The Tools of Subsurface Analysis

WELL LOGS

Delimit of surfaces & identify sediments penetrated

- Resistivity Logs
- Spontaneous Potential (SP) Logs
- Gamma Ray Logs
- Neutron Logs
- Density Logs
- Sonic (acoustic) Logs

THE TOOLS OF SUBSURFACE ANALYSIS

Facies analysis of subsurface data depends on tools which delimit of surfaces and provide clues as to the sediments they contain:

- Well logs
- Cores
- Seismic
- Gravity & magnetic

WELL LOGS VERSUS SEISMIC

- **Well logs**
  - Great vertical resolution
  - Delimit bounding surfaces
  - Establish lithology of sediments penetrated
- **Seismic**
  - Great lateral continuity and resolution
  - Define gross sediment geometry

TOOLS ARE KEYS TO ALLOSTRATIGRAPHY & SEQUENCE STRATIGRAPHY

- Allostratigraphy:

bounding discontinuities including erosion surfaces, marine flooding surfaces, tuffs, and/or turbidity boundaries etc. as time markers

- Sequence Stratigraphy: higher level allostratigraphic model which interprets depositional origin of sedimentary strata as products of "relative sea level change"

THE TOOLS OF SUBSURFACE ANALYSIS

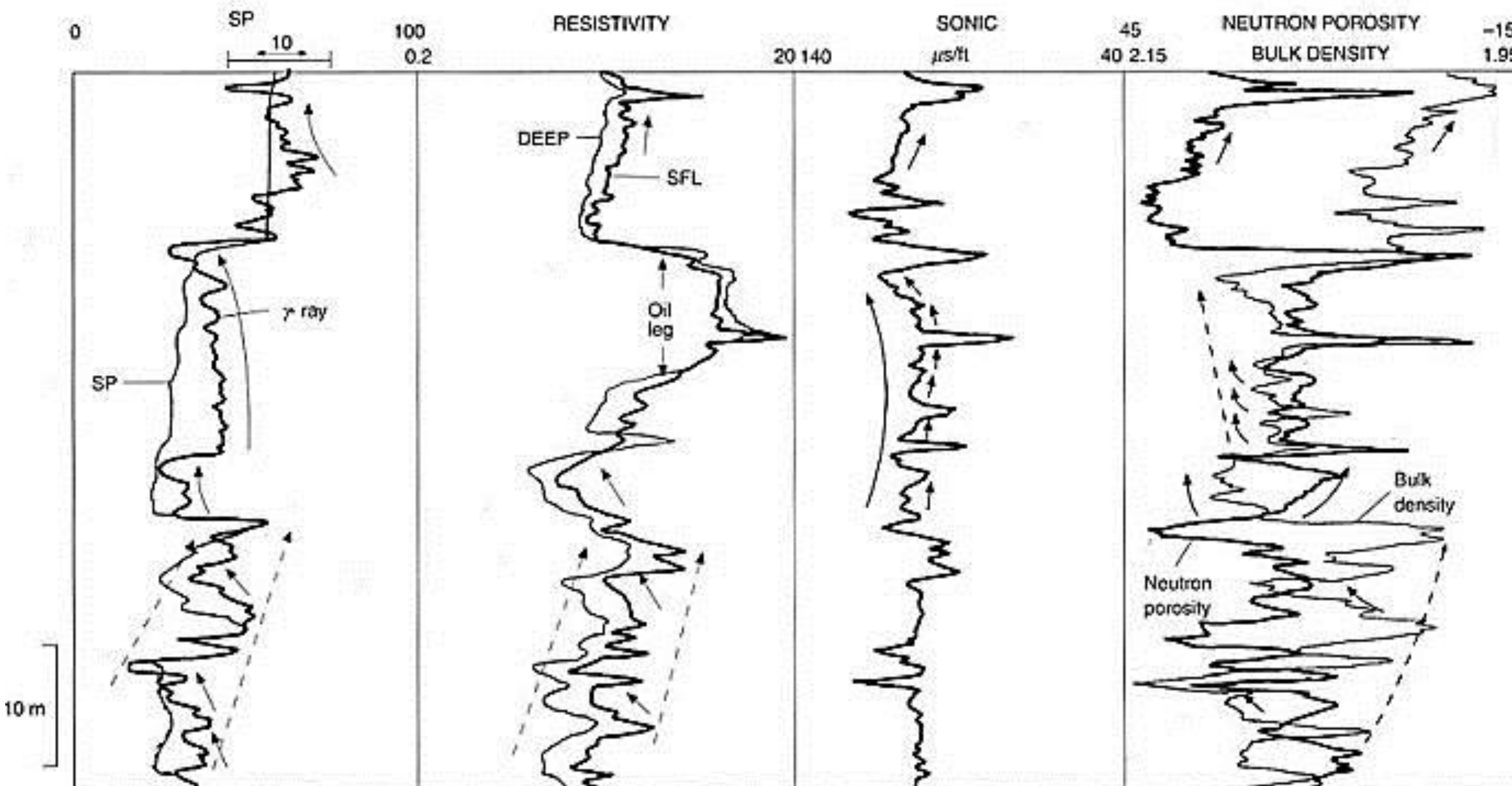
Facies analysis of subsurface data depends on tools which delimit of surfaces and provide clues as to the sediments they contain:

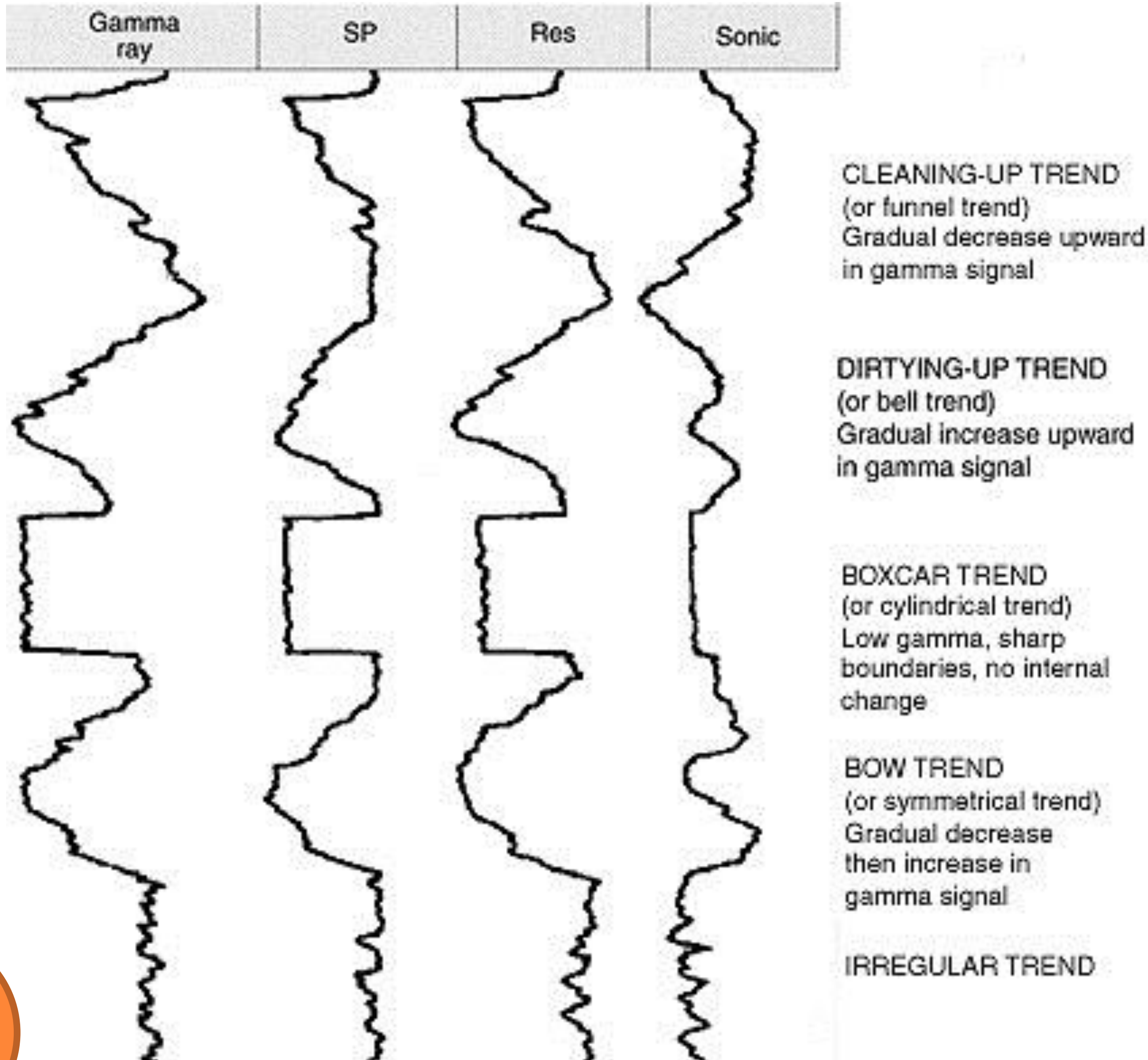
- **Well logs**
- **Seismic**

WELL LOGS

Delimit of surfaces & identify sediments penetrated

- Resistivity Logs
- Spontaneous Potential (SP) Logs
- Gamma Ray Logs
- Neutron Logs
- Density Logs
- Sonic (acoustic) Logs


0
SP
10
100
0.2
RESISTIVITY
20 140
SONIC
μs/ft
45
40 2.15
NEUTRON POROSITY
BULK DENSITY
-15
1.95
DEEP
SFL
γ ray
Oil
leg
SP
Bulk
density
Neutron
porosity
10 m

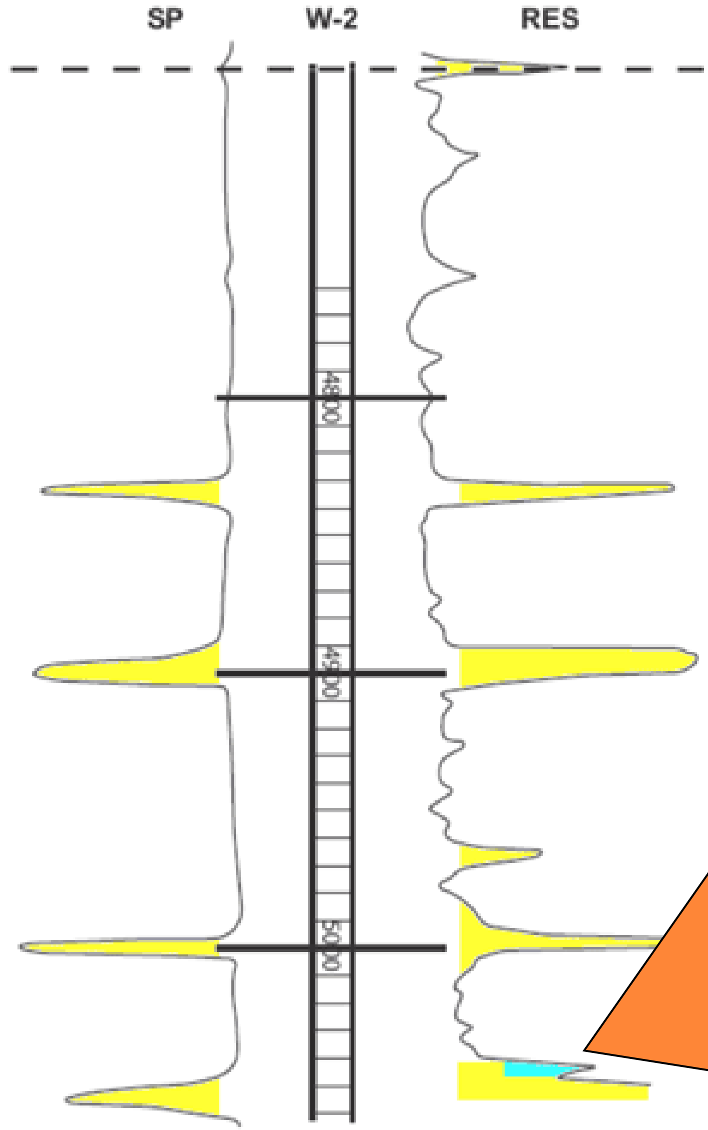


Gamma ray
SP
Res
Sonic
CLEANING-UP TREND
(or funnel trend)
Gradual decrease upward
in gamma signal
DIRTYING-UP TREND
(or bell trend)
Gradual increase upward
in gamma signal
BOXCAR TREND
(or cylindrical trend)
Low gamma, sharp
boundaries, no internal
change
BOW TREND
(or symmetrical trend)
Gradual decrease
then increase in
gamma signal
IRREGULAR TREND

