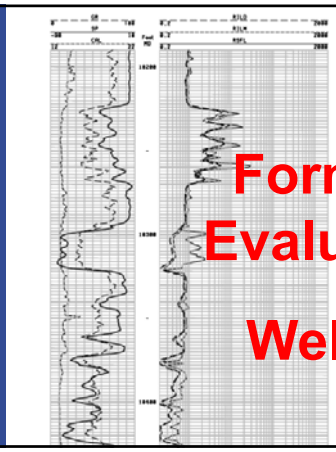


Formation Evaluations:

Well logs

Geo493K

What do we need to find out?

- Rock type?
  - Sandstone? Shale? Limestone? Mineralogy?
- Rock Properties
  - Porosity
  - Permeability
  - Bedding Orientation
  - Fractures?
  - Temperature
  - Organic content
- Fluids
  - Type (water, oil, gas)
  - Saturation
  - Salinity
  - Pressure
- Engineering
  - Well trajectory (coord)
  - Shape of hole
  - Casing Joints
  - Quality of cement
  - etc

Reading in Selley Ch. 3

What for? (Log applications)

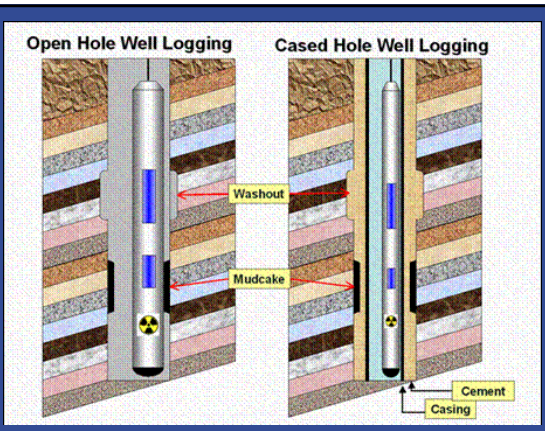
- Stratigraphic correlation
- Formation Tops
- Quantitative Oil, Gas, Water saturations
- Porosity
- Correlation with seismic data
- Sedimentological studies
- Reservoir modeling
- Structural studies
- Economics
- etc

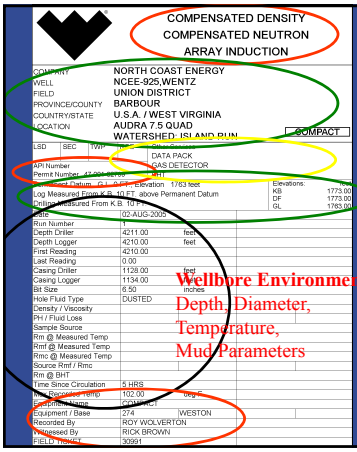
What can we measure?

- Electrical Properties
- Natural radioactivity
- Induced radioactivity
- Acoustic Properties (sonic velocity)
- Shape of hole
- Noise
- Temperature
- Depth
- Tilt of hole
- …

The Logging Operation

- Lower the tool to the bottom
- 100 to 200 feet repeat section measured at the bottom
- Then tool is raised through the entire well
- Casing may prevent some logs from working
- Logging speed: 1800 to 3600 ft/hour
- Information pertinent to both the logging run and the well is recorded on the header.
- Logs recorded digitally.





Title
Services Associated With Data on Log
Basic Information
Company, Well Name
Location
API Number
Permit Number
Other Services
During Same Trip
Detailed Location & Elevation Information
KB Kelly Bushing
DF Derrick Floor
GL Ground Level
Equipment & Personnel
Logging Engineer & Witnesses

Wellbore Environment
Depth, Diameter, Temperature, Mud Parameters

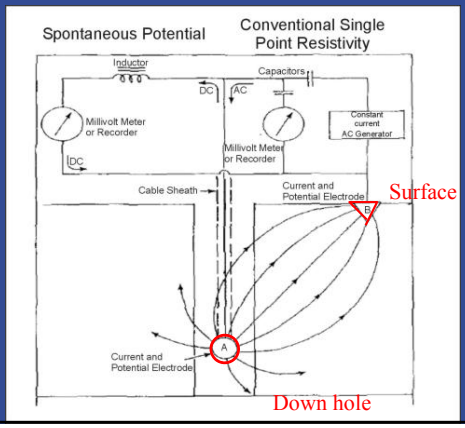
Log Types

- Lithologic Logs
  - Spontaneous Potential (SP)
  - Gamma Ray (GR)
- Porosity Logs
  - Neutron
  - Density
  - Sonic
- Resistivity Logs (Fluid Type)
  - Resistivity
  - Induction

