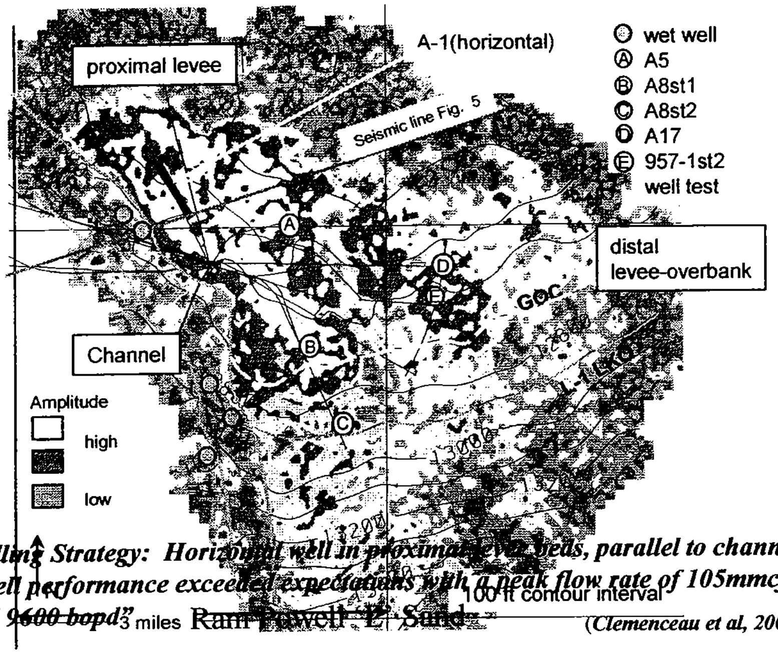
Ram Powell ‘L’ Sand



(Clemenceau et al, 2000)

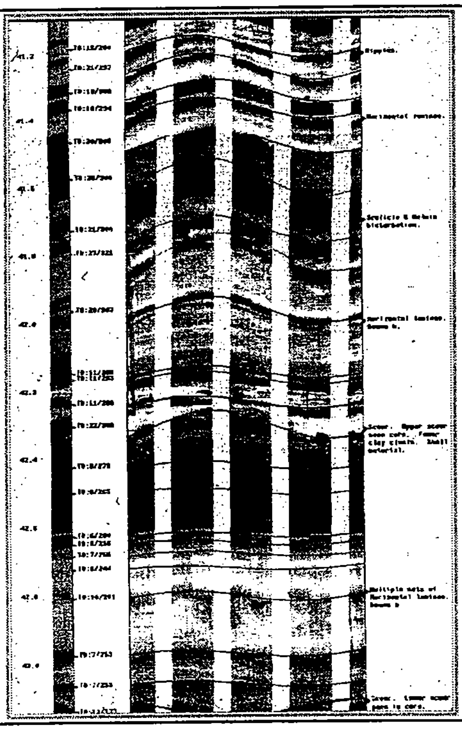


(Clemenceau et al., 2000)



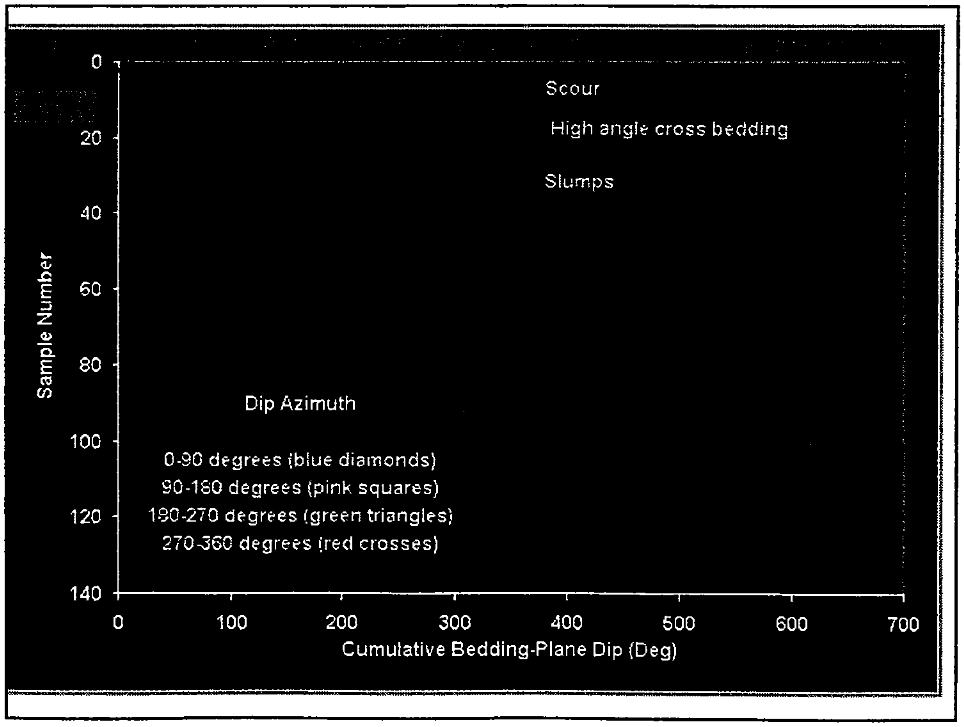
Drilling Strategy: Horizontal well in proximal levee beds, parallel to channel: "Well performance exceeded expectations with a peak flow rate of 105mmcfgd and 9600 bopd"

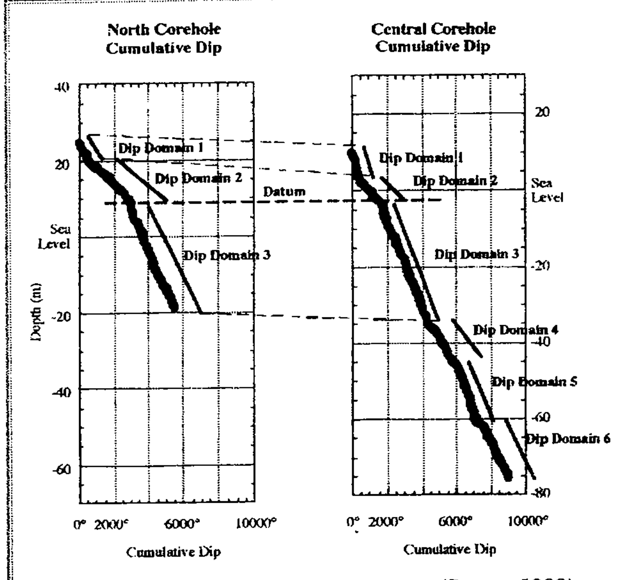
(*Clemenceau et al, 2000*)



CUMULATATIVE DIP MAGNITUDE AND DIRECTION CALCULATIONS

Sample	Depth (ft.)	Dip (°)	Cum. Dip (°)	Dip Dir. (°)
1	3767	2	2	257
2	3775	6	8	221
3	3776	5	13	240
4	3782	4	17	247
5	3791	4	21	234
6	3793	3	24	226
7	3797	5	29	230





(Spang, 1998)

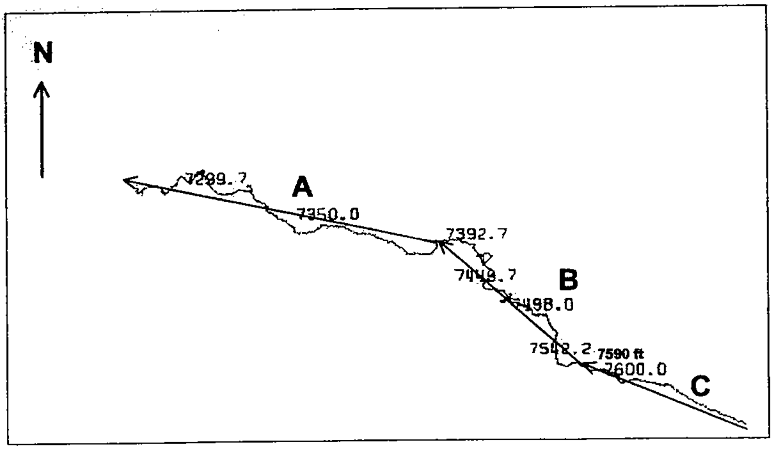


Figure 4.3 Vector plot for beds with gamma ray value > 80 API unit in the Dad and upper member of the Lewis Shale in the Pilgrim Federal well. The beds are dipping to the west-northwest. Inflection points are shown. Depth is in ft.

MODIFIED FISCHER PLOT

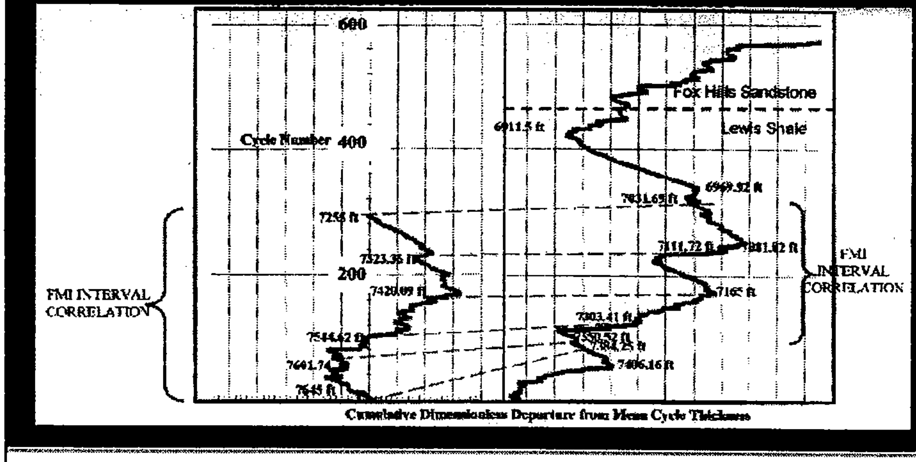
Cycle No.	Cycle Top (ft.)	Cycle Thick (ft.)	Depart. from MCT	Dim. Depart from MCT	Cum. Dim Depart. from MCT
283	14036	0.88	0.21	0.31	
282	14037	0.24	-0.43	-0.64	

260	14045	0.43	-0.24	-0.35	0.50
259	14045	0.78	0.12	0.18	0.85
258	14046	1.12	0.45	0.67	0.67

- •Mean Cycle Thickness (MCT) for this sequence = 0.67ft.
- •Dimensionless Departure from MCT =Depart./MCT
- •Cum. Dimensionless Depart from MCT starts at bottom of sequence

---

Two wells--5 miles apart...