RESISTIVITY LOGS

The most commonly used logs:

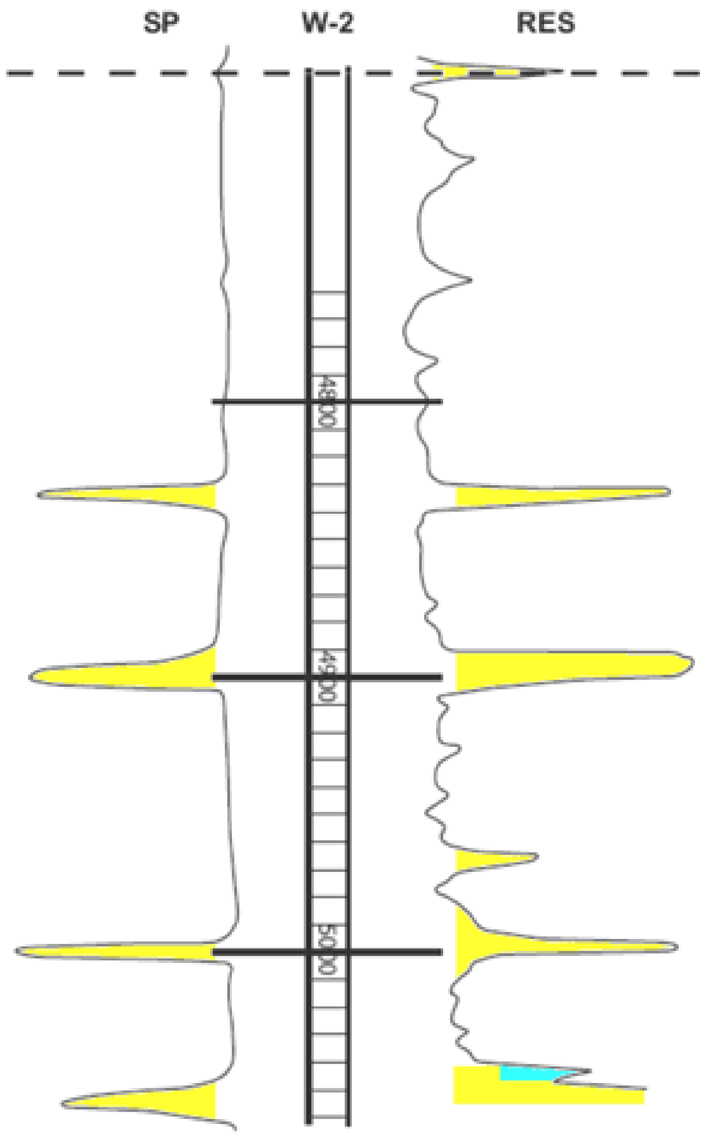
- Measures resistance of flow of electric current
- Is function of porosity & pore fluid in rock
- Frequently used to identify lithology


SP
W-2
RES
4800
4900
5000

SPONTANEOUS POTENTIAL (SP) LOGS

Next most common log

- **Measures electrical current in well**
- **Result of salinity differences between formation water and the borehole mud**
- **Separates bed boundaries of permeable sands & impermeable shales.**