- Other
  - Dipmeter
  - Caliper
  - Temperature
  - Acoustic
  - FMI
  - Many more …

Spontaneous Potential (SP)

- One of the Oldest Logging Measurements
  - Used Commercially in 1931
- Discovered as Noise in Resistivity
- Found to be Related to Presence of Sandstone
- Lithology tool



The well works like a battery

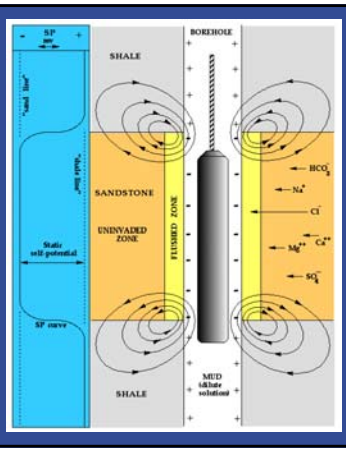
$E = -K \log (a_w/a_{mf})$

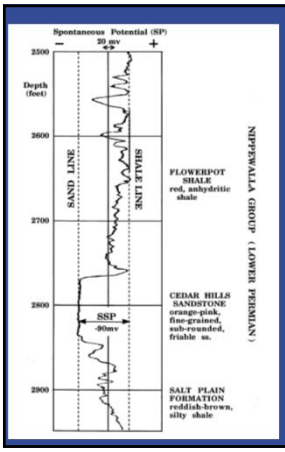
E is in millivolts

a_w = water salinity

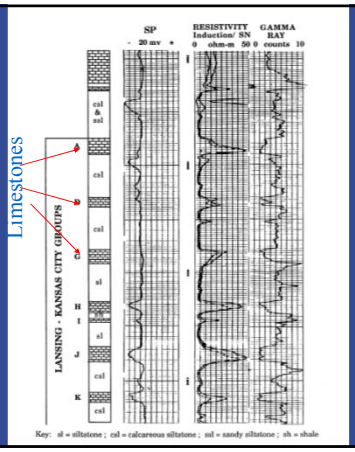
a_{mf} = mud salinity

Ion flow is easier in permeable sandstones





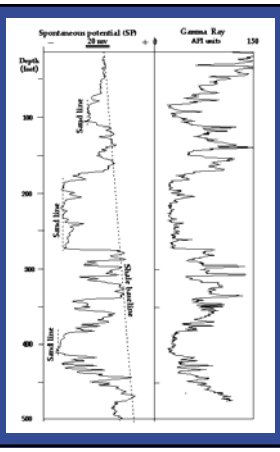
Typical SP log



SP has Poor Limestone Response

Spontaneous Potential (SP) Drift

SP readings are depth-dependent

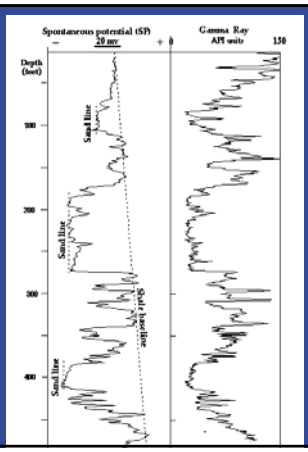


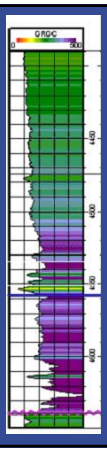
Gamma Ray Log

- Lithology log
- Measures natural radioactivity
- Uses a scintilometer (Geiger counter)
- Potassium (K), Uranium (U), Thorium (Th), Phosphorous (P)
- K → abundant in clay → shales
- Unaffected by fluids
- High U → reducing environ. → abundant organic matter
- "API units", relative to a standard

SP and Gamma Ray

- Gamma Ray in API Units
- Plotted on the left of the well
- Shales swing right





Marcellus Gamma Ray

Mahantango Fm.

Green = low GR
Purple = high GR

Lower Marcellus

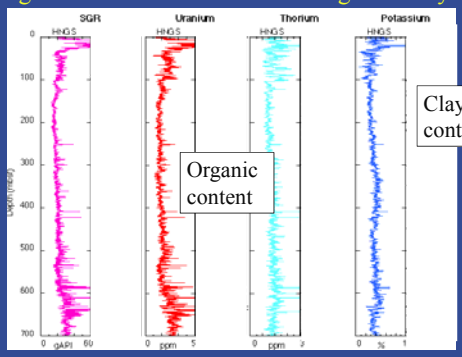
Onondaga Limestone

Pimpinella 1

MegaEnergy Op. Inc.

