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Spontaneous Potential

General

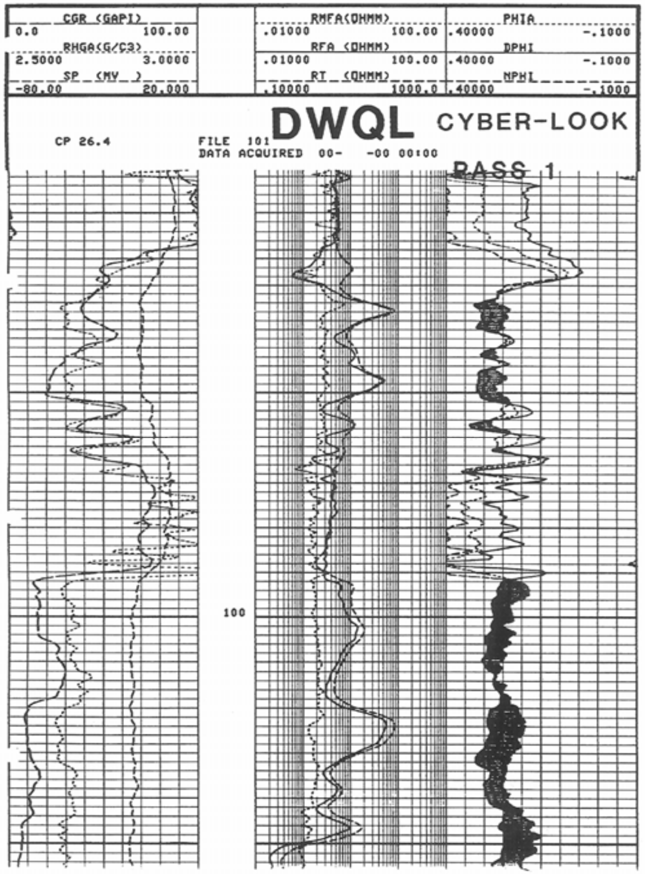
- Spontaneous Potential is one of the earliest logs used and still in use
- Primarily used for determining gross lithology, i.e reservoir vs non-reservoir (permeable vs non-permeable)
- Correlation
- Several other equally important use

The SP Log

- A record of *Direct Current (DC) voltage* (or *Potential*) that develops naturally (*spontaneous)* between a moveable electrode in the well and a fixed electrode located at the surface
- Measured in *millivolts (mV)*
- Mnemonics: SP
- SP response created by electric voltages arising from elctrochemical factors in the borehole and adjacent rocks
- SP Readings are caused by differences in salinities between mud filtrate and formation waters in permeable beds
- Salinity of a fluid is inversely proportional to its resistivity, so in practice mud filtrate salinity is indicated by mud filtrate resistivity (R_{mf}) and formation water salinity by formation water resisitivity (R_w)
- Conductive fluid necessary in borehole to create SP response, so SP cannot be used in nonconductive (e.g. oil based) drilling muds or in air-filled holes

The SP Log

- Usually displayed in the left track (correlation)
- Used to
  - Detect permeable beds
  - Detect boundaries of permeable beds
  - Determine formation-water resistivity (R_w)
  - Determine the volume of shale in permeable beds
  - Detection of hydrocarbons by the suppression of the SP curve



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Introduction to the term *SSP*

- SSP:
  - Static Spontaneous Potential
  - Maximum SP that a thick, shale free, porous and permeable formation can have for a given ratio between R_{mf} and R_w
  - Determined by formula or by chart
  - Necessary for determining accurate values of R_w and volume of shale