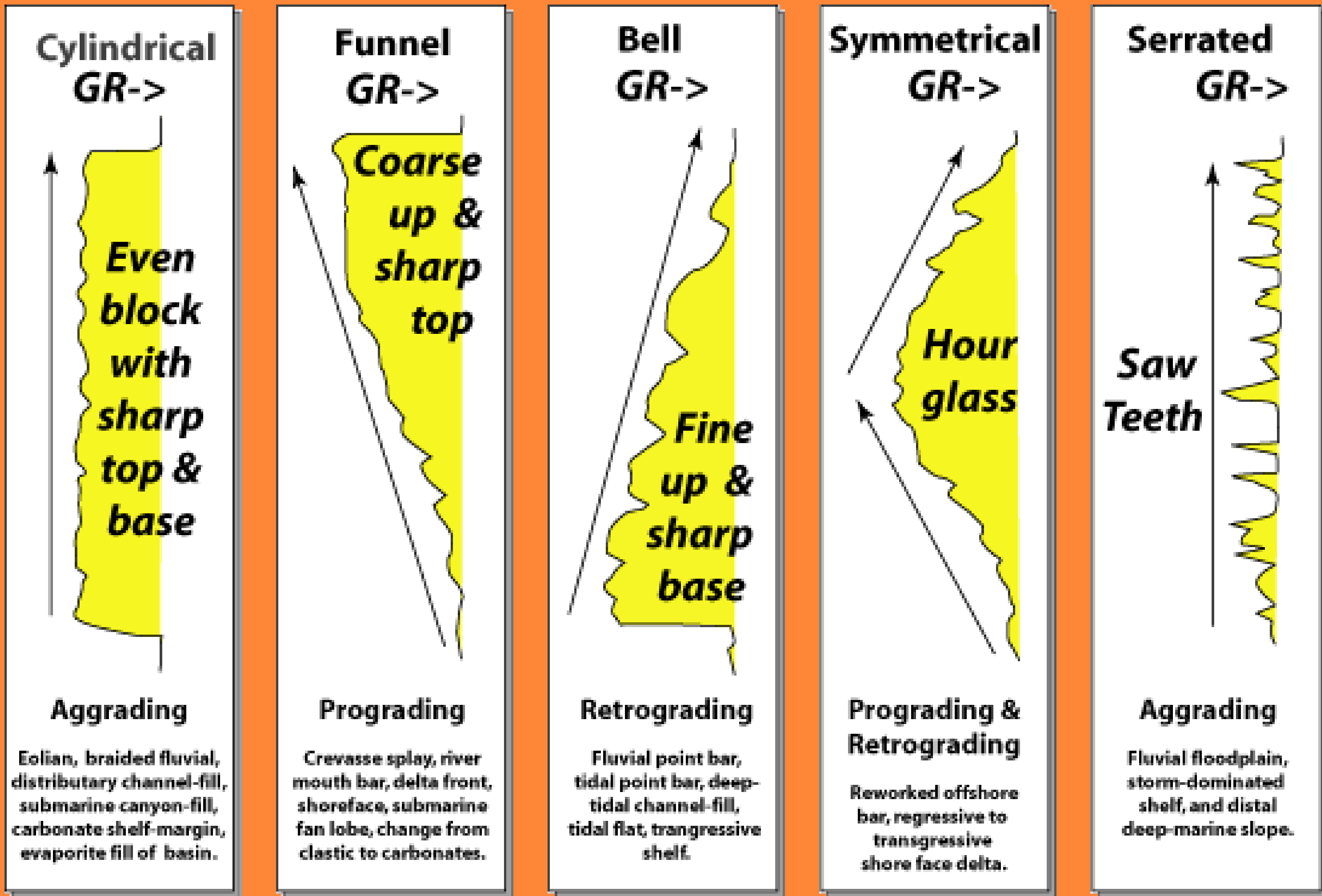

SP
W-2
RES
4800
4900
5000

Gamma Ray Logs

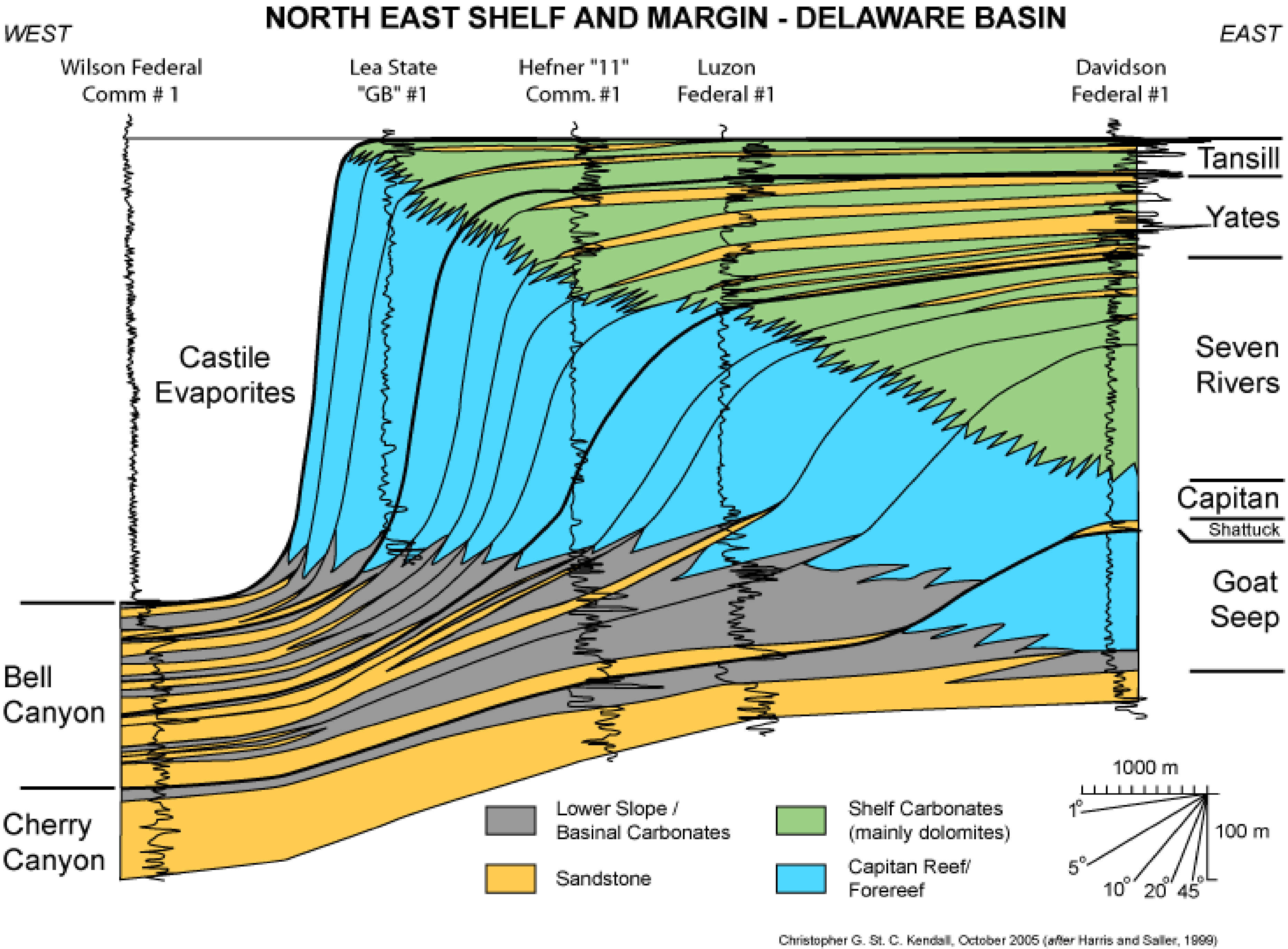
Another common log

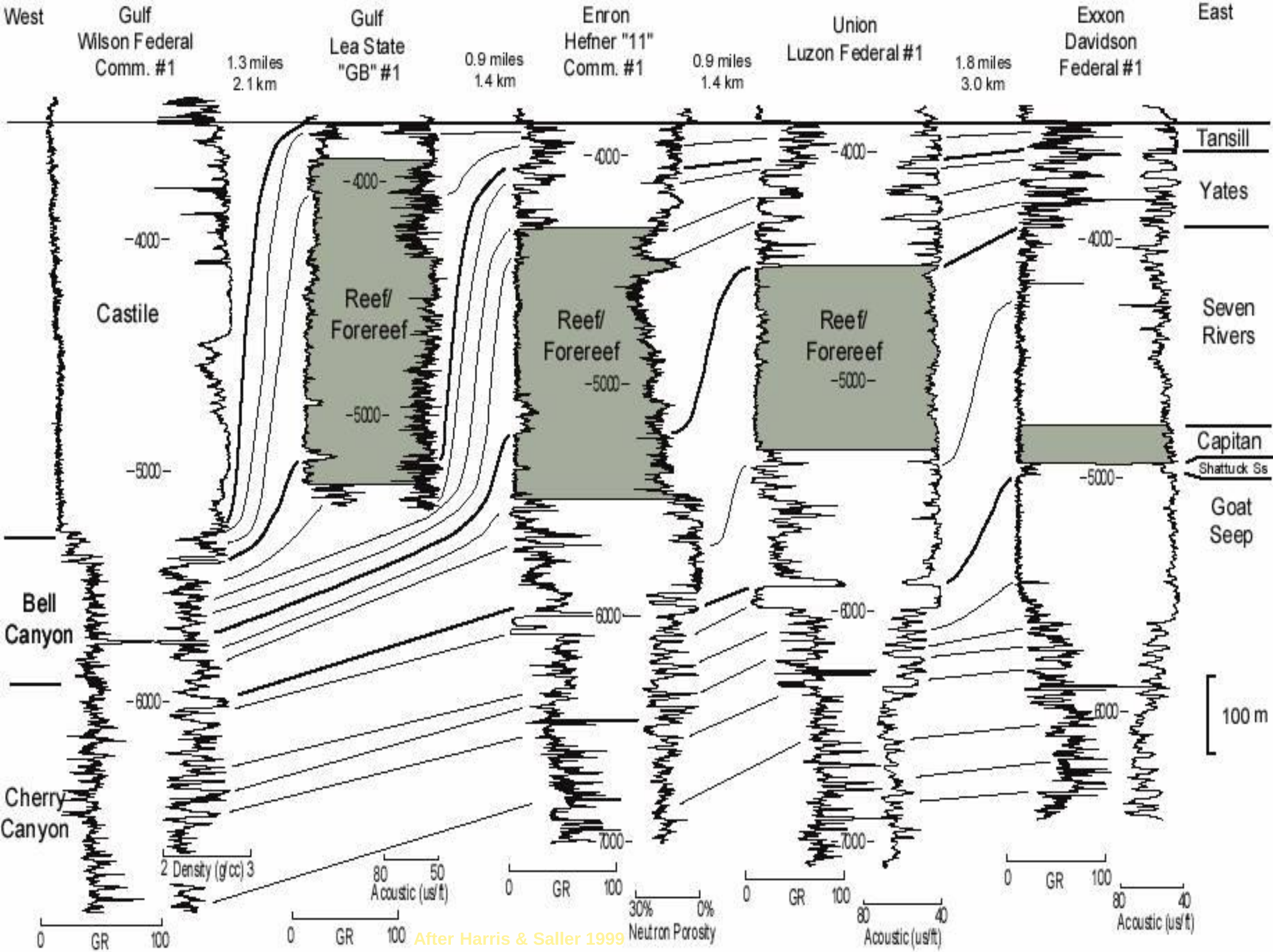
- Records radioactivity of a formation
- Shales have high gamma radioactive response
- Gamma ray logs infer grain size (and so subsequently inferred depositional energy)
- Gamma ray logs are most commonly used logs for sequence stratigraphic analysis

General Gamma Ray Response to Variations in Grain Size



C. G. St. C. Kendall 2005 (modified from Emery, 1996)


NORTH EAST SHELF AND MARGIN - DELAWARE BASIN
WEST
EAST
Wilson Federal Comm # 1
Lea State "GB" #1
Hefner "11" Comm. #1
Luzon Federal #1
Davidson Federal #1
Tansill
Yates
Seven Rivers
Capitan
Shattuck
Goat Seep
Castile Evaporites
Bell Canyon
Cherry Canyon
Lower Slope / Basinal Carbonates
Sandstone
Shelf Carbonates (mainly dolomites)
Capitan Reef/ Forereef
1000 m
100 m
1°
5°
10°
20°
45°
Christopher G. St. C. Kendall, October 2005 (after Harris and Saller, 1999)



After Harris & Saller 1999

NEUTRON LOGS

Another common log

- Measures porosity of formation
- Uses quantity of hydrogen present
- Measures lithology when used with Density Log

DENSITY LOGS

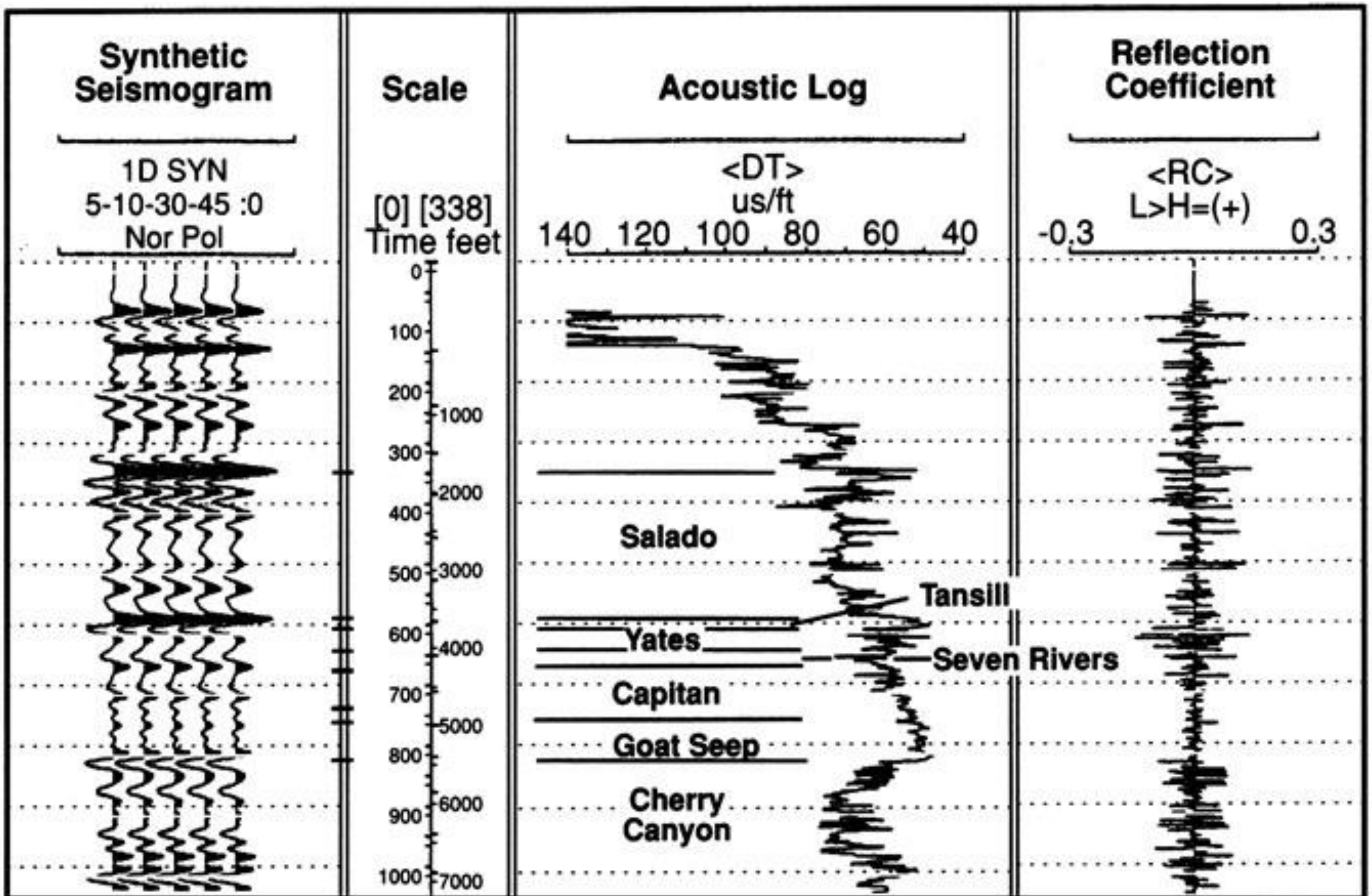
A common log

- Measures formation's bulk density
- Used as a porosity measure
- Differentiates lithologies with Neutron Log
- Used with Sonic Logs to generate synthetic seismic traces to match to seismic lines

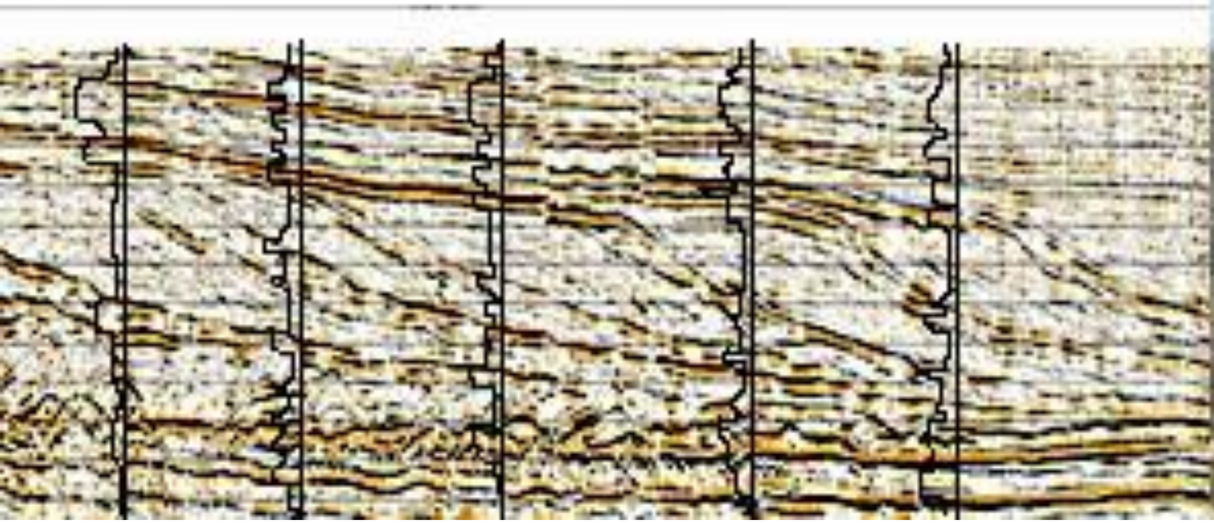
SONIC (ACOUSTIC) LOGS

Another common log

- Measures of speed of sound in formation
- Tied to porosity and lithology
- Used with Density Logs to generate Synthetic Seismic traces to match to Seismic lines



After Saller & Harris, 1999



THE TOOLS OF SUBSURFACE ANALYSIS

Facies analysis of subsurface data depends on tools which delimit of surfaces and provide clues as to the sediments they contain:

- **Well logs**
- **Seismic**

SEISMIC

Seismic stratigraphic interpretation used to:

- **Define geometries of genetic reflection packages that envelope seismic sequences and systems tracts.**
- **Identify bounding discontinuities on basis of reflection termination patterns and continuity.**

SEISMIC BOUNDARIES

Termination below discontinuity, or upper sequence boundary :

- **Toplap termination**
- **Truncation of sediment surface**
- **Often channel bottom**

Above a discontinuity defining lower sequence boundary:

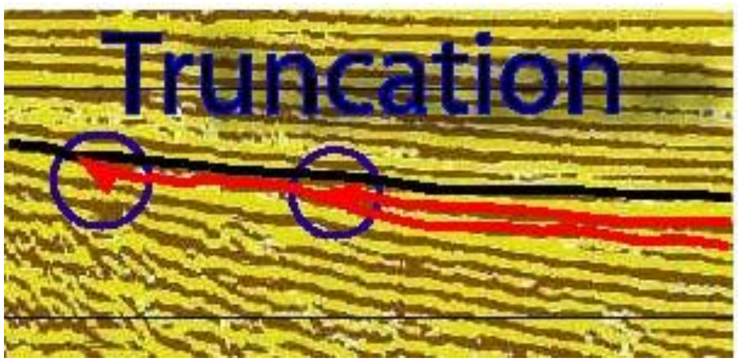
- **Onlap over surface**
- **Downlap surface**

SEISMIC BOUNDARIES

Below Boundary - Toplap termination

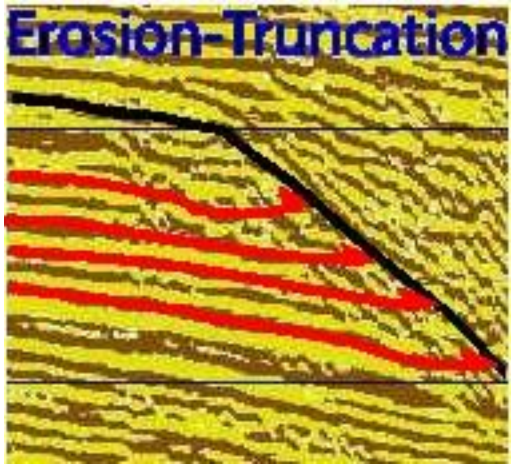
SEISMIC BOUNDARIES

Below Boundary - Truncation of surface



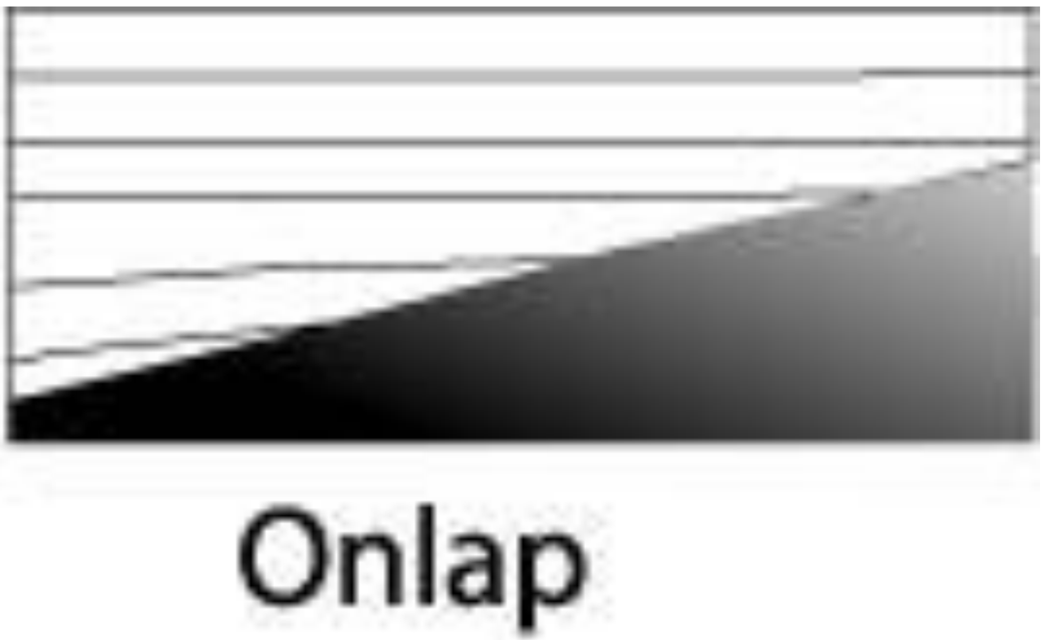
SEISMIC BOUNDARIES

Channeled Surface – Below Boundary



SEISMIC BOUNDARIES

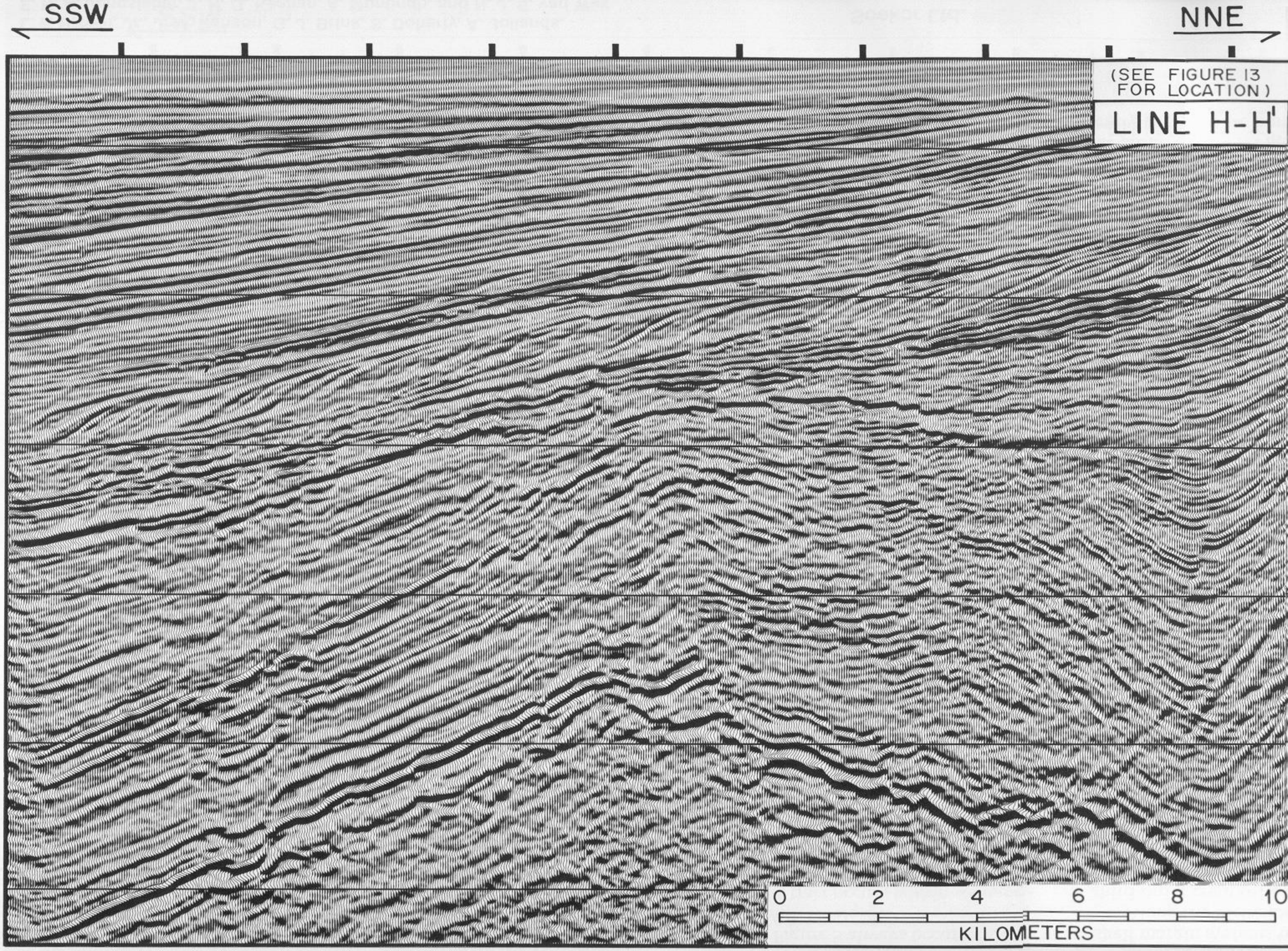
Over Boundary - Onlap onto surface



(from Mitchum et al., 1977)

SEISMIC BOUNDARIES

Over Boundary- Downlap onto surface


SSW
NNE
(SEE FIGURE 13 FOR LOCATION)
LINE H-H'
0 2 4 6 8 10
KILOMETERS

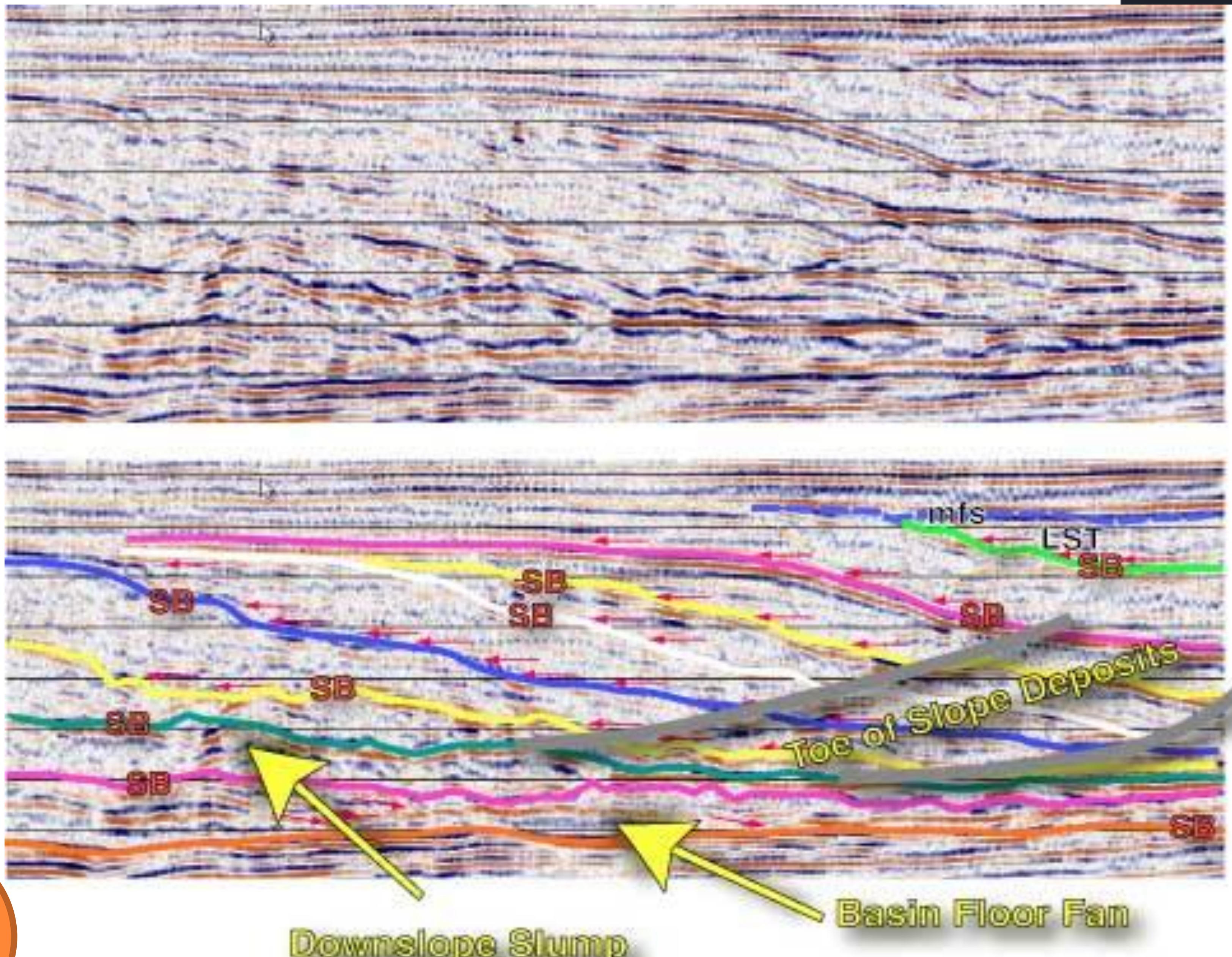


Figure 10. Sequences and system tract interpretation.