Spectral Gamma Ray

Distinguishes the different sources of gamma rays

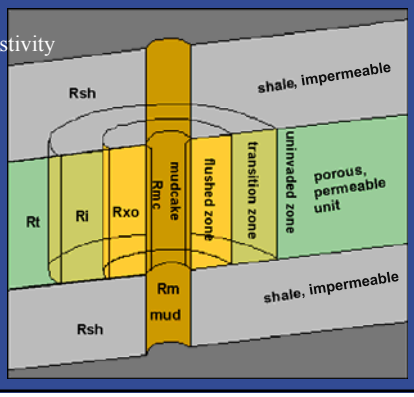


Resistivity Log Applications

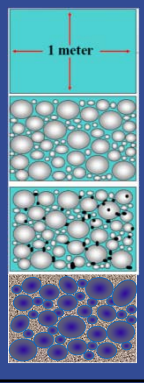
- Determination of Hydrocarbon-Bearing vs. Water-Bearing Zones
- Water Saturation S_w
- Geopressure Detection
- Depth of Invasion
- Stratigraphic Correlation

The Borehole Environment

R= resistivity (ohms)



Resistivity



Resistivity of Saline Water - Rw

Resistivity of Water and Formation

Resistivity of Water, Hydrocarbons, and Formation

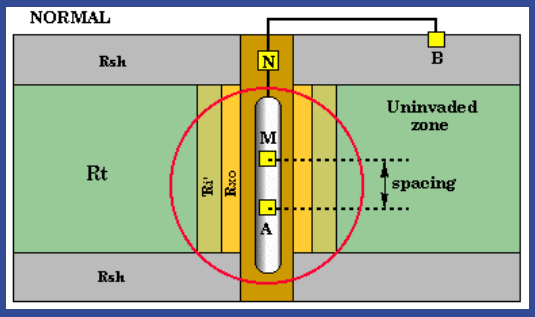
Resistivity of Tight Formation (no porosity)

Resistivity Tool Background

- Three Classes
  - Electrode Logs
  - Laterologs
    - Focused Electrodes
  - Induction
- Measure Resistivity in Ohms

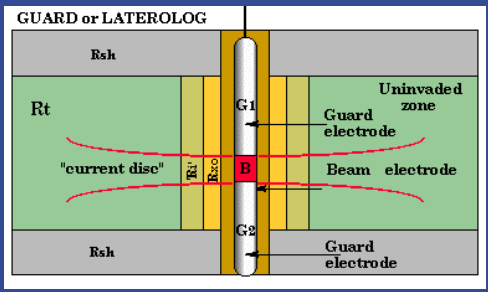
Normal Resistivity Tool

Spacing of electrodes determines penetration



Guard or Laterolog Tool

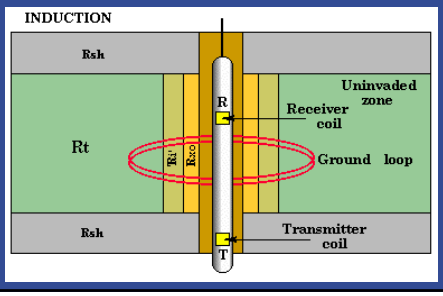
The guard electrodes focus the current in a narrow disk



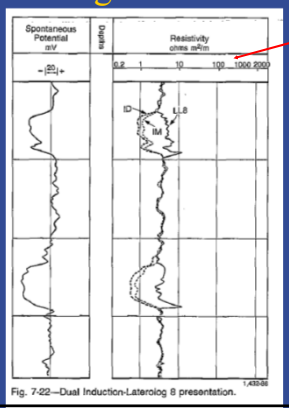
Induction (Conductivity) Tool

Receiver coil measures the induced electrical field created in the rocks by the transmitter coil

Works with oil based mud, or air



Log Presentation and Scales



Log Scale Ohms

ID, IM, LL8 measure resistivity at different distances form the borehole.