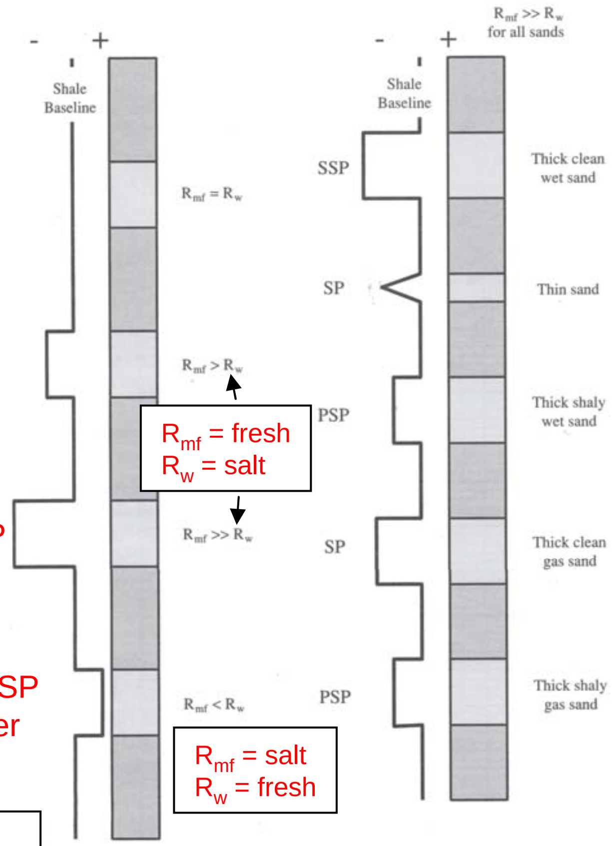
What influences SP measurement

- SP influenced by:
  - Bed thickness
  - Bed resistivity
  - Borehole diameter
  - Invasion
  - Shale content
  - Hydrocarbon content

  and, most important
  - Ratio of R_{mf} and R_w

Normal SP

Reversed SP
Fresh water

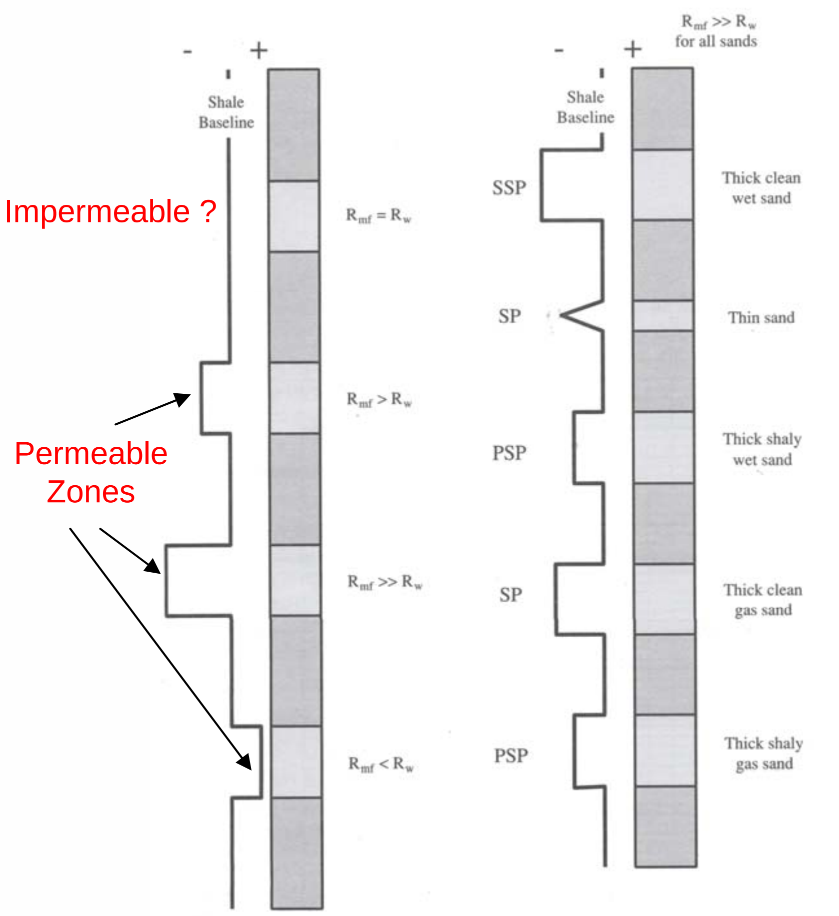


SSP: Max deflection possible for given Rmf/Rw
SP: SP response due to presence of thins beds and/or gas presence
PSP: Pseudostatic SP; SP when shale is present

What influences SP measurement

- Bed Thickness
  - Thin formations (<3m) the measured SP is less than the SSP.
  - Narrow, pointed SP curve; correction for bed thickness required
- Bed Resistivity
  - Higher resistivities reduce the reflection of the SP curve
- Borehole and Invasion
  - Usually very small and can, in general, be ignored
- Shale Content
  - Presence of shale in a permeable formation, reduces the SP deflection
- Hydrocarbon Content
  - In hydrocarbon-bearing zones, the SP curves deflection is reduced: ***Hydrocarbon suppression*****.** Only qualitative, not possible to determine S_{hc}