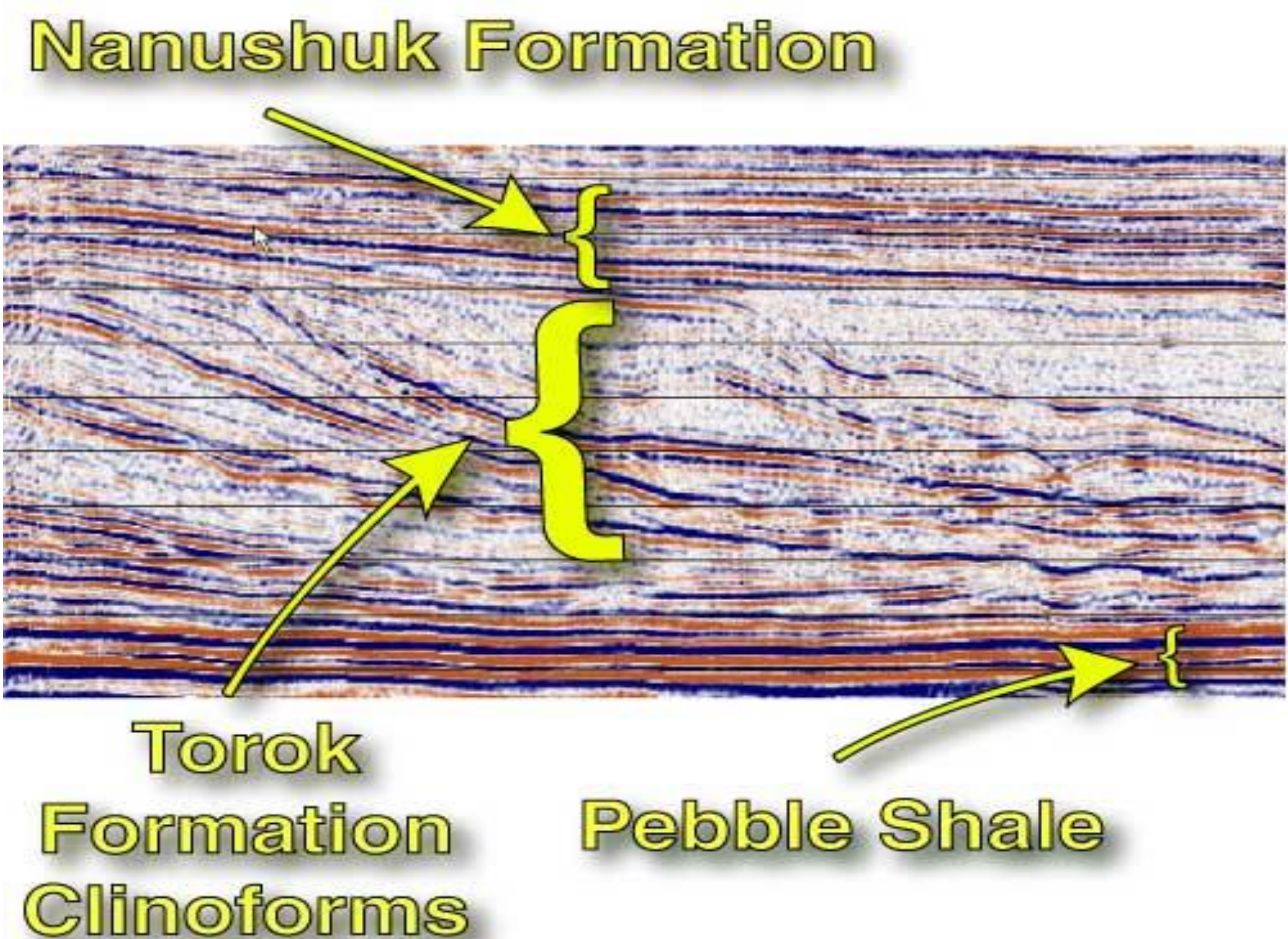


Figure 3. Regional seismic line illustrating the stratigraphic relationships among the major rock units within the NPRA.

SEQUENCE STRATIGRAPHY

Subdivision & interpretation of sedimentary record using a framework surfaces seen in outcrops, well logs, & 2-D and 3-D seismic.
Include:

- Surfaces of erosion & non-deposition (sequence boundaries)
- Flooding (trangressive surfaces [TS] &/or maximum flooding surfaces [mfs]) & high stand condensed surfaces

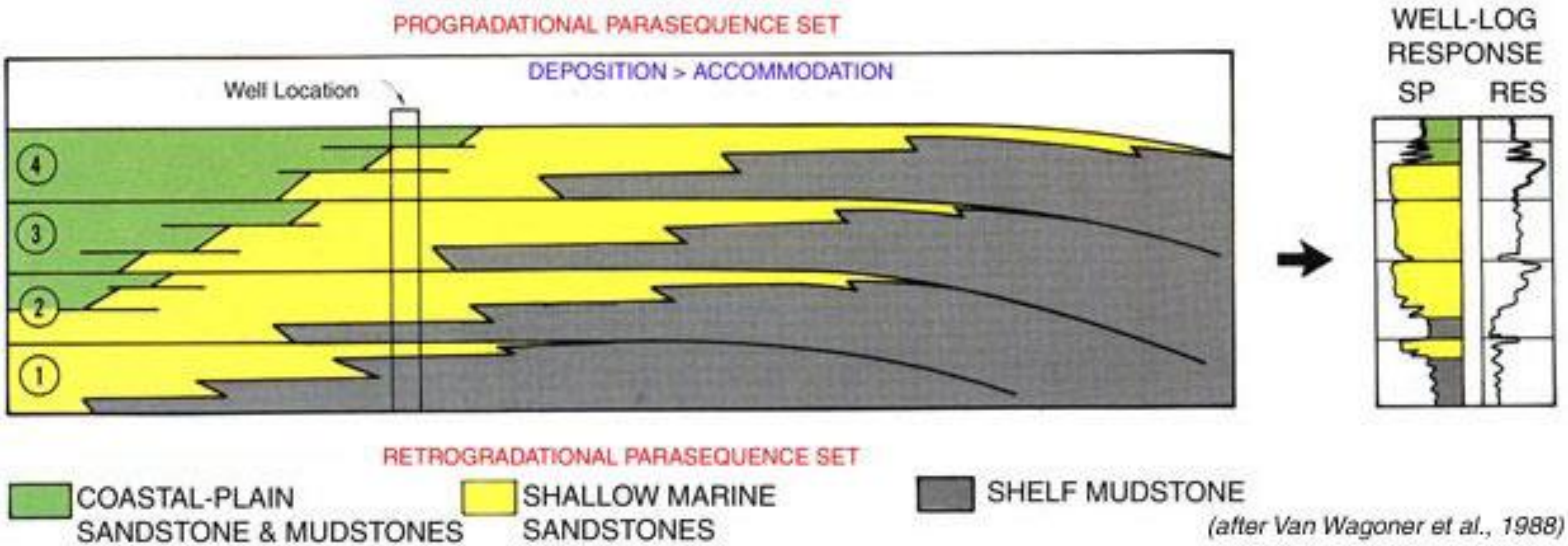
This framework used to predict the extent of sedimentary facies geometry, lithologic character, grain size, sorting & reservoir quality

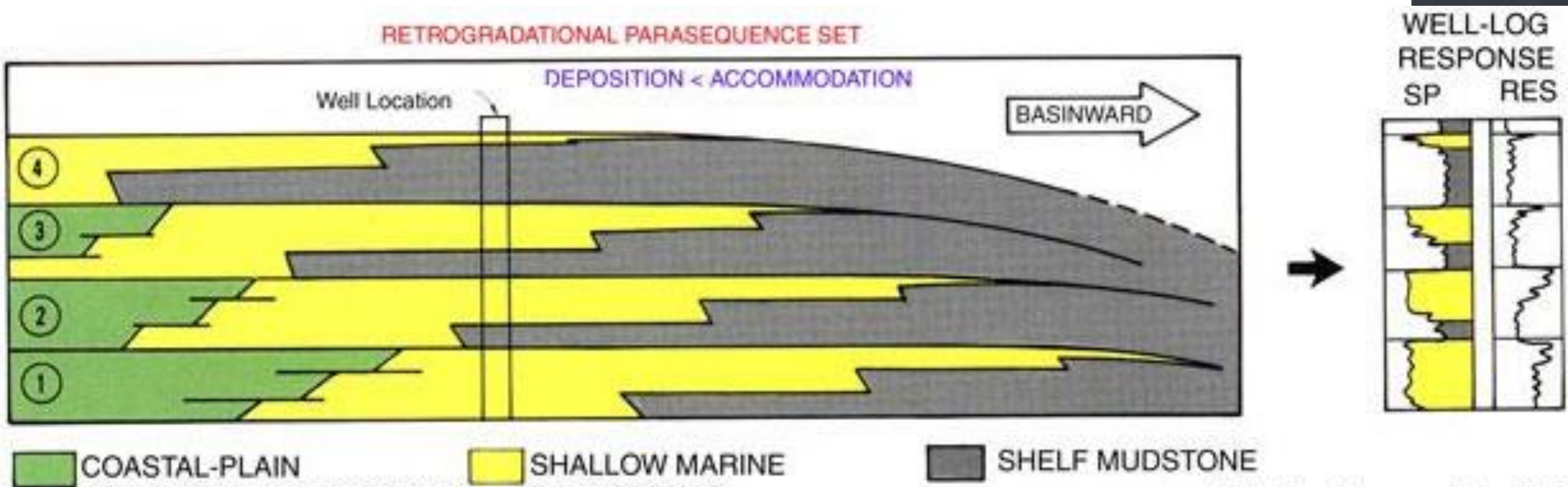
TOOLS DEFINE BOUNDING SURFACES

These surfaces subdivide sedimentary rock & provide:-

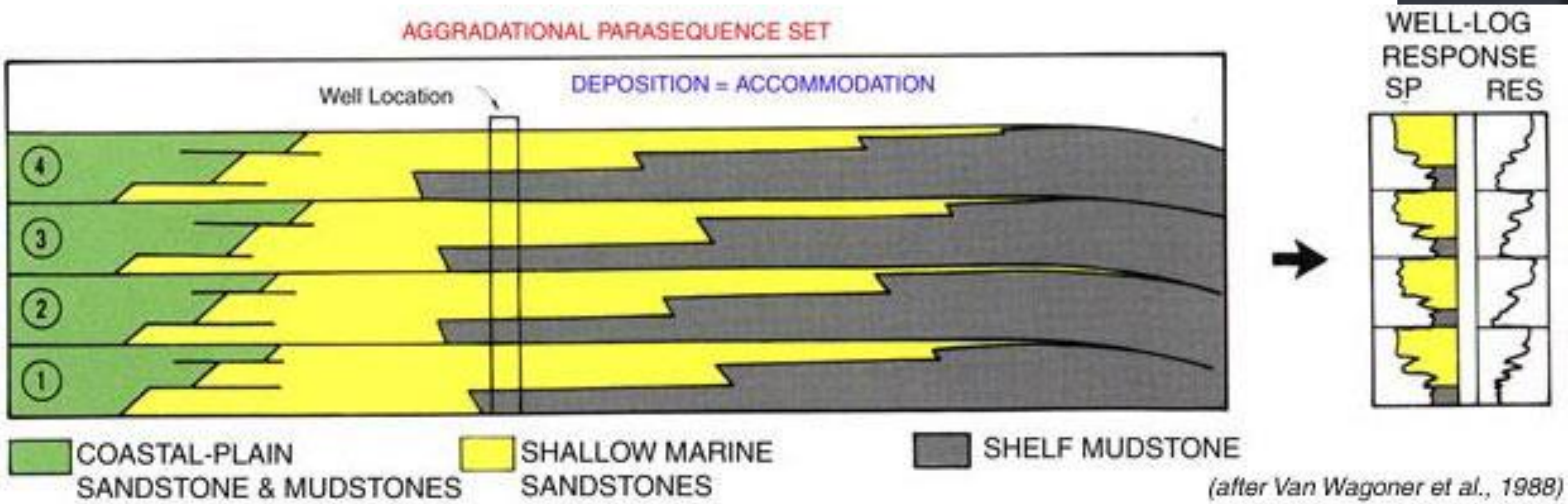
- Relative time framework for sedimentary succession
- Better understanding of inter-relationship of depositional settings & their lateral correlation