ID= deep induction

IM= medium induction

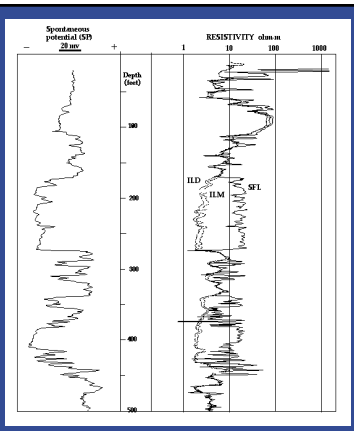
LL8= shallow induction

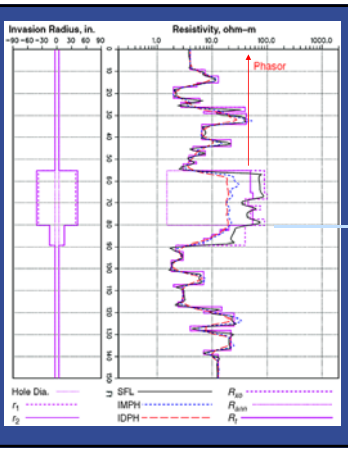
Resistivity logs : spherically-focussed (SFL),

medium induction (ILM), and

deep induction (ILD)

Is there oil in these reservoirs?





Model Resistivity Logs

Gas zone (50 Ω)

Water zone (2-20 Ω)

Flushed zone

Uninvaded zone

Calculating Water Saturation

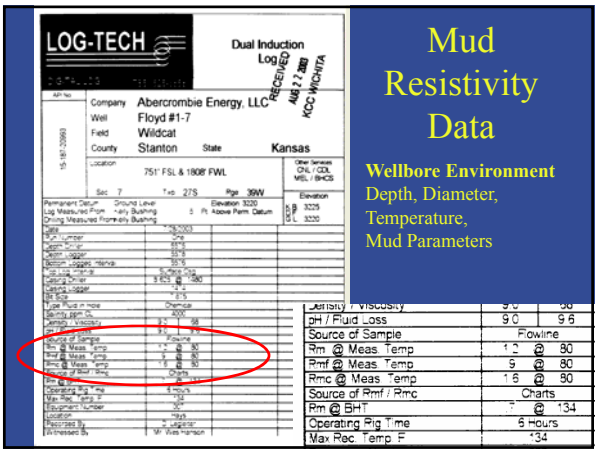
$$S_w = \frac{(R_{xo}/R_t)^{5/8}}{(R_{mf}/R_w)}$$

R_{xo}= Resistivity of flushed zone

R_w= Resistivity of formation water

R_{mf}= Resistivity of mud filtrate

Rt= Resistivity of uninvaded zone


LOG-TECH

Dual Induction Log

RECEIVED
AUG 27 2008
KCC WICHITA

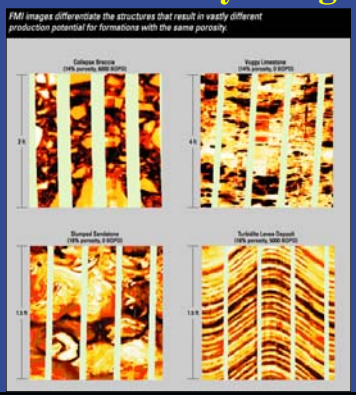
Company Abercrombie Energy, LLC
Well Floyd #1-7
Field Wildcat
County Stanton State Kansas
Location 751' FSL & 1808' FWL
Sec 7 Twp 27S Rge 39W
Permanent Datum Ground Level Elevation 3230
Log Measured From Kelly Bushing 5 Ft Above Perm. Datum
Drilling Measured From Kelly Bushing
Elevation 3225 KB 3230 DF 3229 GL 3220

Density / Viscosity	9.0	56
pH / Fluid Loss	9.0	9.6
Source of Sample	Flowline	
Rm @ Meas. Temp	1.2 @ 80	
Rmf @ Meas. Temp	.9 @ 80	
Rmc @ Meas. Temp	1.6 @ 80	
Source of Rmf / Rmc	Charts	
Rm @ BHT	.7 @ 134	
Operating Rig Time	6 Hours	
Max Rec. Temp. F	134	

Mud Resistivity Data

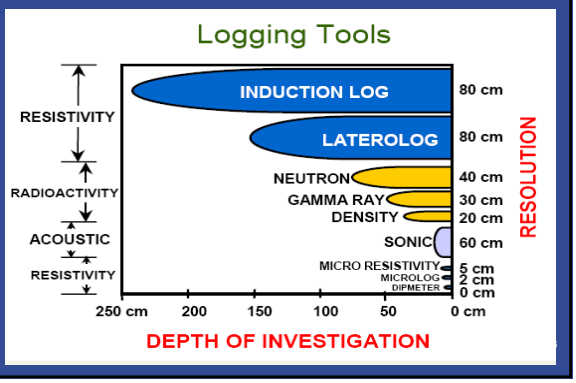
Wellbore Environment
Depth, Diameter, Temperature, Mud Parameters