BOREHOLE IMAGE AND DIPMETER LOGS

- PROVIDES ELECTRICAL/ACOUSTIC IMAGE OF BOREHOLE WALL

- WATER-BASED OR SYNTHETIC MUDS REQUIRED
  - OBMI Log (^{TM} Schlumberger)
- FIRST USED TO OBSERVE FAULTS AND FRACTURES

- NOW USED FOR SEDIMENTARY/STRATIGRAPHIC INTERPRETATION; PROVIDES INFORMATION ON BEDDING AND STRATIFICATION STYLES, BED CONTINUITY AWAY FROM WELLBORE, ETC.

- DIPMETER DATA CAN BE USED FOR CORRELATION AND INTERPRETATION PURPOSES

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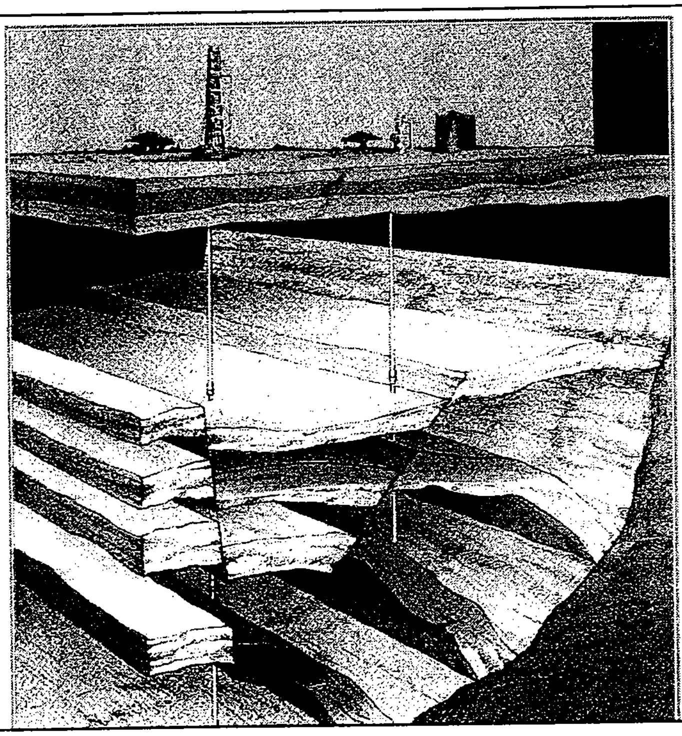
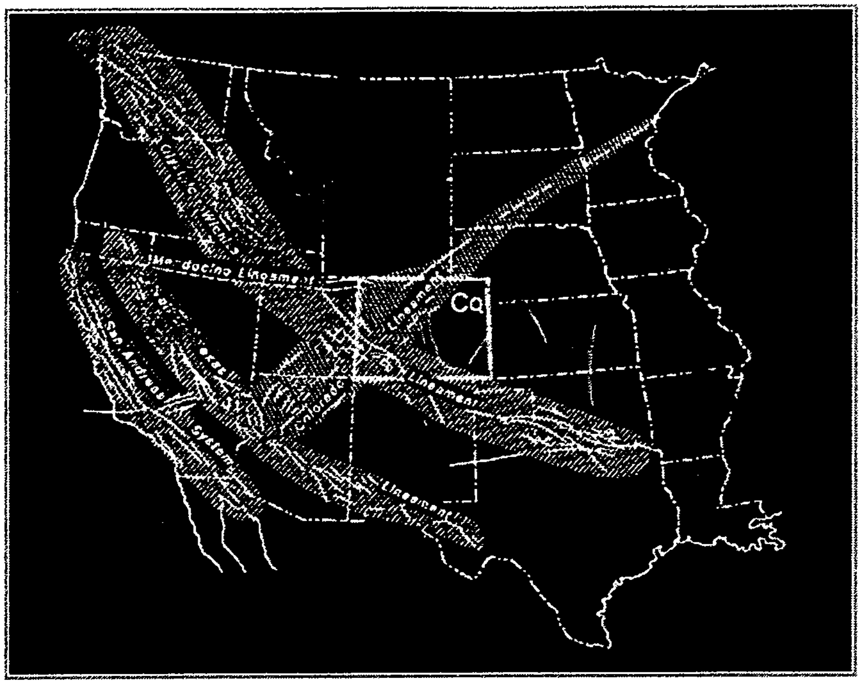
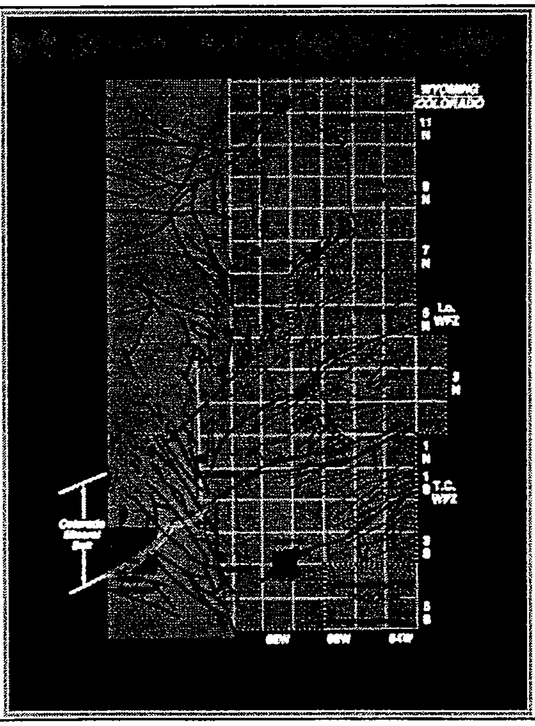
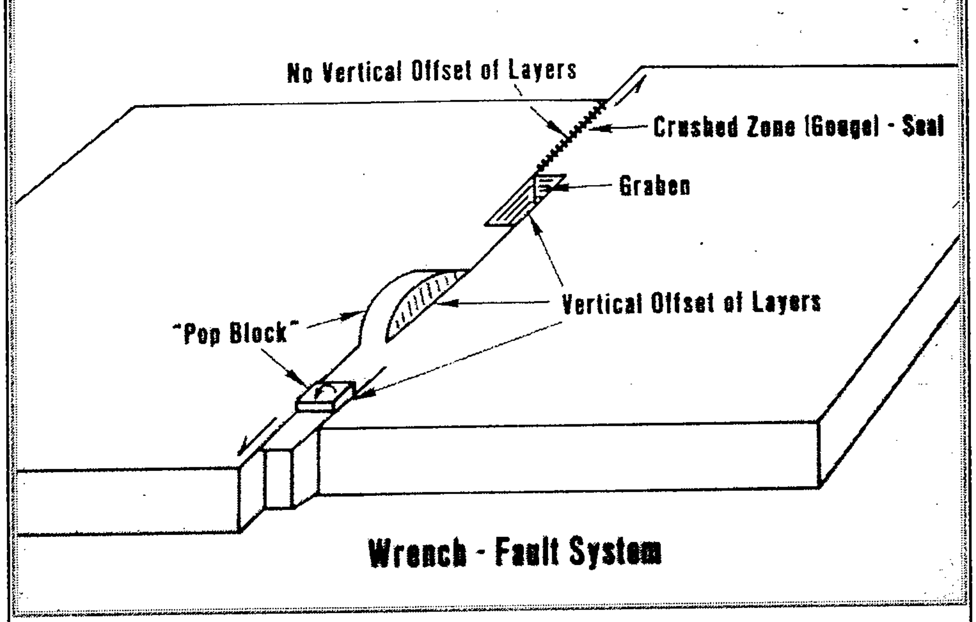
STRUCTURAL COMPARTMENTALIZATION

- ROCKY MOUNTAIN EXAMPLES
- MORE COMMON THAN PREVIOUSLY THOUGHT

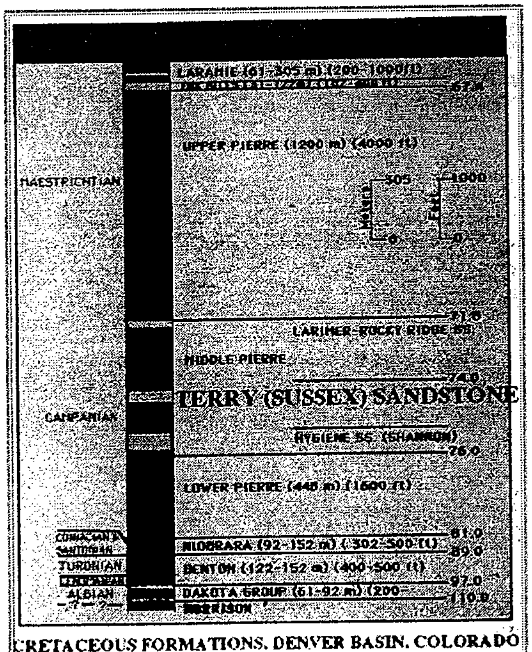



Olympic Wichita
Mendocino Lineament
Lineament
Cq
San Andreas
System
Colorado
Lineament
Lineament