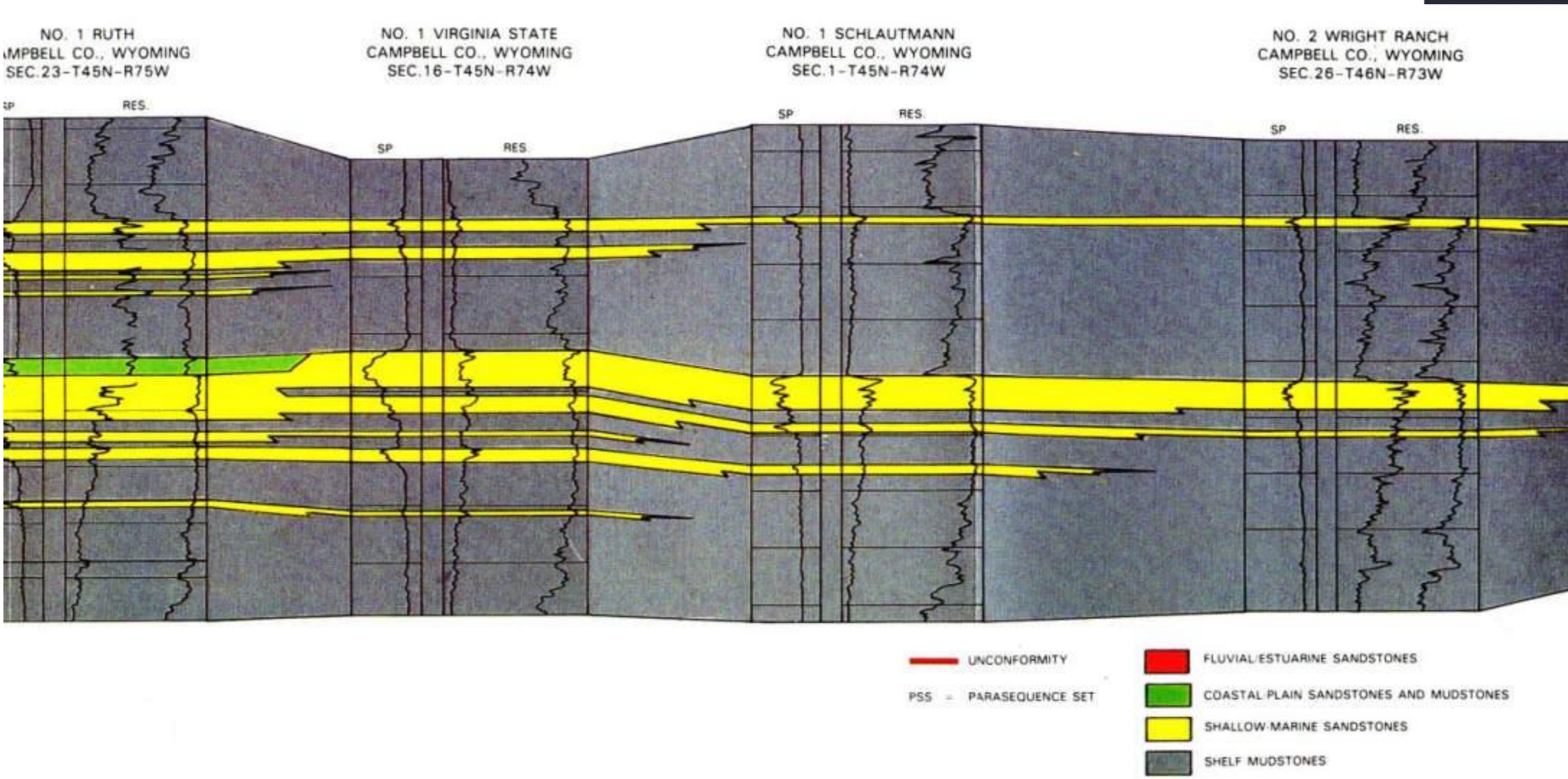
  Conceptual models follow that link the processes that formed the sediments and enable the prediction of their gross geometries


PROGRADATIONAL PARASEQUENCE SET
DEPOSITION > ACCOMMODATION
Well Location
4
3
2
1
RETROGRADATIONAL PARASEQUENCE SET
WELL-LOG RESPONSE
SP
RES
COASTAL-PLAIN SANDSTONE & MUDSTONES
SHALLOW MARINE SANDSTONES
SHELF MUDSTONE
(after Van Wagoner et al., 1988)

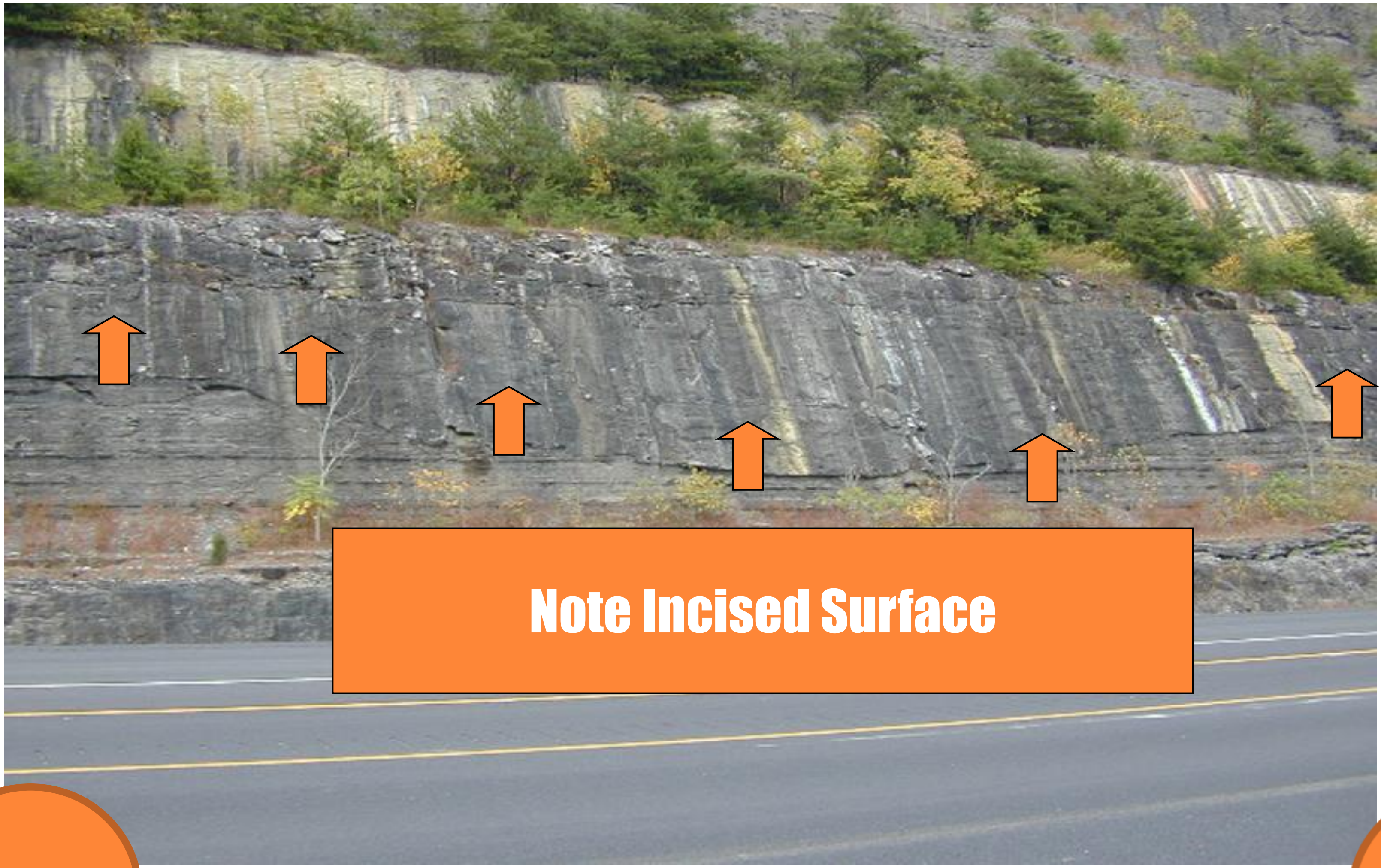


(after Van Wagoner et al., 1988)


AGGRADATIONAL PARASEQUENCE SET
DEPOSITION = ACCOMMODATION
Well Location
4
3
2
1
WELL-LOG
RESPONSE
SP
RES
COASTAL-PLAIN
SANDSTONE & MUDSTONES
SHALLOW MARINE
SANDSTONES
SHELF MUDSTONE
(after Van Wagoner et al., 1988)

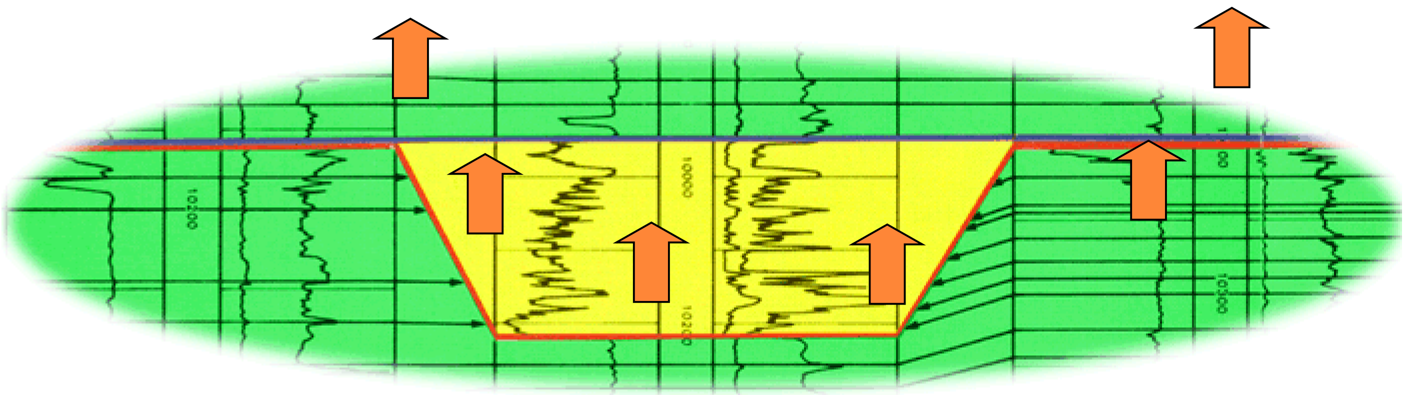

NO. 1 RUTH
CAMPBELL CO., WYOMING
SEC.23-T45N-R75W
SP
RES.
NO. 1 VIRGINIA STATE
CAMPBELL CO., WYOMING
SEC.16-T45N-R74W
SP
RES.
NO. 1 SCHLAUTMANN
CAMPBELL CO., WYOMING
SEC.1-T45N-R74W
SP
RES.
NO. 2 WRIGHT RANCH
CAMPBELL CO., WYOMING
SEC.26-T46N-R73W
SP
RES.
UNCONFORMITY
PSS = PARASEQUENCE SET
FLUVIAL/ESTUARINE SANDSTONES
COASTAL PLAIN SANDSTONES AND MUDSTONES
SHALLOW-MARINE SANDSTONES
SHELF MUDSTONES