Resistivity Imaging Logs



FMI = Formation Micro Imaging

Resolution vs. Investigation

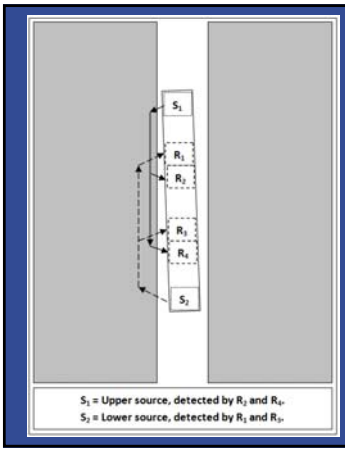


Sonic Logs

Measures of interval travel time in formation

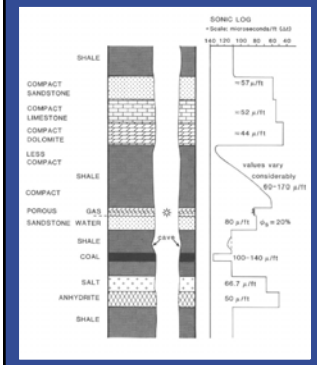
Δt (μsec/ft) = 1/V

- Δt is related to Density which depends on: Lithology, Porosity, and Fluid Content
- Used to generate Synthetic Seismic traces to link wells logs to seismic data



Source-receiver arrangement for a sonic logging tool

Sonic Logs



Rock matrix

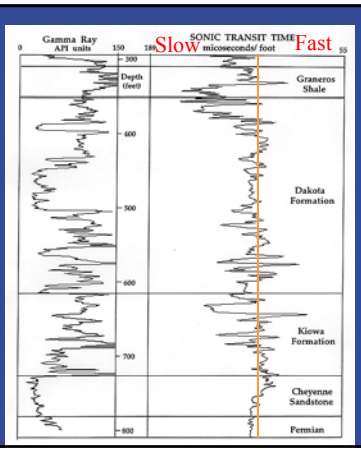
Log meas.

$$\phi_s = \frac{\Delta t - \Delta t_{ma}}{\Delta t_p - \Delta t_{ma}}$$

Porosity Pore fluid

Mineral	Δt_{ma} (μs/ft)	ρ_{ma} (g/cc)	V_{ma} (ft/s)
Compact sandstone	55.6 – 51.3	2.65	18000 – 19500
Limestone	47.6 – 43.5	2.71	21000 – 23000
Dolomite	43.5 – 38.5	2.87	23000 – 26000
Anhydrite	50.0	2.98	20000
Halite	66.7	2.03	15000
Shale	170 – 60	2.4 – 2.7	5880 – 16660
Bituminous coal	140 – 100	1.2 – 1.8	7140 – 10000
Lignite	180 – 140	1.1 – 1.5	5560 – 7140
Casing	57.1	7.85	17500
Water, 200,000 ppm, 15 psi	189.3	1.15	5340
Water, 150,000 ppm, 15 psi	186.0	1.12	5380
Water, 100,000 ppm, 15 psi	182.5	1.09	5500
Oil	238	0.85	4200
Methane, 15 psi	626	0.25	1600

Glover

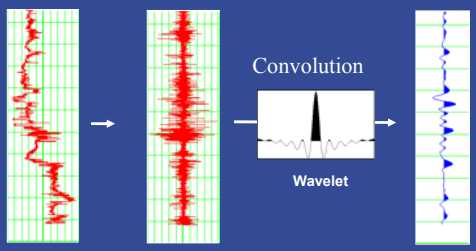


Sonic Log Example

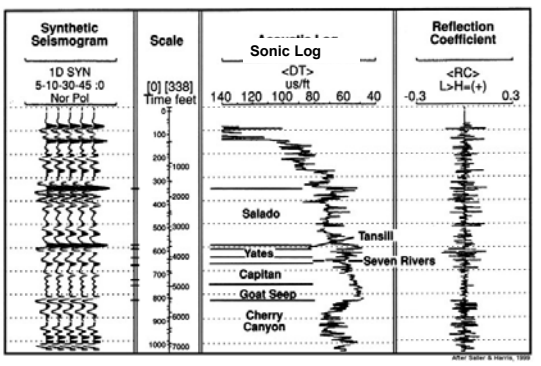
Which unit is the best reservoir (low shale and high porosity)?