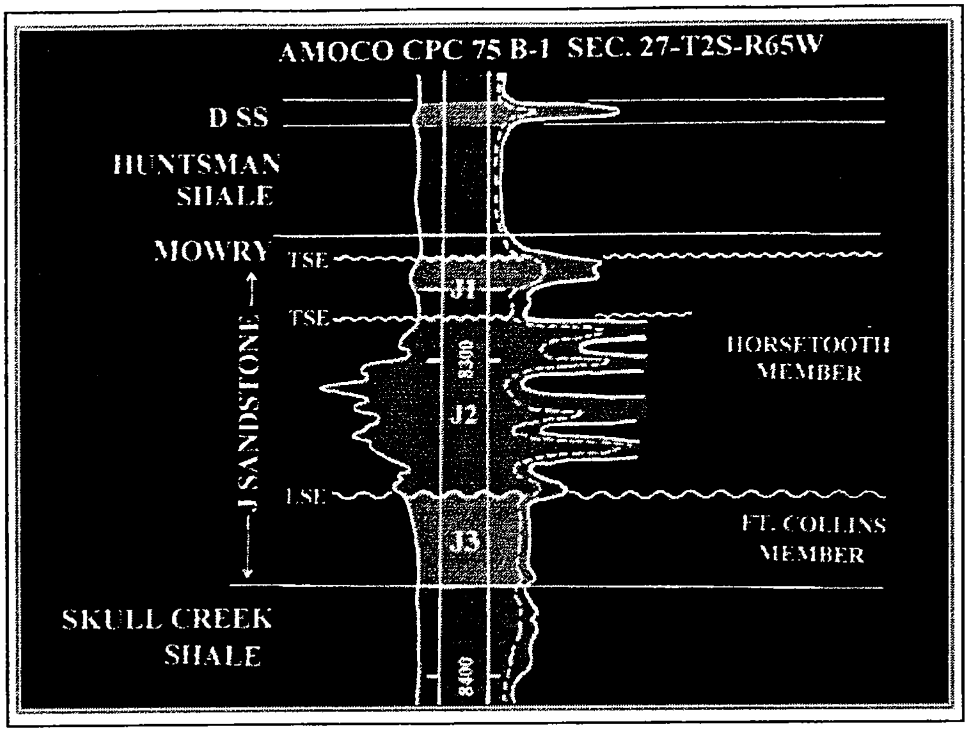

WYOMING
COLORADO
11 N
9 N
7 N
5 N
Lo. WFZ
3 N
1 N
1 S
T.C. WFZ
3 S
5 S
Colorado Mineral Belt
68W
66W
64W

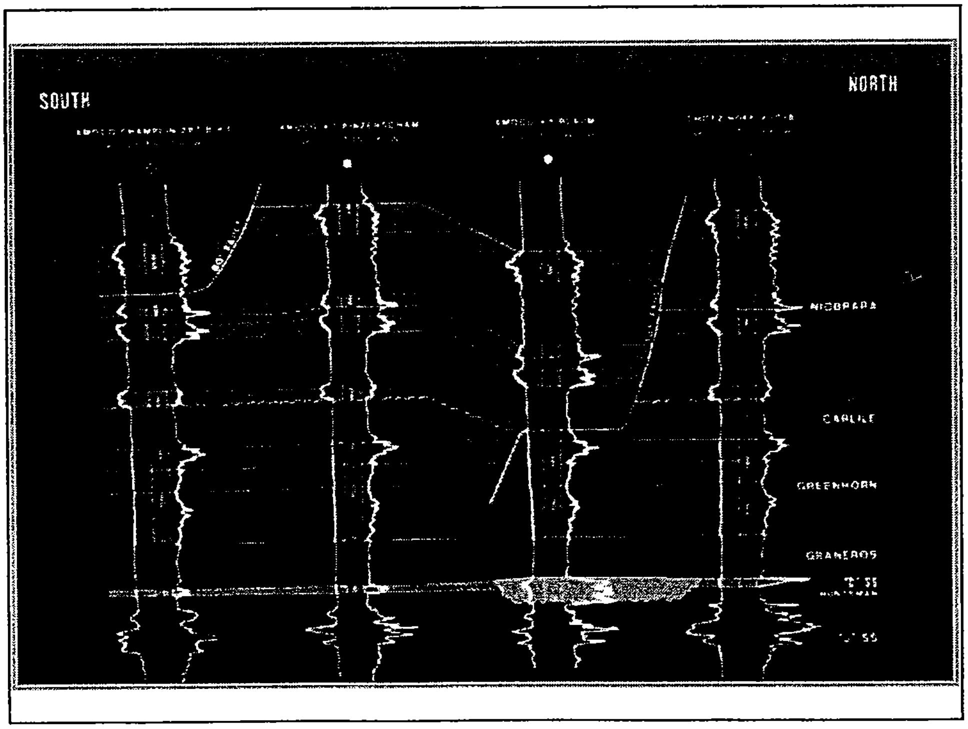


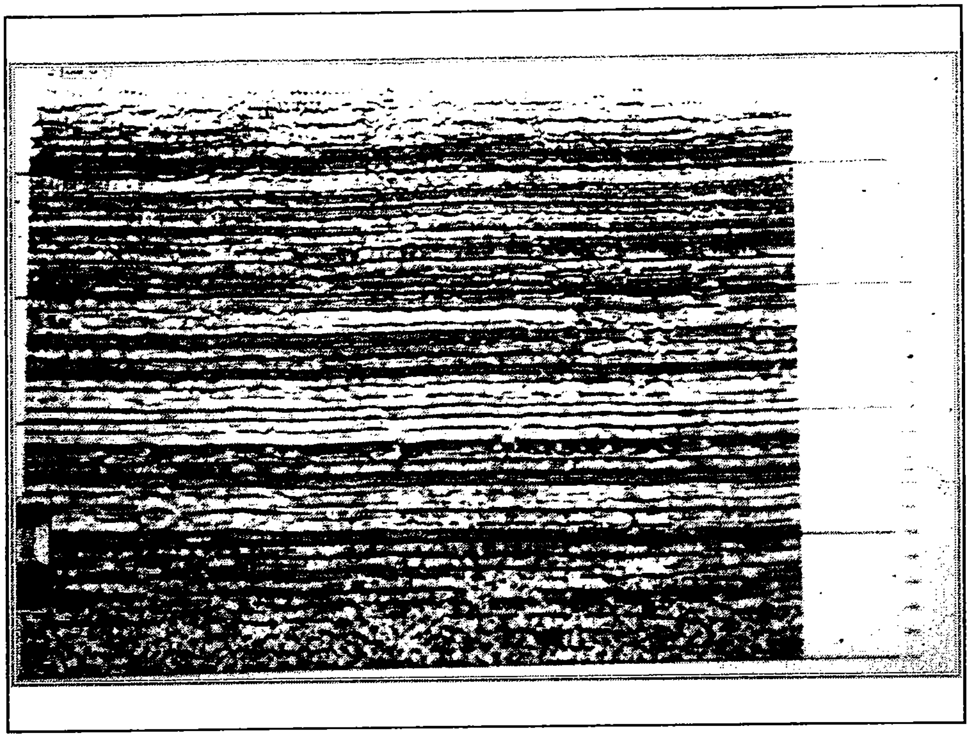
Wrench - Fault System

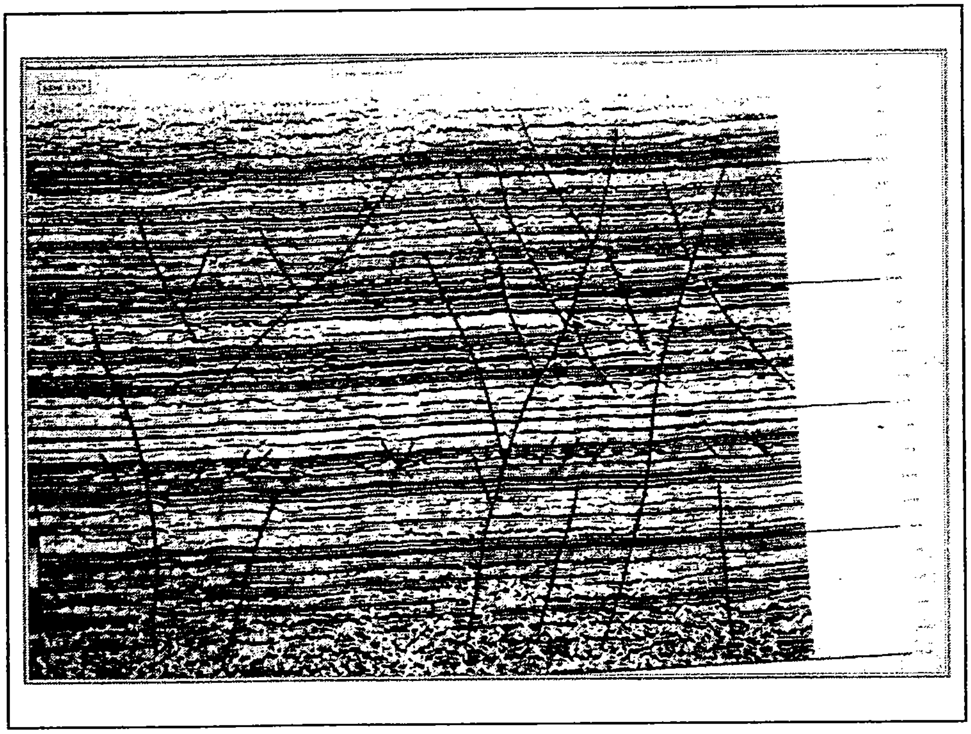


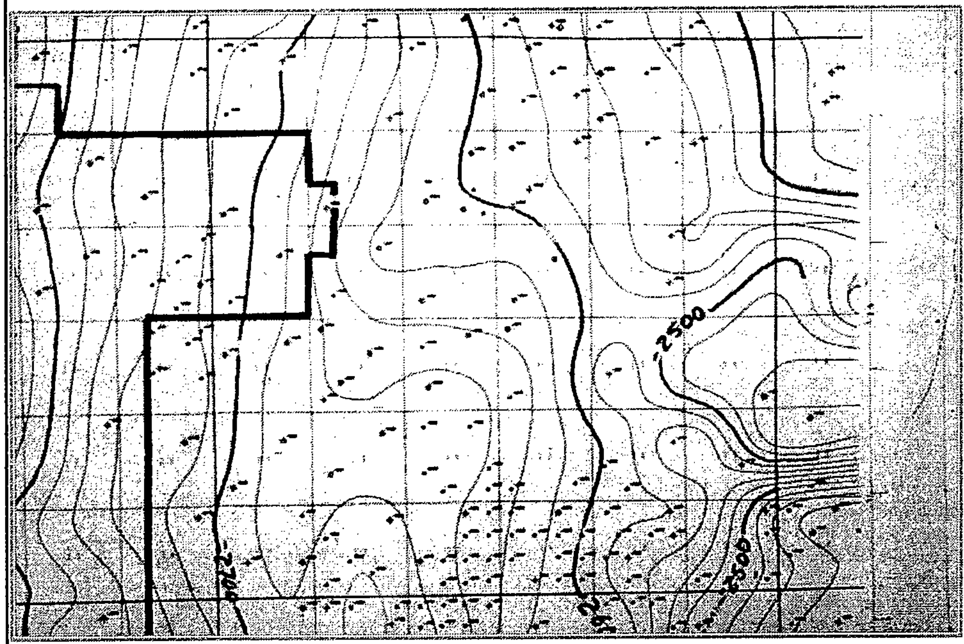
CRETACEOUS FORMATIONS, DENVER BASIN, COLORADO (after Porter and Weimer, 1982).