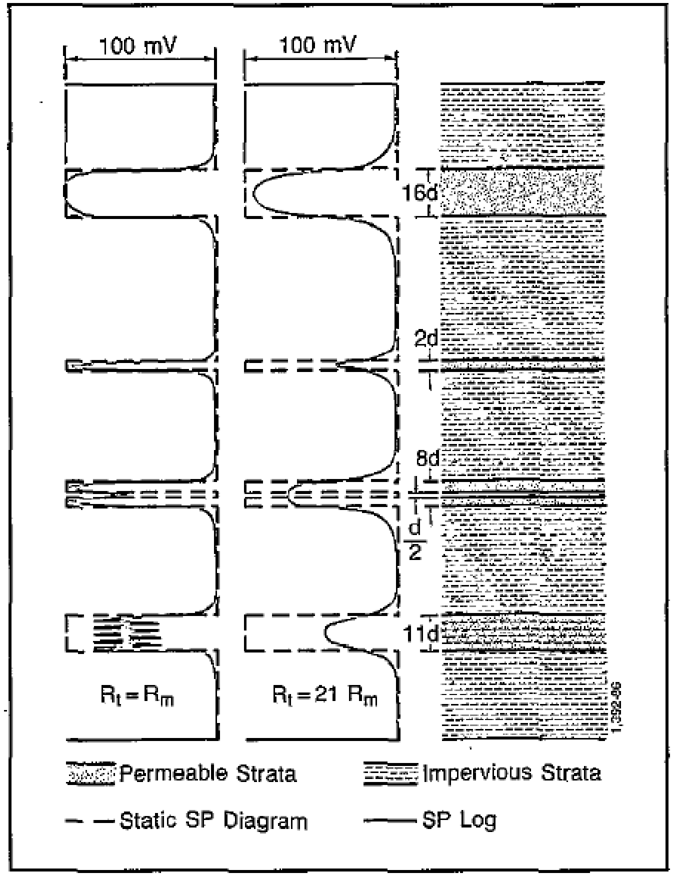
Shale Baseline



- Shale Baseline:
  - The relatively constant SP response of shales
  - Assumed to be zero
  - Permeable zones indicated where there is a deflection from the shale baseline
    - SP readings are measured relative to the shale baseline
  - Can drift over long distances. Of little consequence for single formations

Shape of the SP curve

- Shape and Amplitude of the SP deflection opposite a permeable bed depends on:
  - Thickness, *h*, and true resistivity, R_t, of the permeable bed
  - Resistivity, R_{xo}, and diameter, d_i, of the zone contaminated by mud filtrate invasion
  - Resistivity, R_s, of the adjacent shale formation
  - Resistivity of the mud, R_m, and the diameter, d_h, of the borehole



Formation Water Resistivity (R_w) from SP

Remember:

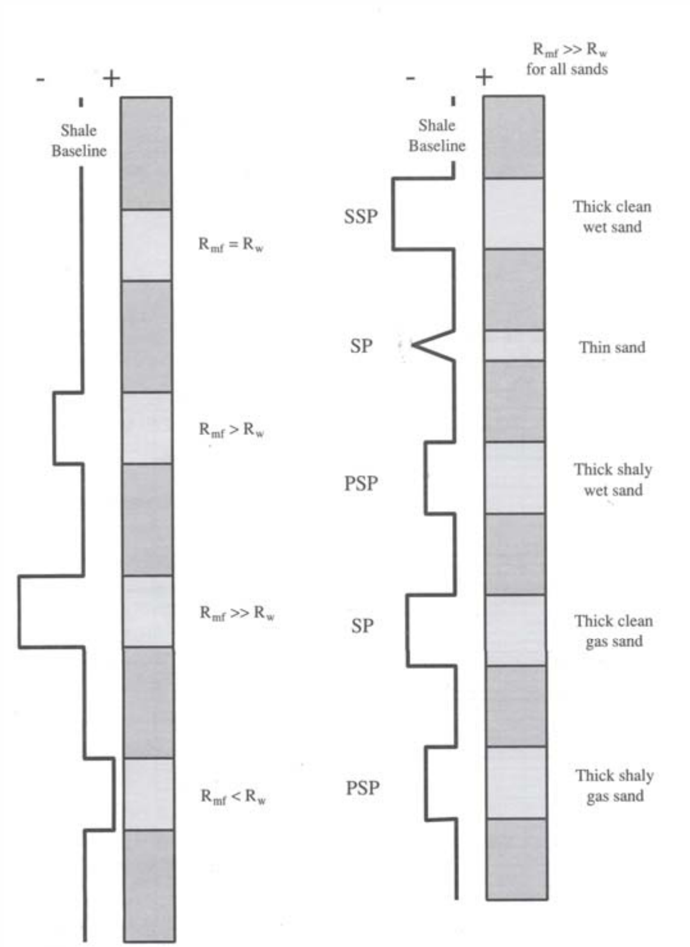
$$S_w = \left(\frac{R_0}{R_t}\right)^{\frac{1}{n}} = \left(\frac{F \times R_w}{R_t}\right)^{\frac{1}{n}} = \left(\frac{a \times R_w}{R_t \times \phi^m}\right)^{\frac{1}{n}}$$