Well KGS Brungardt #1
Ellis Co., Kansas

Creating synthetic seismic data:



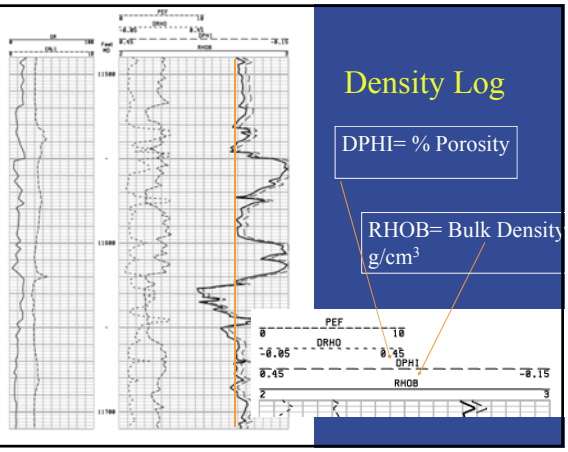
Correlate seismic data (in time) to well data (in depth)



Density Log

- Tool emits gamma rays
- Detects returning scattered gamma rays
- Gamma ray absorption is proportional to rock density

- Measures Density - ρ
- Tied to Lithology, Porosity, and Fluid Content



Density Log

DPHI= % Porosity

RHOB= Bulk Density g/cm^3

Porosity Calculation

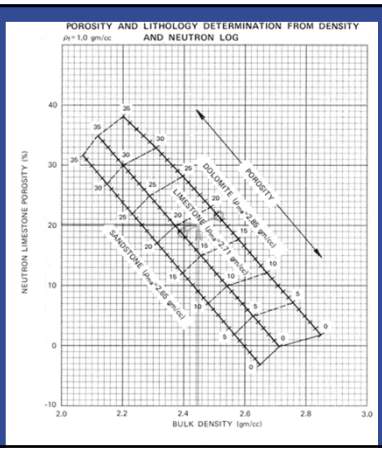
$$DPHI = \phi_D = \frac{RhoMa - RHOB}{RhoMa - RhoFl} = \frac{\rho_{ma} - \rho_b}{\rho_{ma} - \rho_{fl}}$$

DPHI = ϕ_D = density porosity
RHOB = ρ_b = bulk density (from the log)
RhoMa = ρ_{ma} = matrix density
RhoFl = ρ_{fl} = fluid density (often assumed to be mud filtrate density)

	Matrix Value RhoMa		Fluid Value RhoFl	
Sandstone	2.65	2650		
Limestone	2.71	2710		
Dolomite	2.87	2870		
Anhydrite	2.98	2980		
Halite	2.04	2040		
Coal	~1.2	~1200		
Barite	4.09	4090		
Gas			.2	200
Oil			~0.85	~850
Water			1.0 to 1.2	1000 to 1200
Units	*g/cm3*	*Kg/m3*	*g/cm3*	*Kg/m3*

Neutron Log (CNL)

- Tool has a neutron source
- H absorbs neutrons and emits gamma rays
- Tool detects the emitted gamma rays
- H is mostly in formation fluids (water and hydrocarbons)
- Can be run through casing
- Reads low in gas zones
- Cannot distinguish oil from water



Porosity calibration

If lithology is known, neutron and density logs can be calibrated for porosity

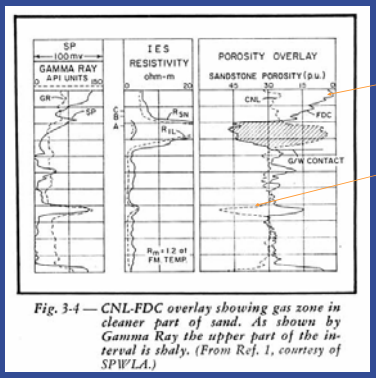
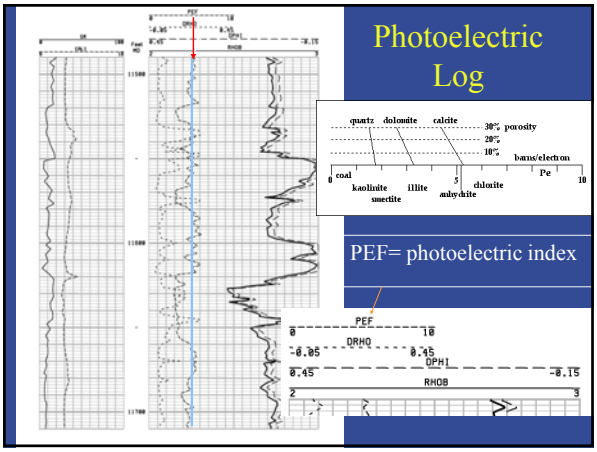


Fig. 3-4 — CNL-FDC overlay showing gas zone in cleaner part of sand. As shown by Gamma Ray the upper part of the interval is shaly. (From Ref. 1, courtesy of SPWLA.)