AMOCO CPC 75 B-1 SEC. 27-T2S-R65W
D SS
HUNTSMAN SHALE
MOWRY
TSE
J1
TSE
J SANDSTONE
8300
J2
HORSETOOTH MEMBER
LSE
J3
FT. COLLINS MEMBER
SKULL CREEK SHALE
8400


SOUTH
NORTH
NIOBRARA
CARLILE
GREENHORN
GRANEROS
"D" SS
HUNTSMAN
"J" SS



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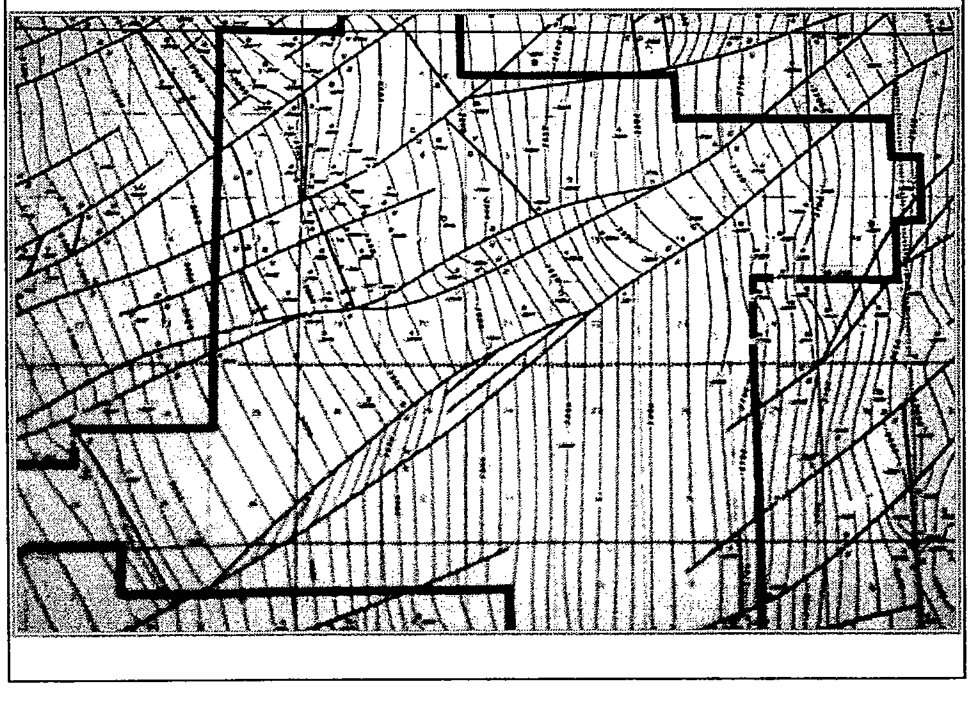
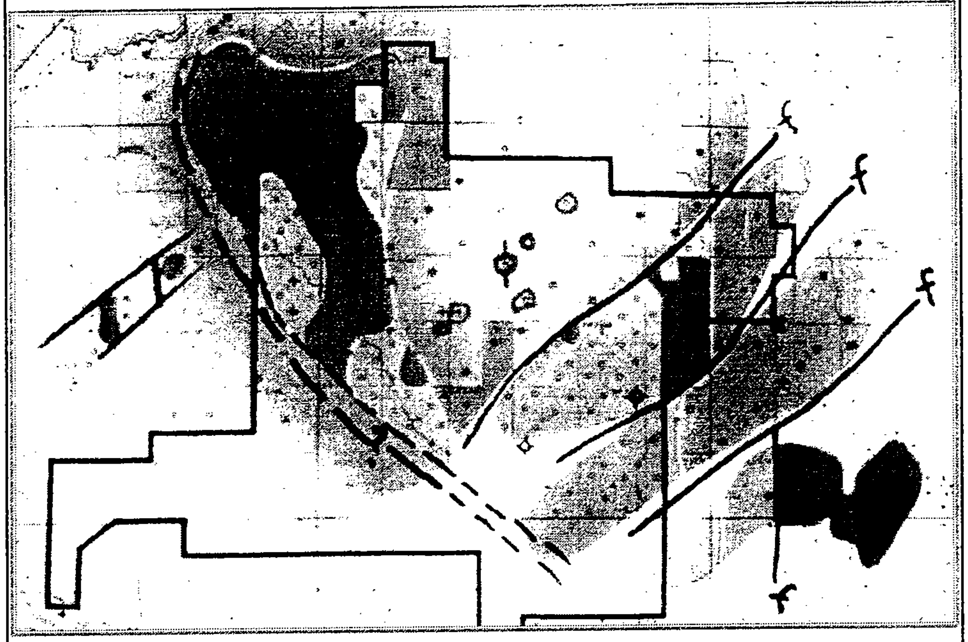
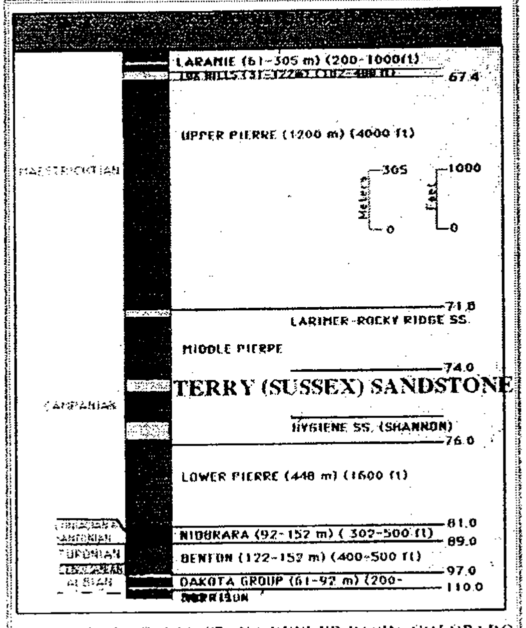
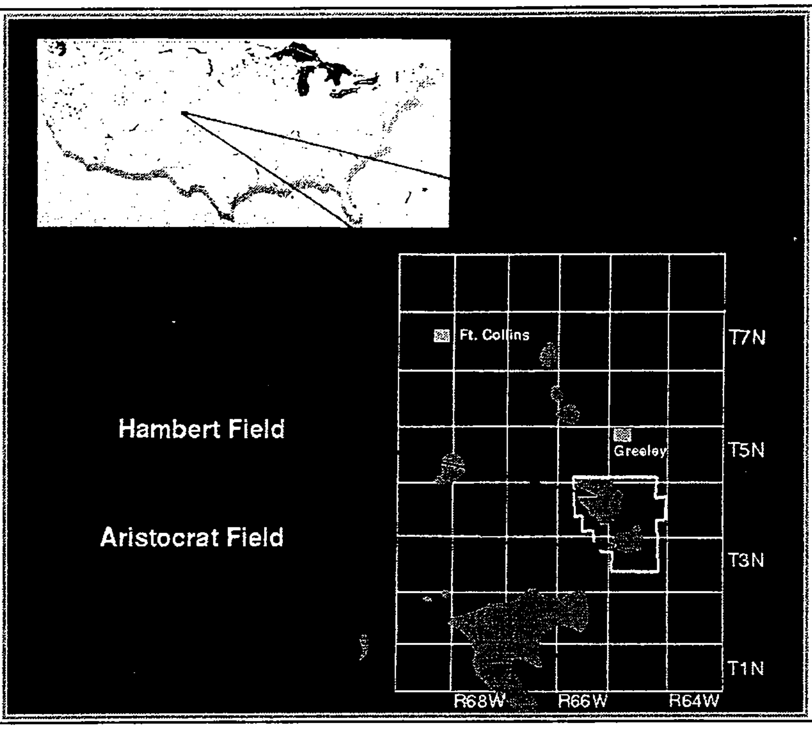
-2500
-2700





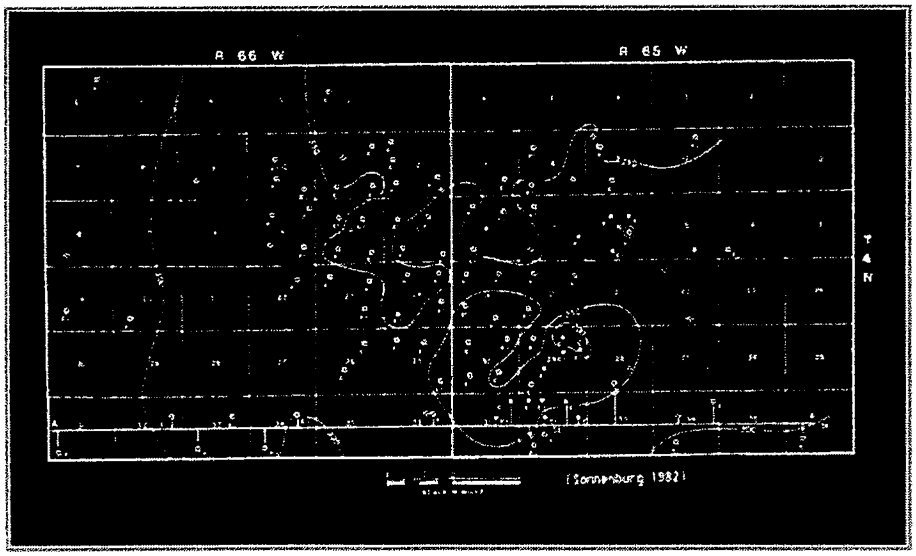


CRETACEOUS FORMATIONS, DENVER BASIN, COLORADO after Porter and Weimer, 1982).