- Procedure:
  - Necessary info: R_{mf} and R_m (at a given T), T_{surf}, TD, BHT
  - Determine Formation Temperature, T_f *(calculate or chart Gen-6)*
  - Correct R_m and R_{mf} for T_f *(chart Gen-9)*
  - Determine *SP* from log: Max SP – Shale Baseline SP
  - Correct *SP* to *SSP* for thin beds (*chart SP4-6*)
  - Determine R_{mf}/R_{we} ratio and from that R_{we} (*chart SP1*)
  - Correct R_{we} to R_w (*chart SP2-3*)

Formation Water Resistivity (R_w) from SP

Identify a zone on the log that is clean, wet and permeable. Pick the max. value of SP in that zone	
Calculate formation T at the depth of SP BHT – Bottom Hole Temperature AMST – Annual Mean Surface Temperature FD – Formation Depth TD – Total Depth T_f – Formation Temperature	$T_f = \left(\frac{BHT - AMST}{TD} \times FD \right) + AMST$
Convert R_{mf} from surface T to formation temperature R_{mf} – R_{mf} at formation temperature R_{mfsurf} – R_{mf} at measured temperature T_{surf} – Measured temperature of R_{mf}	$R_{mf} = \frac{R_{mfsurf}(T_{surf} + 6.77)}{T_f + 6.77}$
Find the equivalent formation water resistivity, R_{we}, from the SP and R_{mf} R_{we} – equivalent R_w	$R_{we} = R_{mf} \times 10^{SP/(61+0.133 \cdot BHT)}$
Convert R_{we} to R_w (at formation T)	$R_w = \frac{R_{we} + 0.131 \times 10^{\left[\frac{1}{\log(BHT/19.9)}\right]-2}}{-0.5 \times R_{we} + 10^{\left[\frac{0.0426}{\log(BHT/50.8)}\right]}}$

Calculation of Shale Volume with SP



$$V_{shale} = 1.0 - \frac{PSP}{SSP}$$

or

$$V_{shale} = \frac{PSP - SSP}{SP_{shale} - SSP}$$

Volume of shale is used in the evaluation of shaly sand reservoirs and as mapping parameter for both sandstone and carbonate facies analysis