Density Porosity

Neutron

Cross over indicates gas



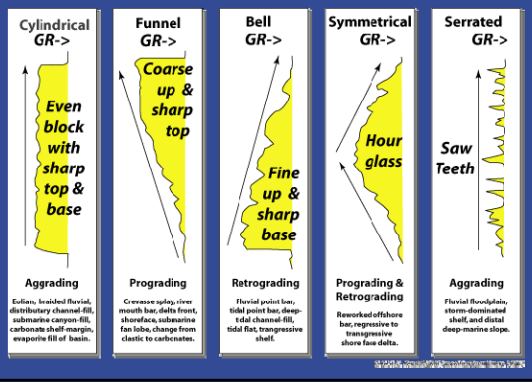
Photoelectric Log

PEF= photoelectric index

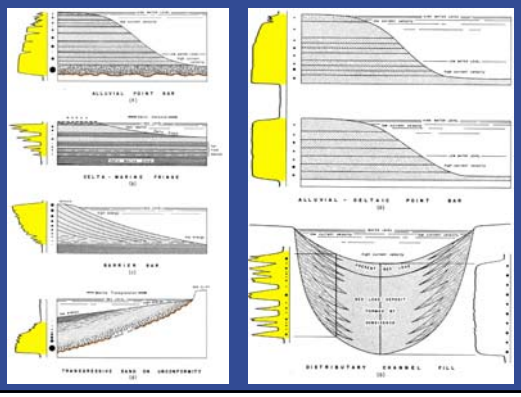
Applications of logs

- Stratigraphic studies
  - Sedimentary facies
- Well correlation
- Reservoir models
- Structural interpretation
  - Fault recognition

Gamma Ray Response to Grain Size



Relating log character to sedimentary facies

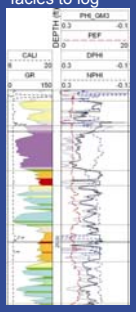


Building a reservoir model model

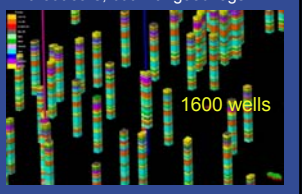
1. Define facies in core

28 cores

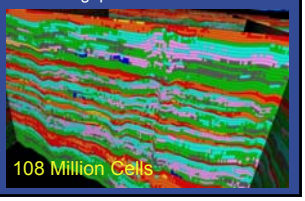
2. Relate facies to log



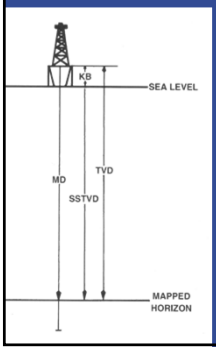
3. Predict facies in wells without core, but with good logs



4. Fill the gaps between wells



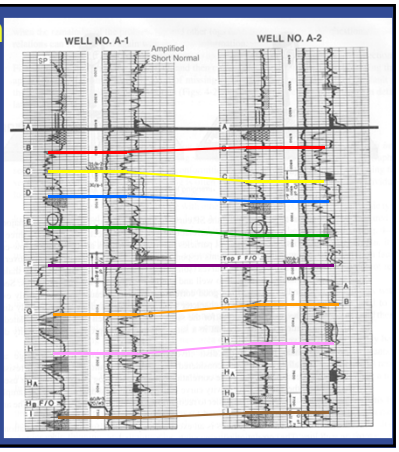
Log Datum Terminology

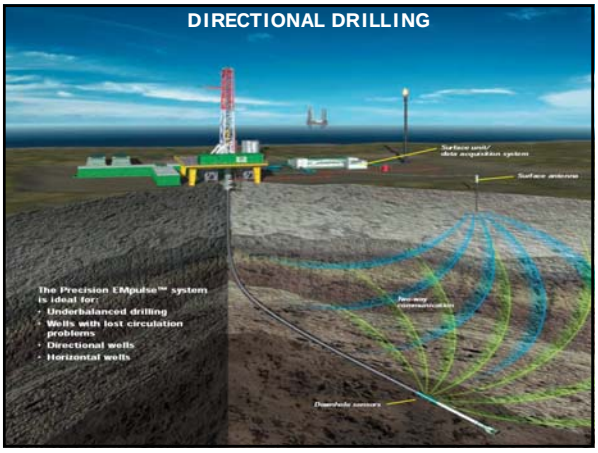


- KB - Kelly Bushing elevation.
- MD - Measured Depth along the wellbore from the Kelly bushing (usually)
- SS – Subsea Depth (Relative to Sealevel)
- TVD – True Vertical Depth, (important for non-vertical wells)
- SSTVD - Sub-Sea True Vertical Depth