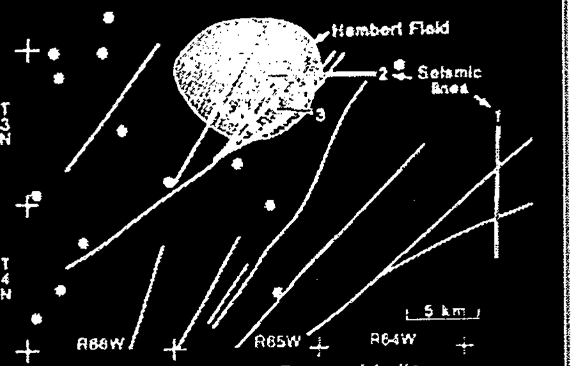


Hambert Field

Aristocrat Field



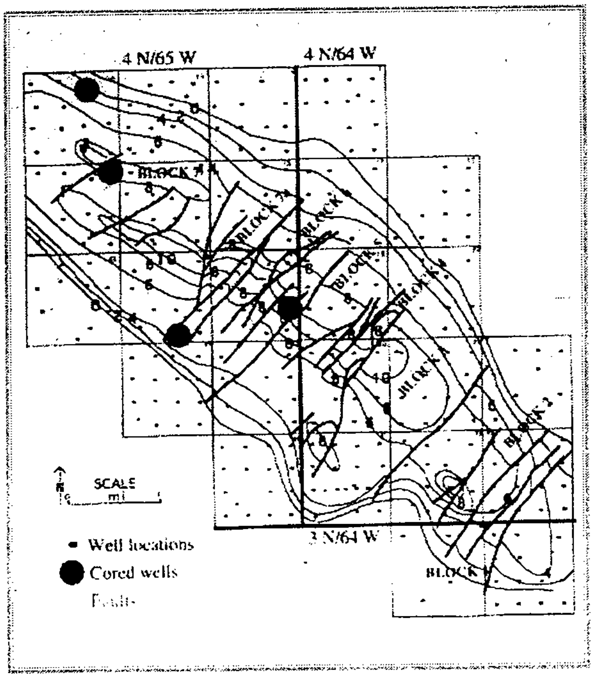
(Sonnenburg 1982)

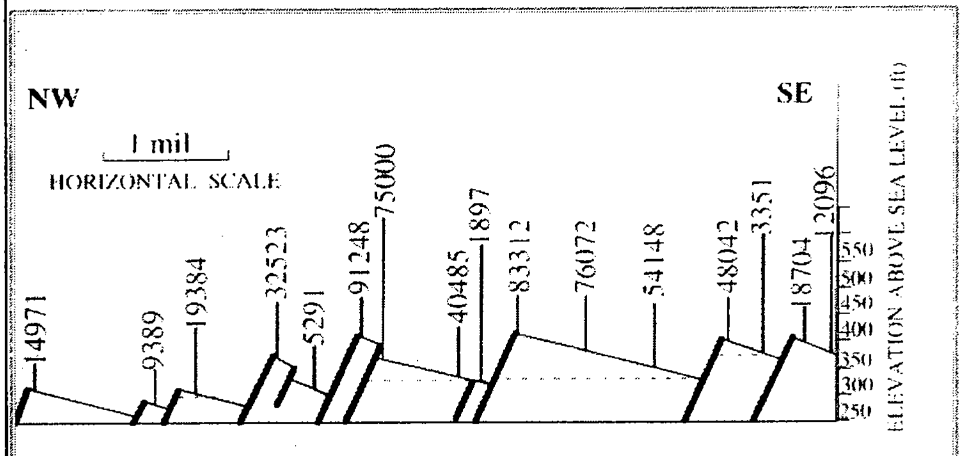


Tectonic Map - Basement faults

Basement fault map interpreted from a regional grid of seismic control. Substantially more seismic data than just the 3 lines shown in this figure were used to delineate the fault zones. Faults were inferred by observing subtle drape, listric normal faults, lack of reflection continuity near basement, diffractions, etc.

(Davis, 1985)

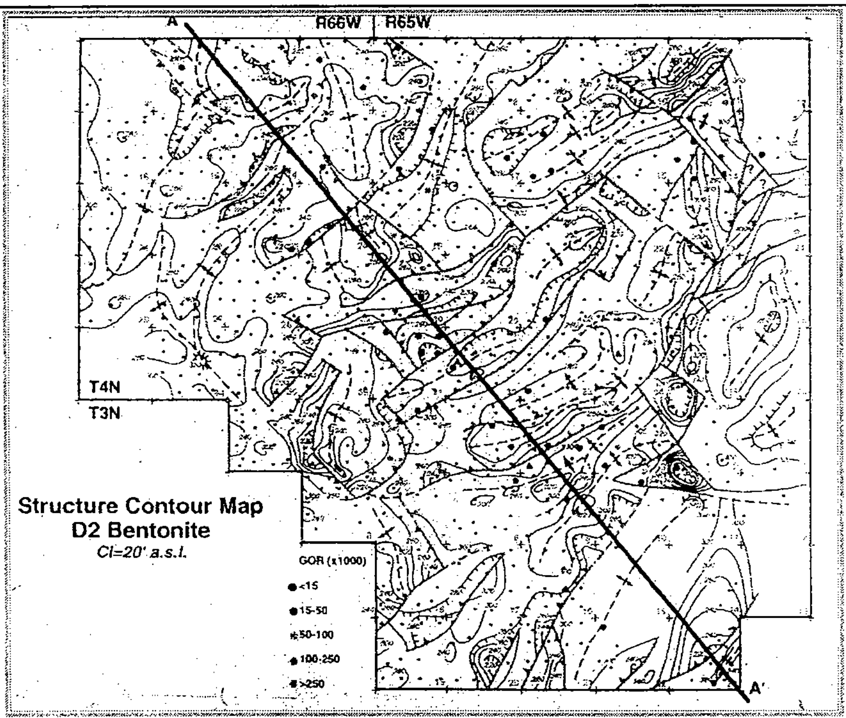




523: Normalized GOR values (cf/bbl) based on first year of prouduction

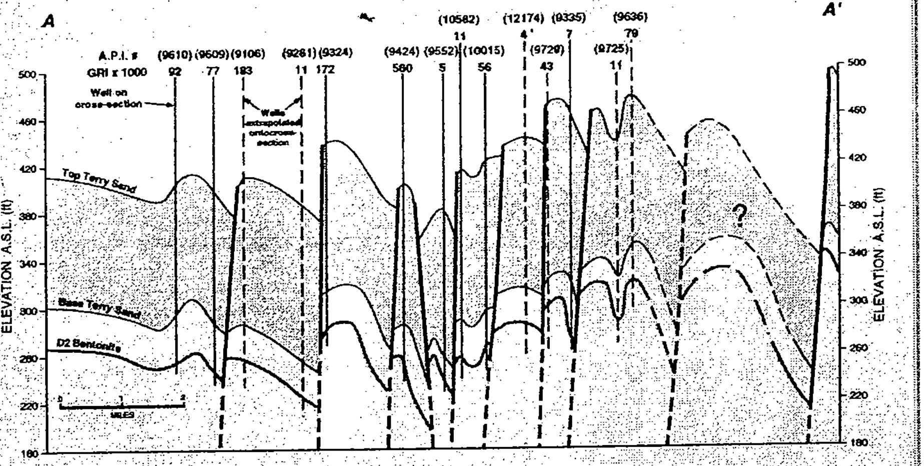
- - - : Interpreted line for GOR = 15,000cf/bbl