DELTA MOUTH BAR - KENTUCKY



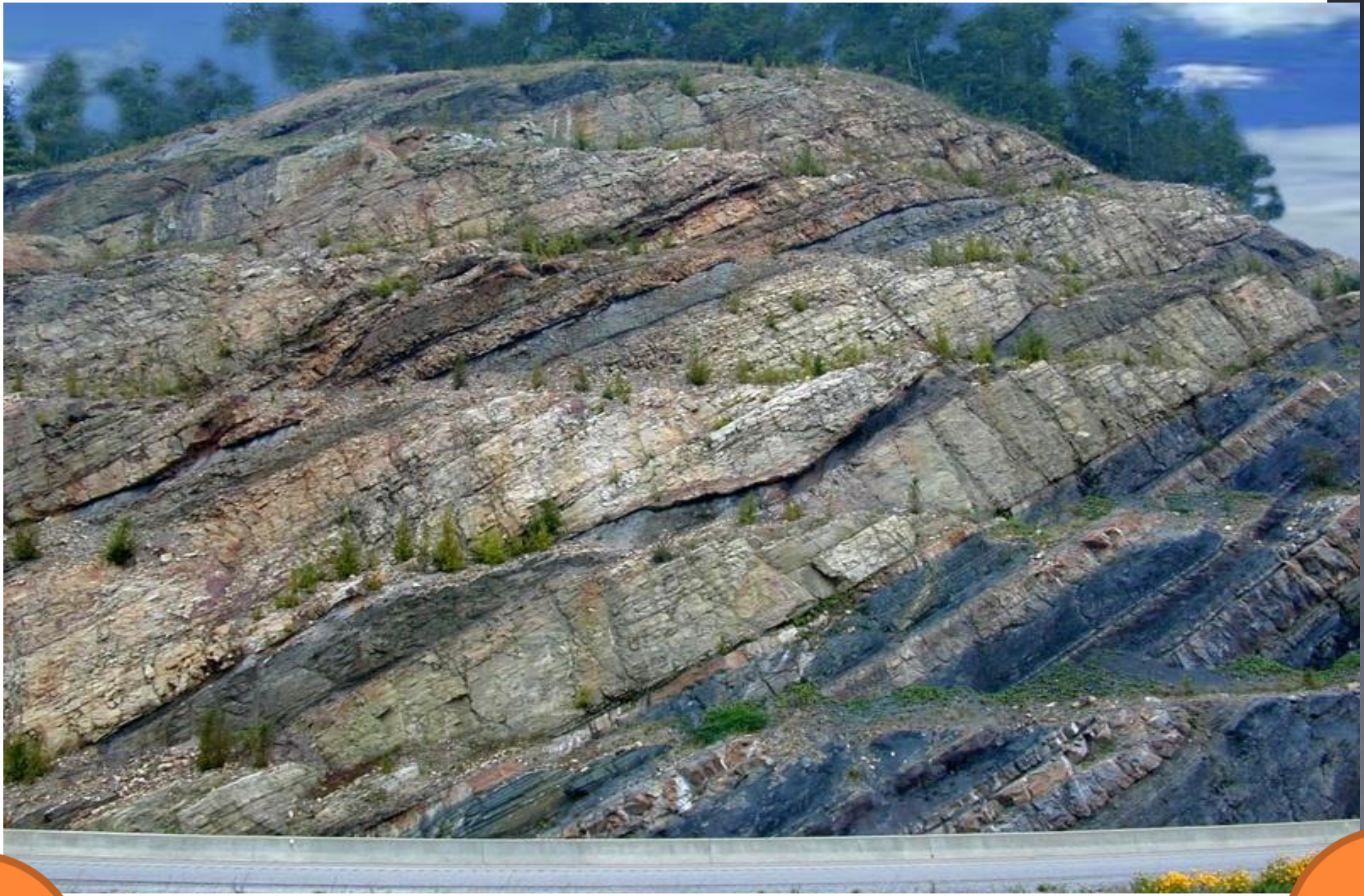
Note Incised Surface

CHANNEL - GULF COAST

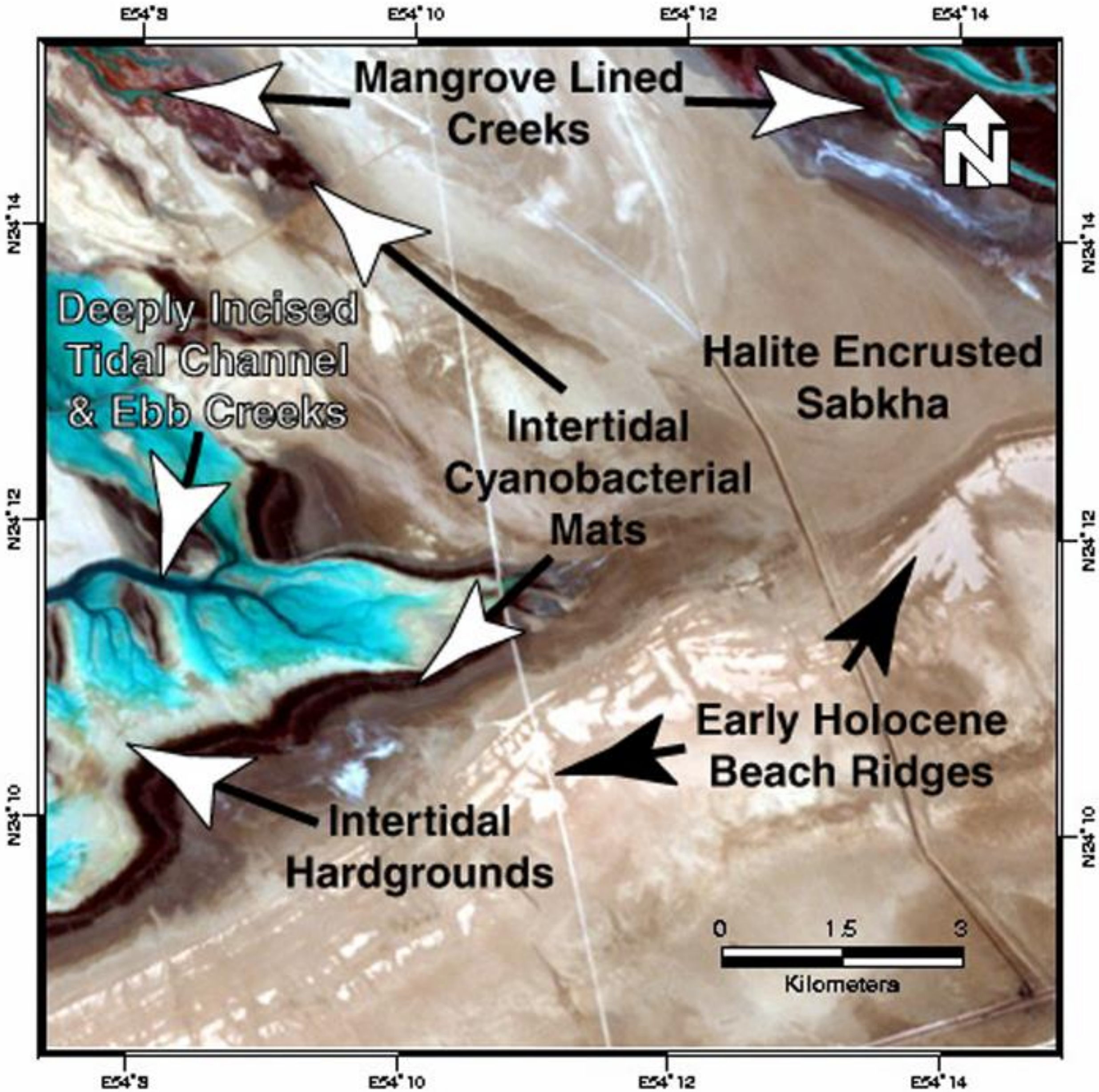


Note Incised Surface

FLOOD DELTAS & CHANNELS - KTY



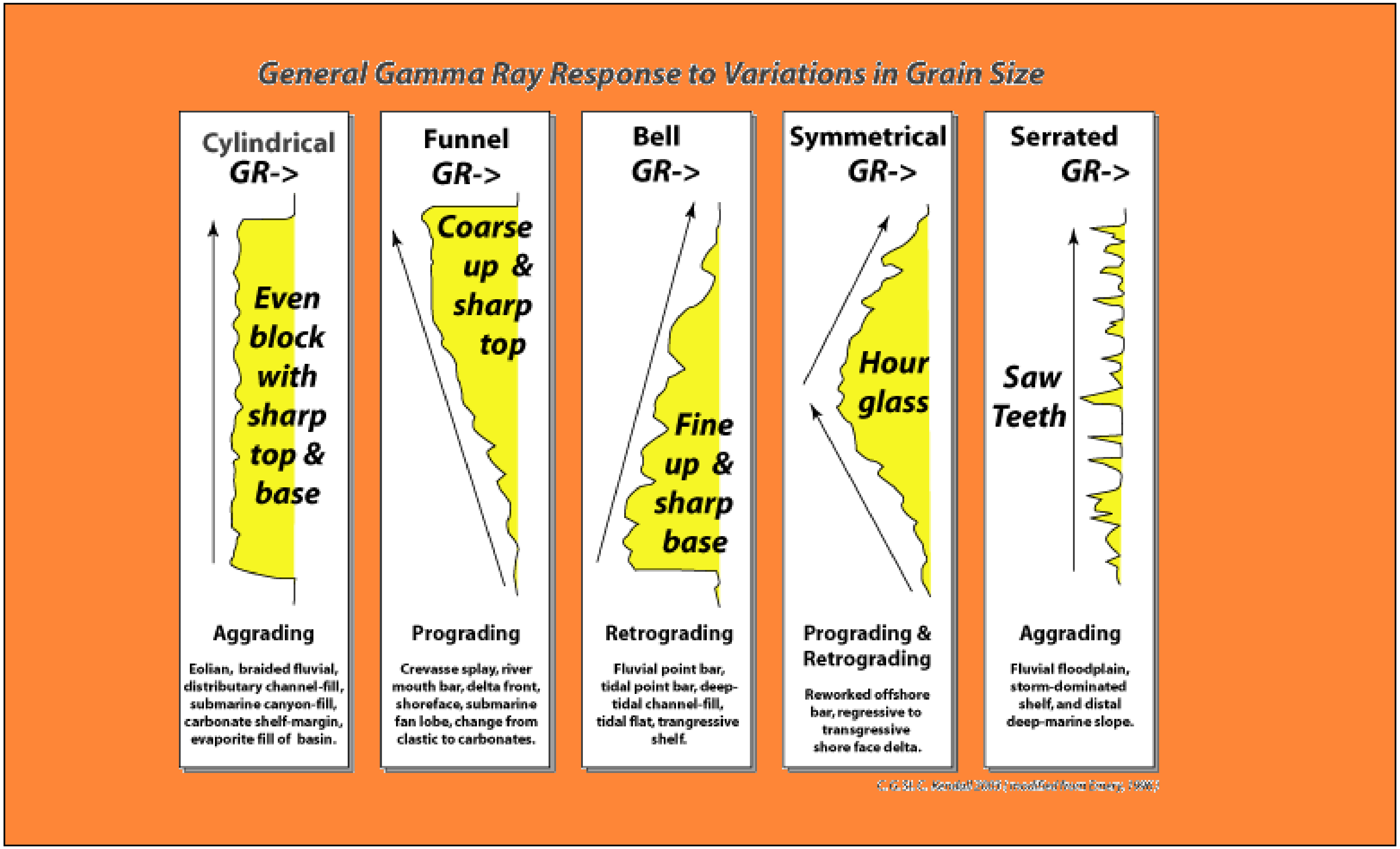
TIDAL CHANNELS KHOR AL BAZAM - UAE



Note Incised Surface


Note Uniform Thickness of Layer

CLASTIC SEQUENCE STRATIGRAPHIC HIERARCHIES



CHANNELS & SHELVES

Channel

Shelf

Both have unique processes & structures that can be used to identify their setting