Correlation Example

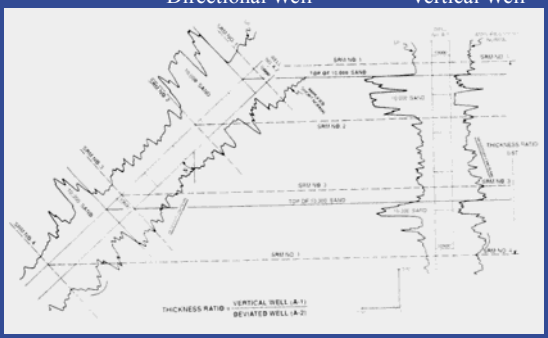
Major Sands on SP





Correlation of directional wells

Directional Well Vertical Well



MWD (or LoggingWD)
Measurement While Drilling

- Tools are part of bottom hole assembly (BHA).
- Gamma ray, directional survey, tool face, borehole pressure, temperature, vibration, shock, torque etc.
- Telemetry for steering well
- Results transmitted digitally
  - mud pulser telemetry

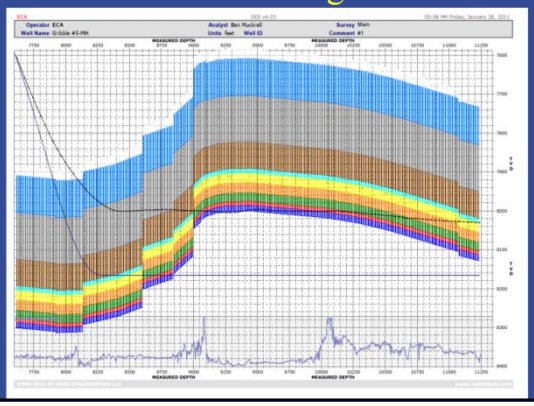
Logging While Drilling
Data Transmission

Mud Pulse Telemetry (Pressure pulses)

Electromagnetic Telemetry (Using conductivity of drill pipe)

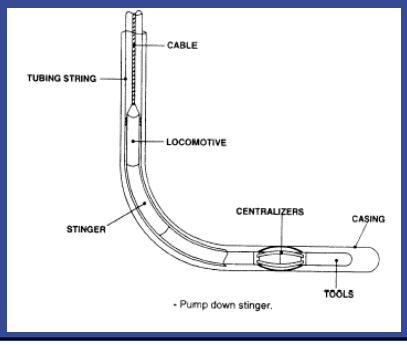
Wired Drill Pipe (The future. Faster and better, but delicate)

Geosteering



Full Logs in Horizontal wells

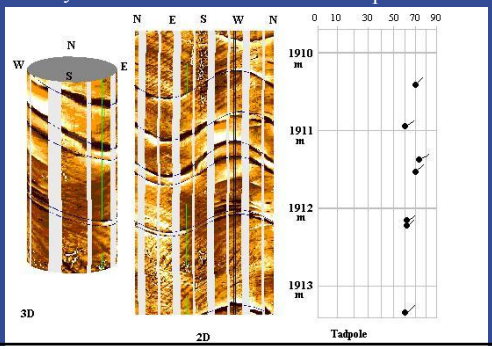
- How do you move the logging tools through the horizontal well?



FMI and Dipmeter Logs

FMI= Formation Micro Imager
Resistivity tools

Dipmeter



Dipmeter Interpretation

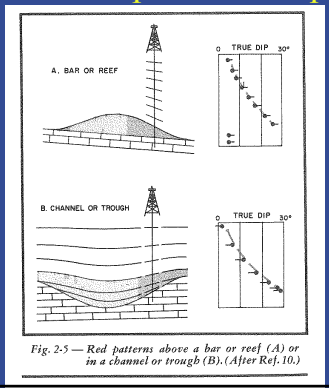


Fig. 2-5 — Red patterns above a bar or reef (A) or in a channel or trough (B). (After Ref. 10.)

Older, simpler version of FMI

Vertical dip variation is characteristic of the structure

Take Home Ideas

- Well logs provide key data for understanding the subsurface
- Lithology, porosity and fluids are 3 important log families
- Usually you can't measure these properties directly, so you must use proxies or indirect measurements
- Multiple logs used in combination are most powerful