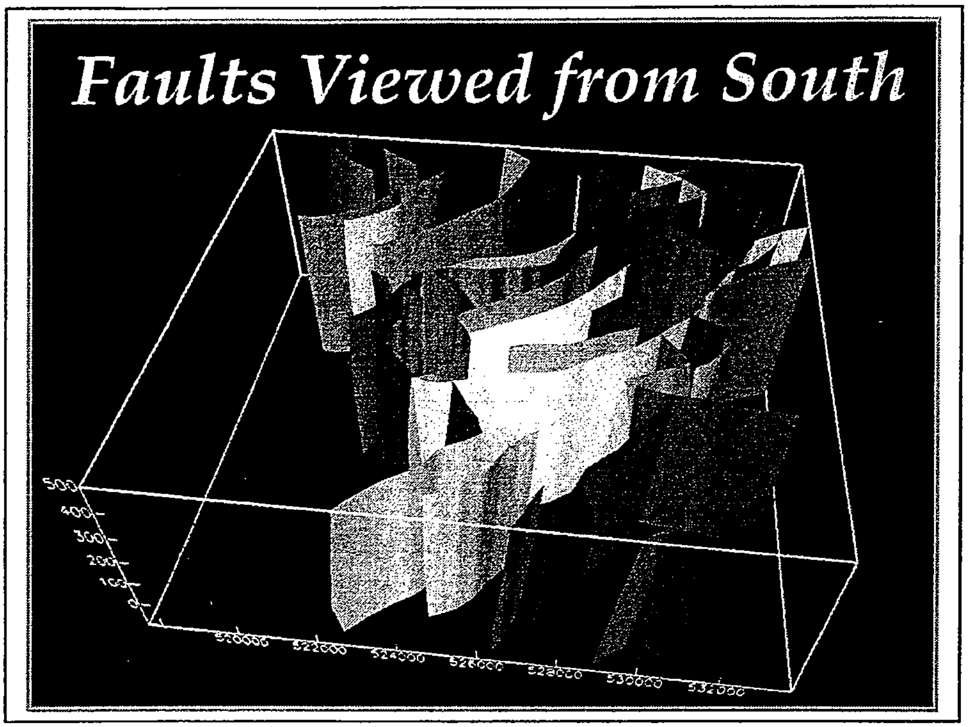
/ : Fault



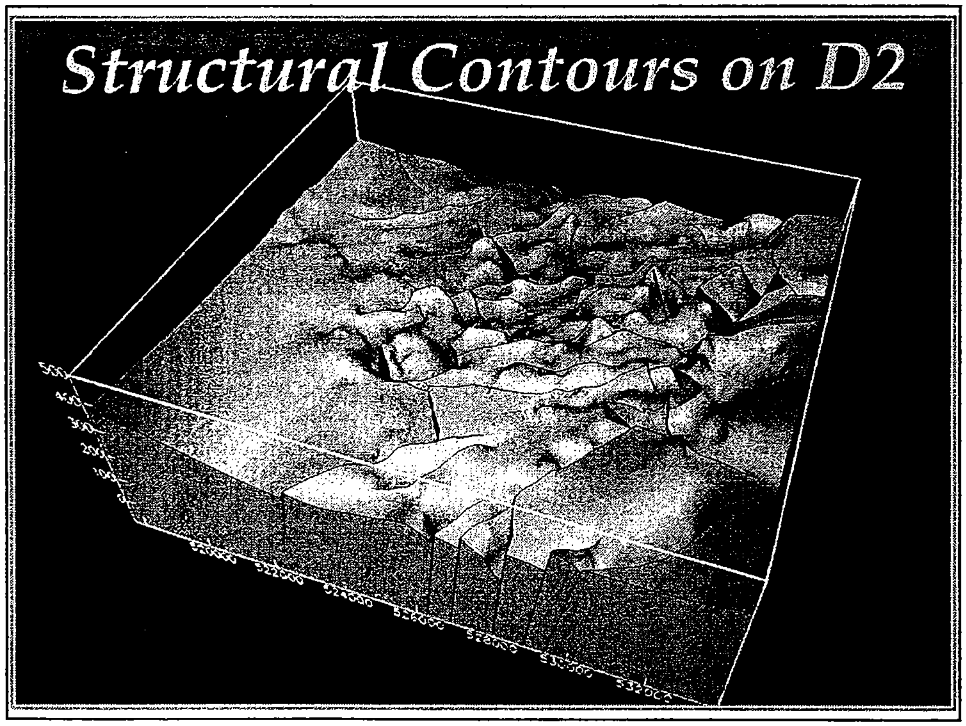
Structure Contour Map
D2 Bentonite
CI=20' a.s.l.

STRUCTURE CROSS-SECTION ON D2 BENTONITE

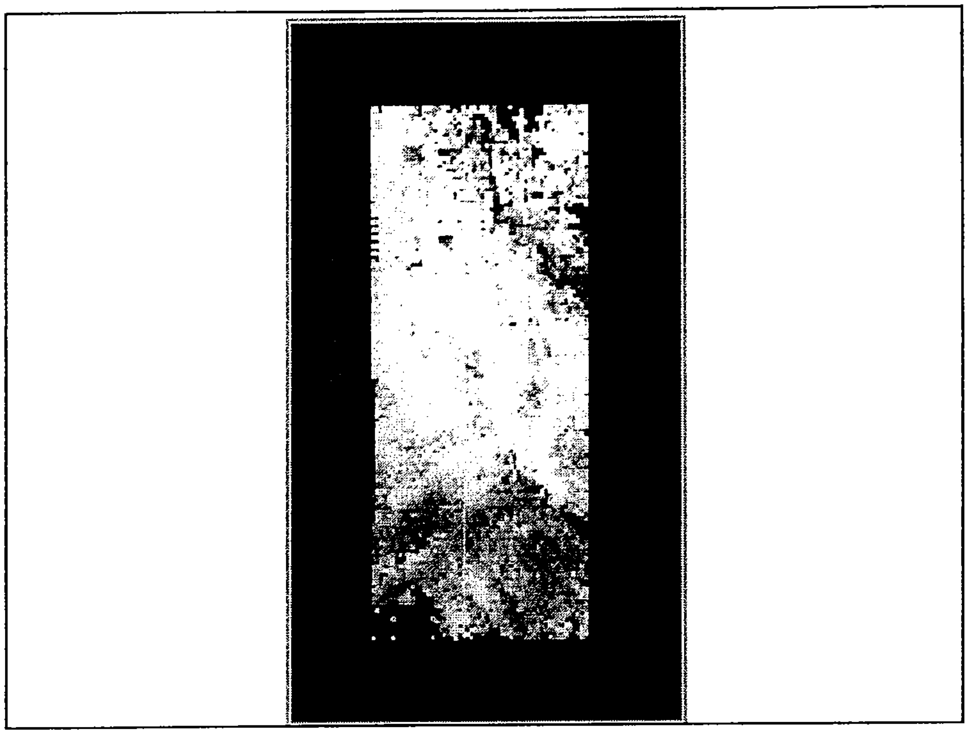


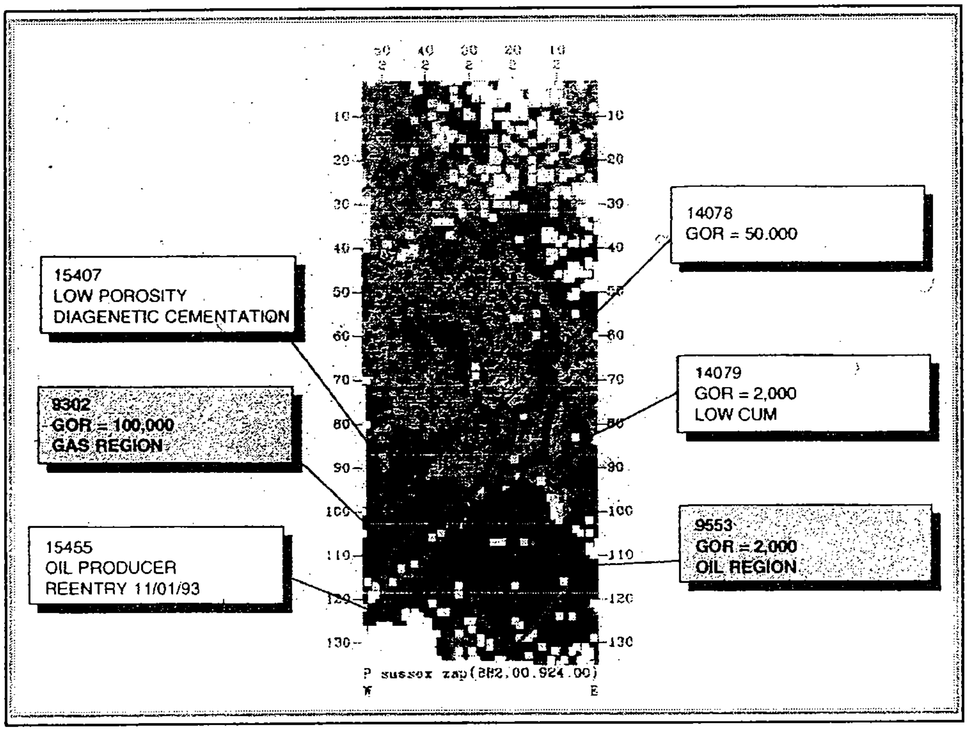


Faults Viewed from South



Structural Contours on D2





15407
LOW POROSITY
DIAGENETIC CEMENTATION

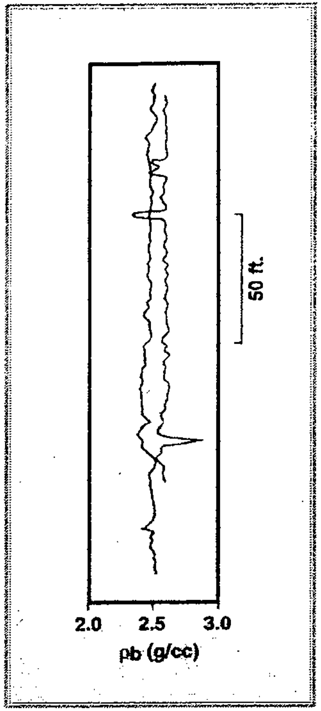
9302
GOR = 100,000
GAS REGION

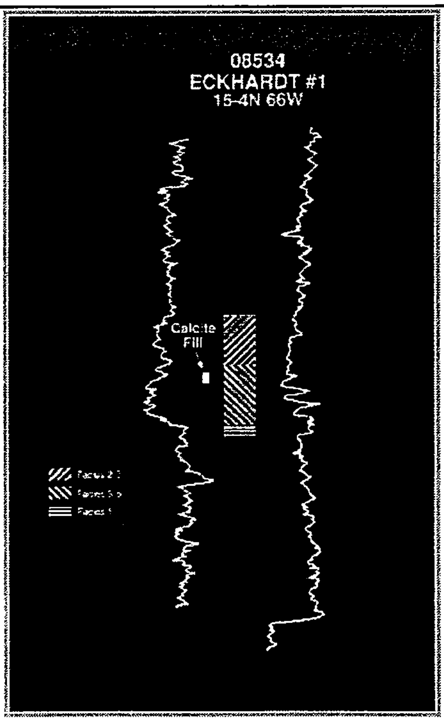
15455
OIL PRODUCER
REENTRY 11/01/93

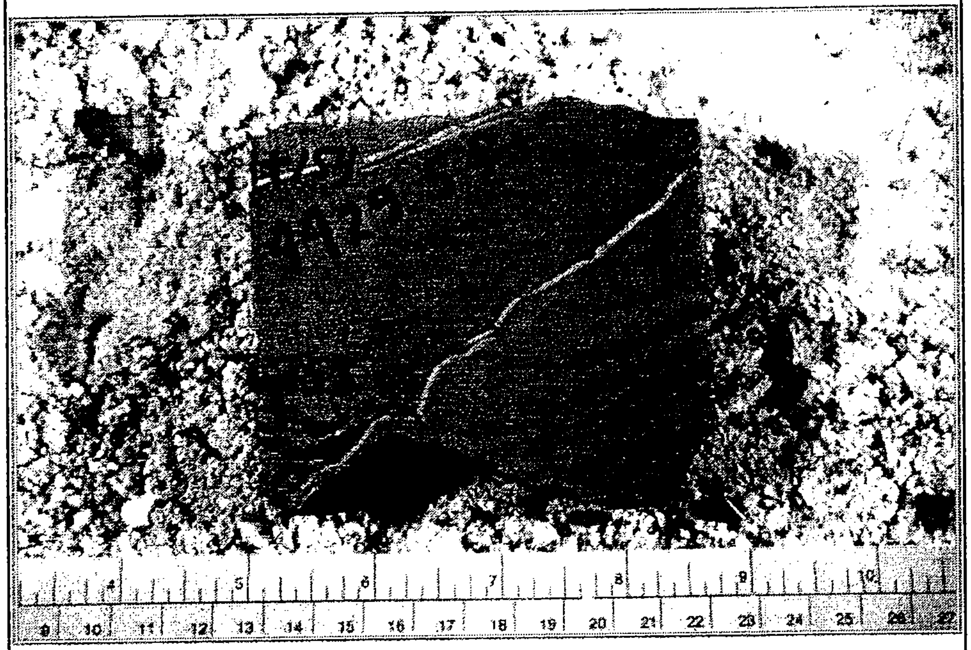
14078
GOR = 50,000

14079
GOR = 2,000
LOW CUM

9553
GOR = 2,000
OIL REGION


50 ft.
2.0
2.5
3.0
ρb (g/cc)