TOOLS ENABLE SEQUENCE STRATIGRAPHIC ANALYSIS

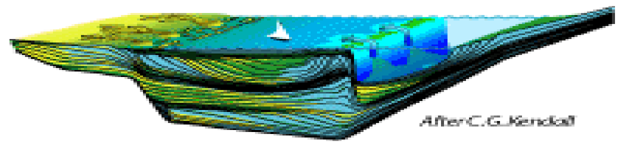
This analysis involves

- Subdivision of section into sequences, para- sequences and beds.
- Link conceptual models with mix of components of the individual sequence, para-sequence or beds.
- Use these to explain the depositional setting in terms of their lithology, grain size, sedimentary structures, contacts character (gradational, abrupt) etc

Creation of stratigraphic cross sections & geologic models of carbonates
The use of sequence stratigraphy to correlate & interpet carbonates from well logs & cores

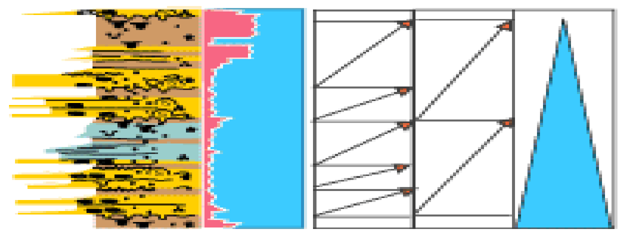
Depositional setting of the carbonates determined from:

Geological model provided by literature



After C.G.Kendall

Graphic column that characterizes
- lithology
- grain size
- sedimentary structures
- fossils
- surfaces subdividing parasequences

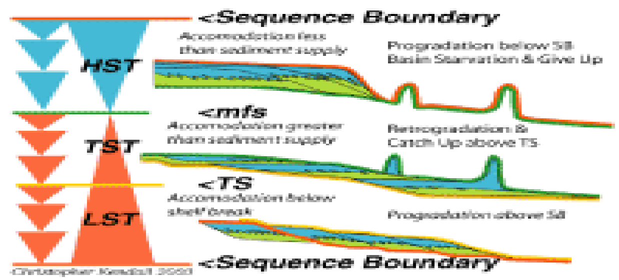


After C.R.Handford

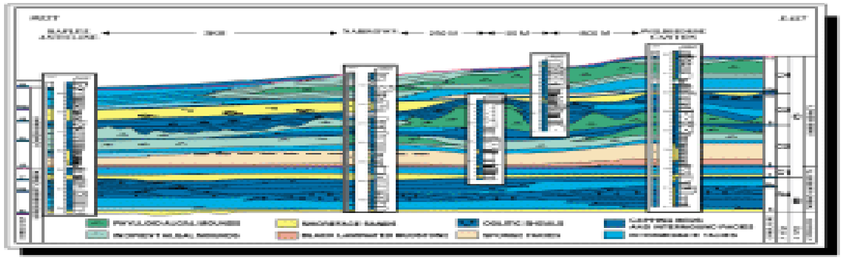
Subdivision by these surface into parasequence stacking patterns reflecting
- Grain size
- Thickness

Facies architecture & trajectory caused by changes in rates of change of sea level, sediment accumulation, and sea floor slope affecting:
- Sequence boundaries (SB)
- Flooding surfaces (TS & mfs)

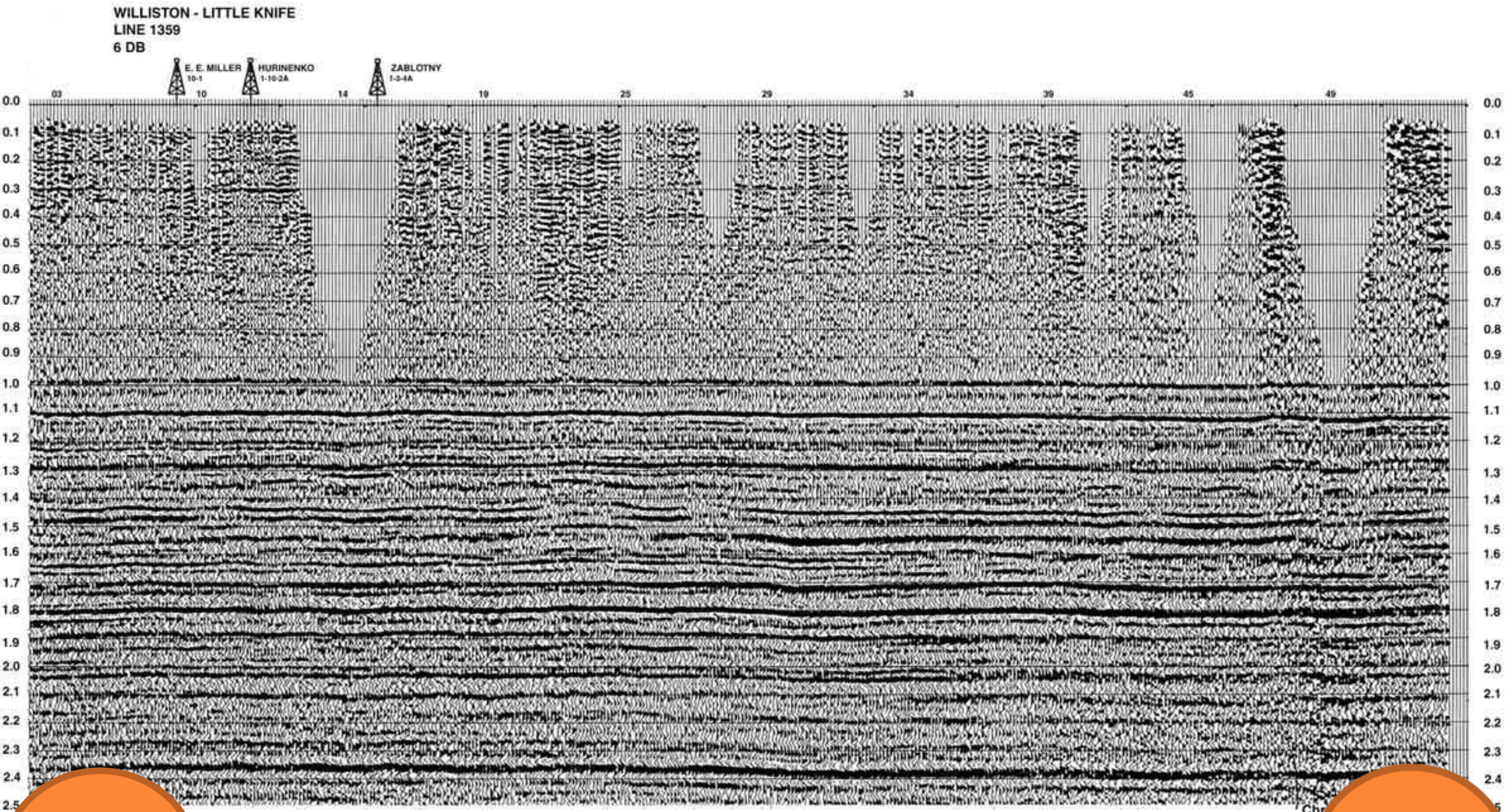
& determining direction of shoreline motion; namely
- Progradation
- Aggradation
- Retrogradation

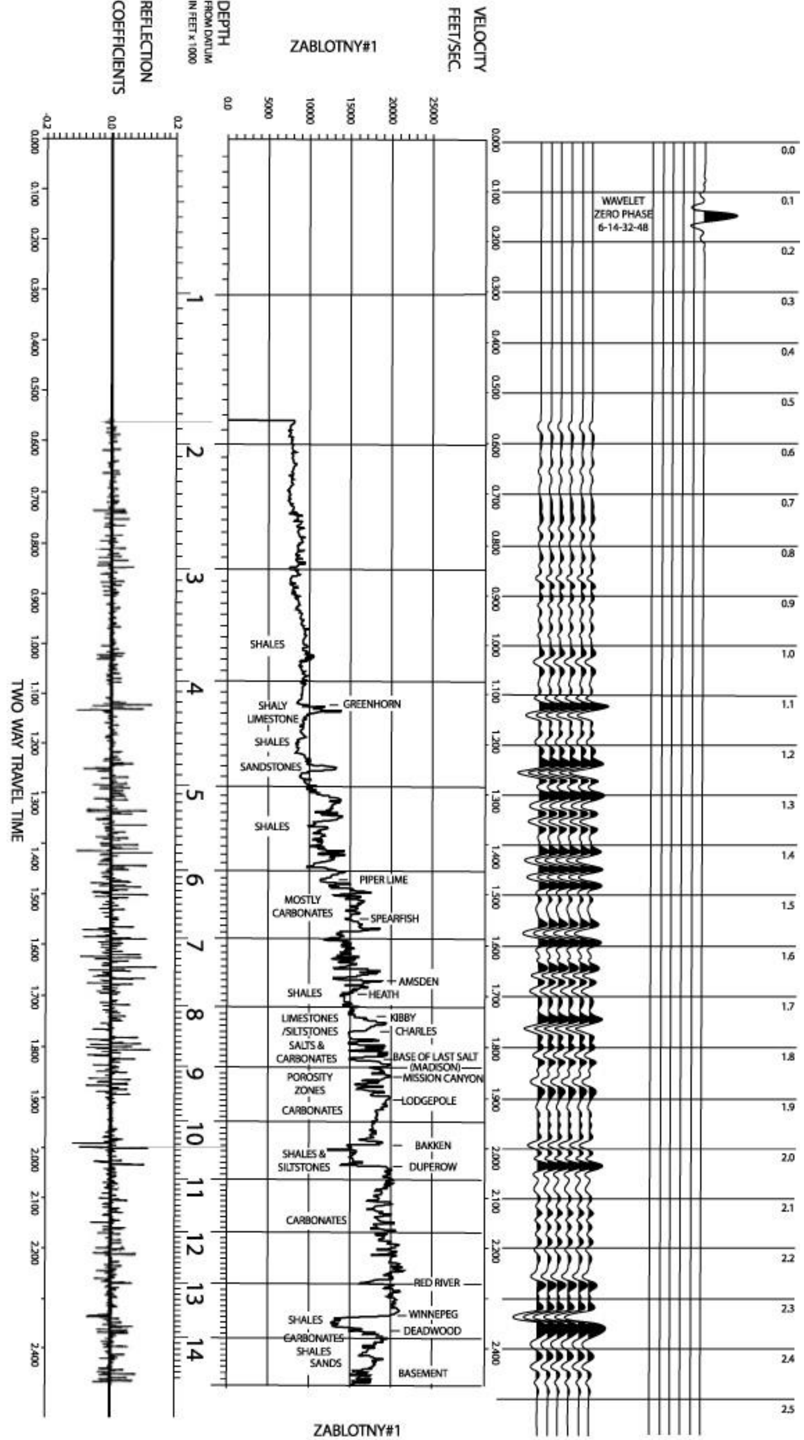


Creation of stratigraphic cross sections & geologic models of carbonates



After Eberli et al 2001


WILLISTON - LITTLE KNIFE
LINE 1359
6 DB
E. E. MILLER
10-1
HURINENKO
1-10-2A
ZABLOTNY
1-3-4A
03
10
14
19
25
29
34
39
45
49
0.0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1.0
1.1
1.2
1.3
1.4
1.5
1.6
1.7
1.8
1.9
2.0
2.1
2.2
2.3
2.4
2.5


ZABLOTNY#1
VELOCITY FEET/SEC
DEPTH FROM DATUM IN FEET x 1000
REFLECTION COEFFICIENTS
TWO WAY TRAVEL TIME
WAVELET
ZERO PHASE
6-14-32-48
SHALES
SHALY LIMESTONE
SHALES
SANDSTONES
SHALES
MOSTLY CARBONATES
SHALES
LIMESTONES /SILTSTONES
SALTS & CARBONATES
POROSITY ZONES
CARBONATES
SHALES & SILTSTONES
CARBONATES
SHALES
CARBONATES
SHALES
SANDS
GREENHORN
PIPER LIME
SPEARFISH
AMSDEN
HEATH
KIBBY
CHARLES
BASE OF LAST SALT
(MADISON)
MISSION CANYON
LODGEPOLE
BAKKEN
DUPEROW
RED RIVER
WINNEPEG
DEADWOOD
BASEMENT
ZABLOTNY#1