08534
ECKHARDT #1
15-4N 66W
Calcite Fill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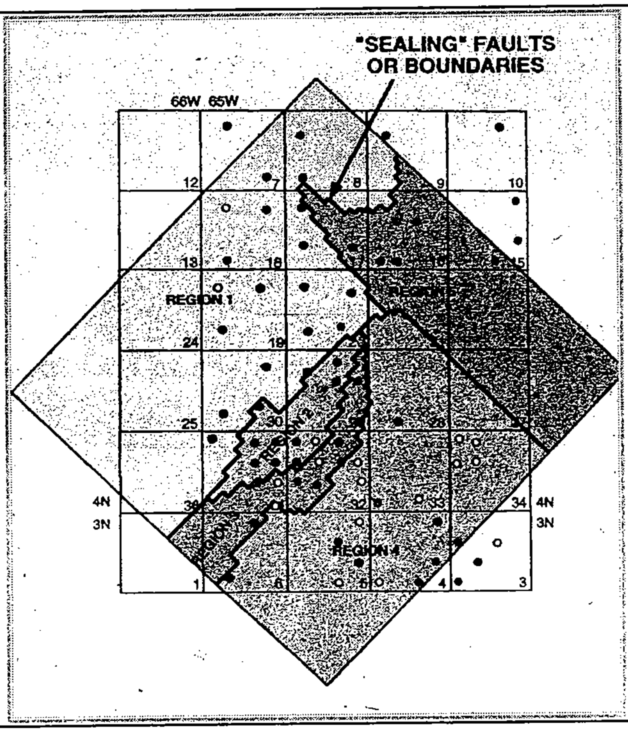
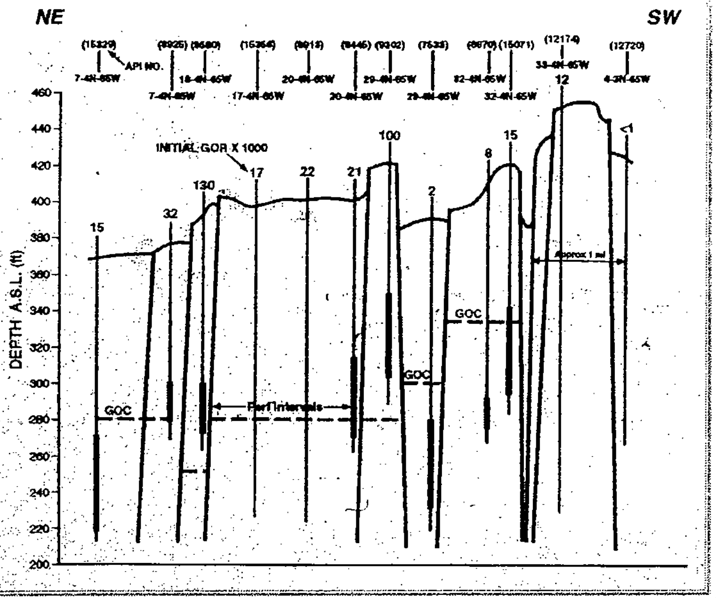
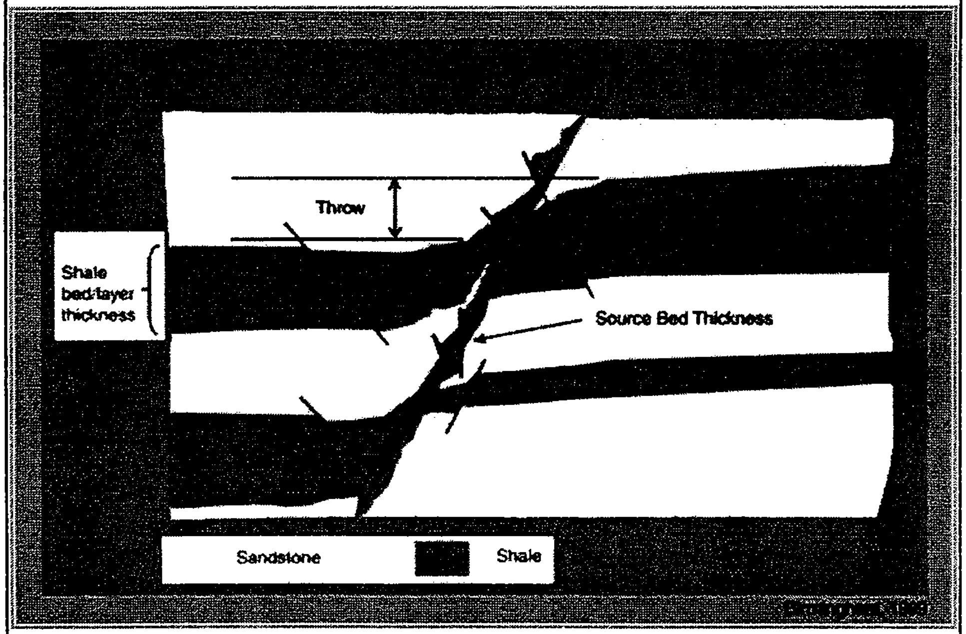
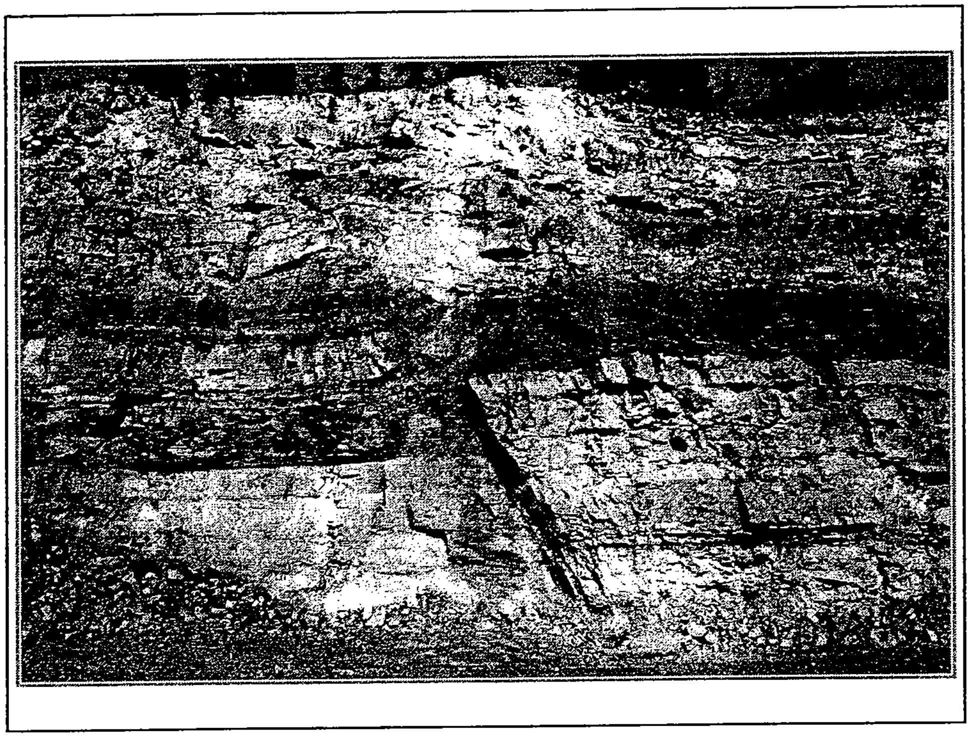
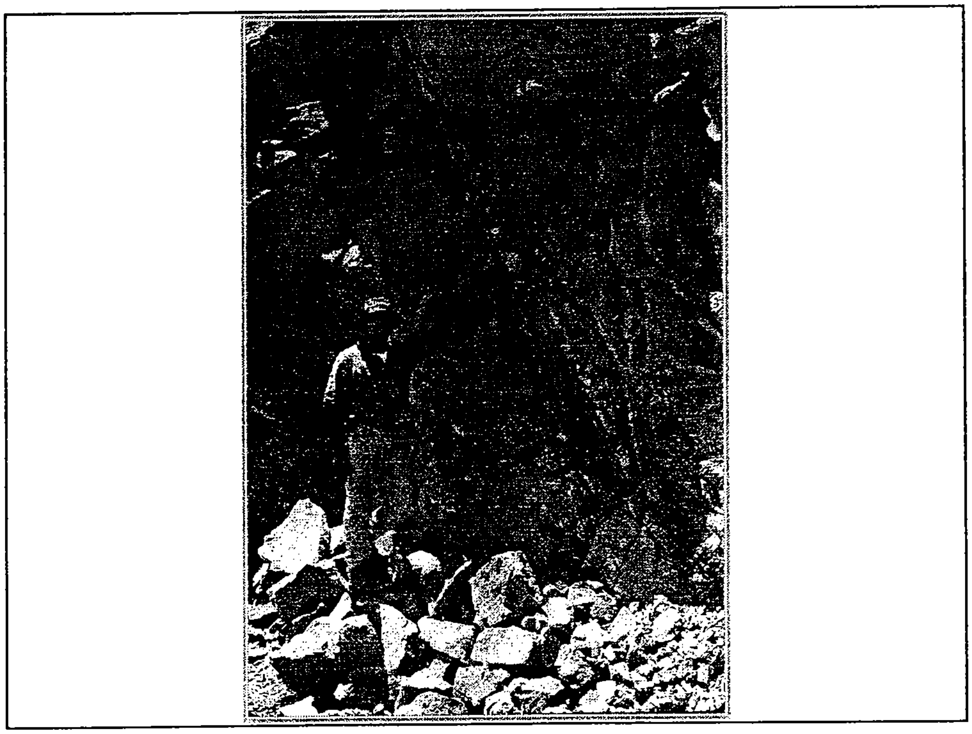

"SEALING" FAULTS OR BOUNDARIES
66W
65W
12
7
8
9
10
13
18
15
REGION 1
24
19
25
30
28
REGION 2
4N
3N
36
32
33
34
4N
3N
REGION 4
1
6
5
4
3

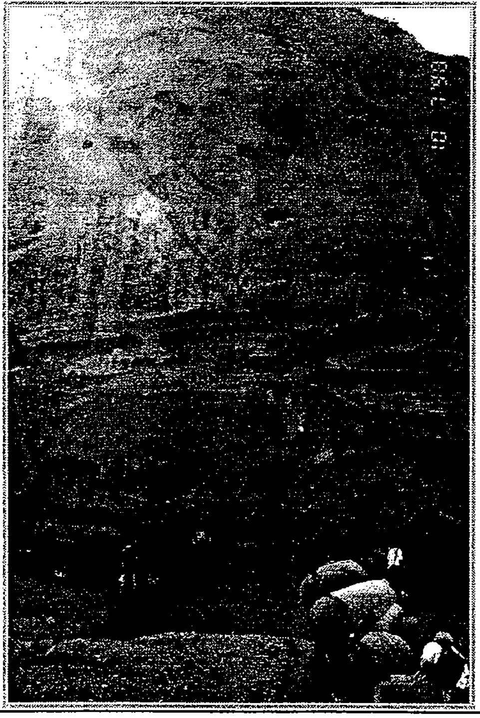
STRUCTURE CROSS-SECTION TOP TERRY SANDSTONE

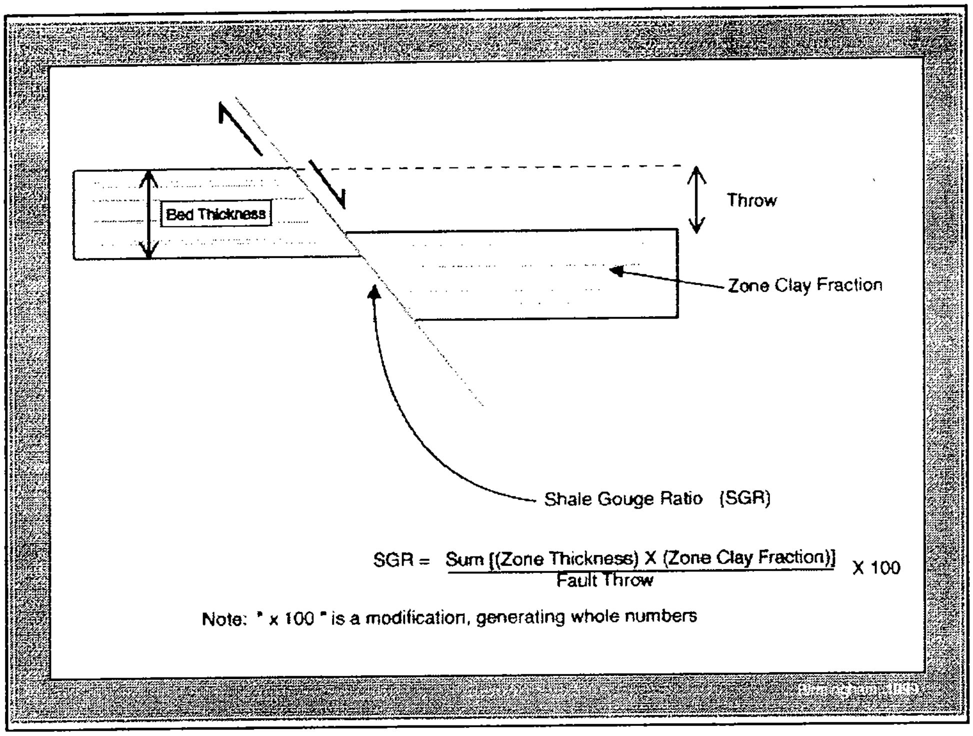








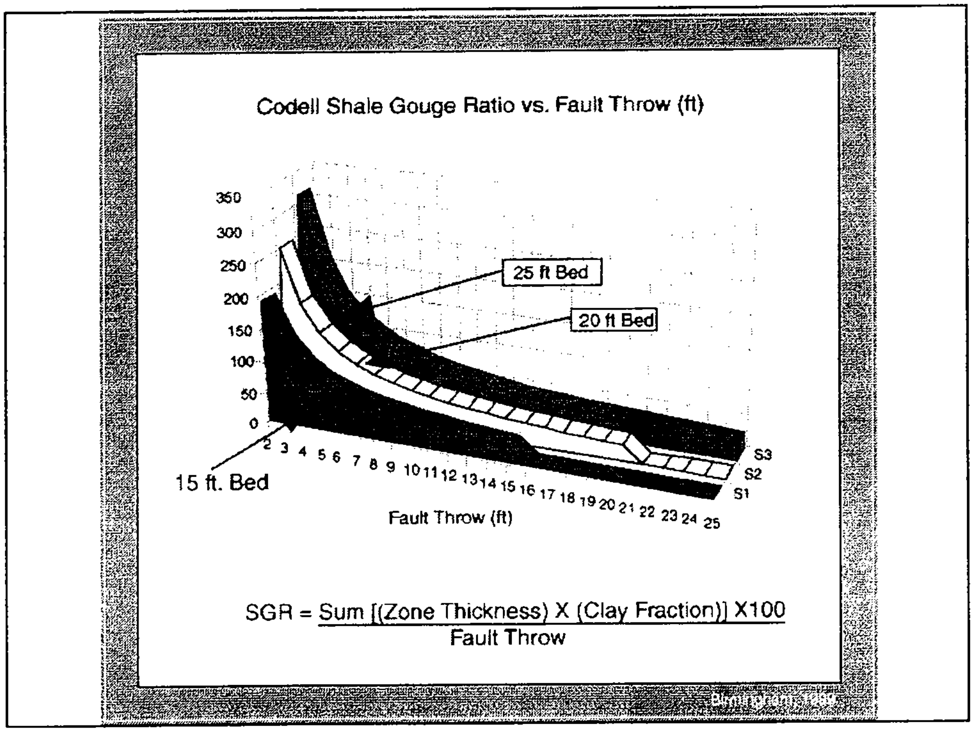




$$SGR = \frac{\text{Sum [(Zone Thickness) X (Zone Clay Fraction)]}}{\text{Fault Throw}} \text{ X 100}$$

Note: " x 100 " is a modification, generating whole numbers

Birmingham, 1999



Codell Shale Gouge Ratio vs. Fault Throw (ft)

$$SGR = \frac{\text{Sum [(Zone Thickness) X (Clay Fraction)] X100}}{\text{Fault Throw}}$$

Birmingham, 1999

SHALE GOUGE RATIO CALCULATION FOR TERRY SANDSTONE

Two wells in Sec. 20

12519 Structural Elev. = 433 ft. GOR= 104,500

14079 Structural Elev. = 380 ft. GOR= 200

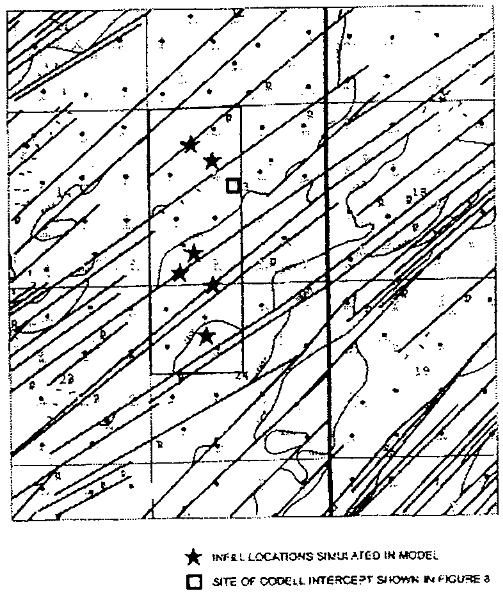
Well	GOR	Spud Date	Distance Apart
12519	104,500	11/88	app. 1300ft. (420m)
14079	200	12/88	

Assume 15 % clay in the Terry Sandstone

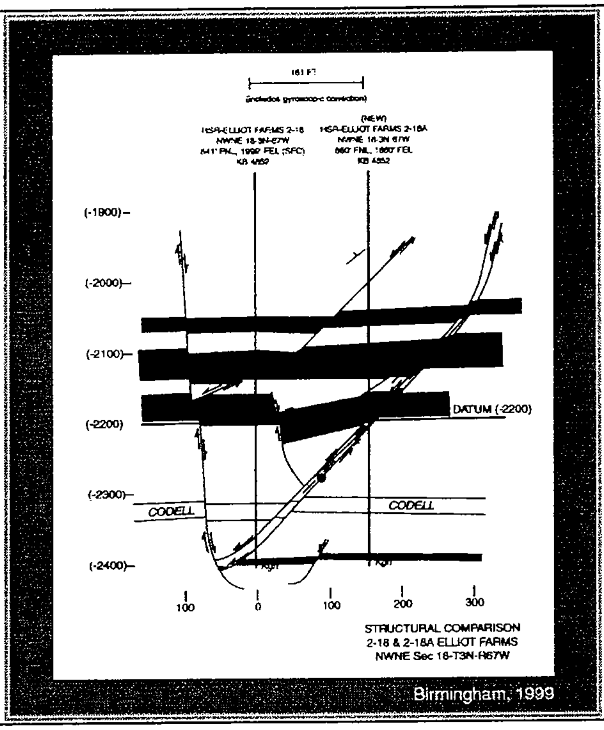
Assume 150ft. thickness of Terry Sandstone

Shale Gouge Ratio = (150ft.)(15) /(433 – 380) = **42**

Assume SGR = 25 for fault gouge to occur, therefore there is gouge present.



Birmingham, 1998



Birmingham, 1999

CONCLUSIONS

- FAULTS MAY BE SEALING IF FILLED WITH CEMENT AND/OR GOUGE
- GOR'S MAY BE USEFUL FOR DETECTING SEALING FAULTS IN THE ABSENCE OF PRESSURE DATA
- FAULTS MAY BE BENEATH SEISMIC RESOLUTION
- TO DETECT SUB-SEISMIC SCALE FAULTS REQUIRES DETAILED MAPPING
- SMALL COMPARTMENTS MAY BE UNTAPPED; CLOSELY SPACED WELLS MAY BE PRODUCTIVE

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