Summary

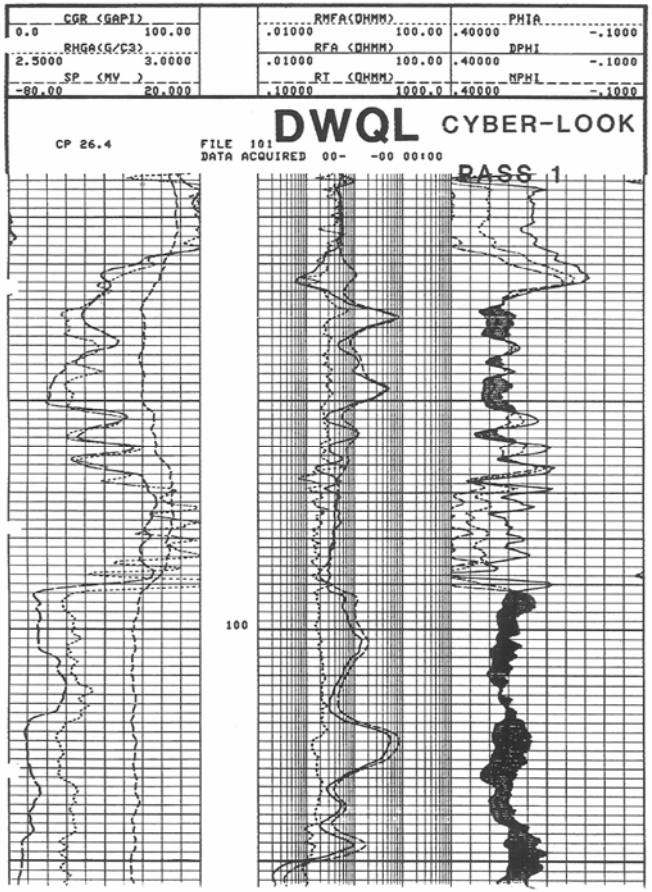
Principal uses of the SP log

	Used for	Knowing
Quantitative	*R_w*	*R_{mf} and T*
	V_{sh}	*SSP and Shale Baseline*
Qualitative	*Permeability indicator*	*Shale Baseline*
	Facies (shaliness)	*Clay/Grain size relationships*
	Correlation	

Gamma Ray

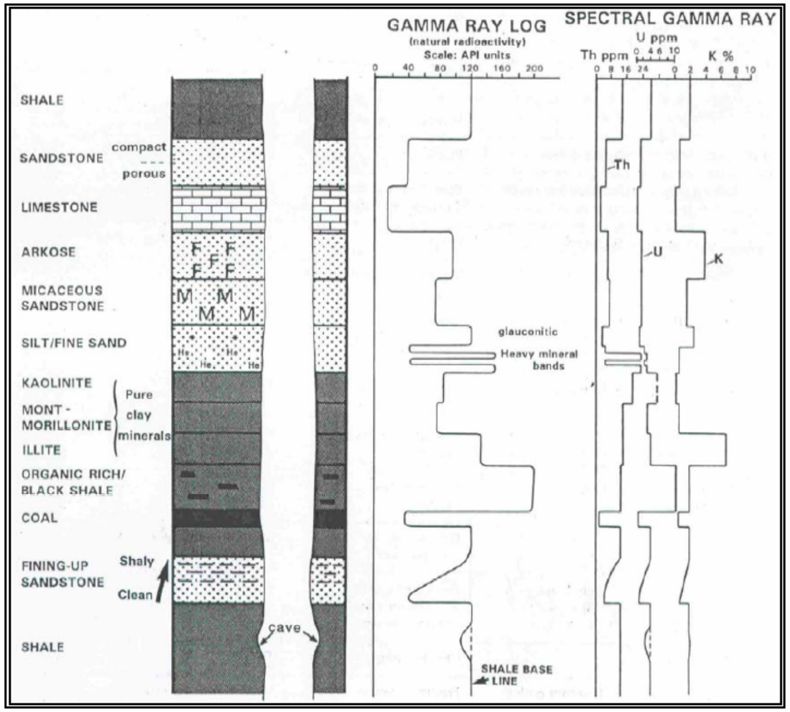
General

- Gamma Ray (GR) tool measures the *natural radioactivity* in formations
- Used to identify lithologies, correlation and V_{sh} calculation
- Shale-free sandstones and carbonates have low concentrations of radioactive material and give low GR readings
- Increasing shale content (= increasing content of radioactive material) cause increasing GR readings
- Be aware, clean sst with K-feldspar, mica, glauconite, or U-rich waters may also produces high GR readings
- Usually displayed in the left track (Correlation track)



Curve Name	***Mnemonics***	***Units***
(Total) Gamma Ray	*GR*	*API*
U-free GR	*GRS, SGR, KTH*	*API*
Potassium	*POTA, K*	*Percent*
Uranium	*URAN, U*	*Ppm*
Thorium	*THOR, TH*	*ppm*

Spectral GR



- The spectral Gamma Ray (SGR) log records not only the number of gamma rays emitted, but also the energy of each
- Processing that information gives curves for the presence of Th, K and U in the formation
- High K, High GR response may indicate a feldspathic, glauconitic or micaceous sst

Calculation of Shale Volume with GR

$$I_{GR} = \frac{GR_{\log} - GR_{\min}}{GR_{\max} - GR_{\min}}$$

$$V_{sh} = 0.083\left(2^{3.7 \cdot I_{GR}} - 1\right)$$

Lariono (1963) *Tertiary Rocks*

$$V_{sh} = \frac{I_{GR}}{3 - 2 \times I_{GR}}$$

Steiber (1970)

$$V_{sh} = 1.7 - \left[3.38 - \left(I_{GR} - 0.7\right)^2\right]^{\frac{1}{2}}$$

Clavier (1971)

$$V_{sh} = 0.33\left(2^{2 \cdot I_{GR}} - 1\right)$$

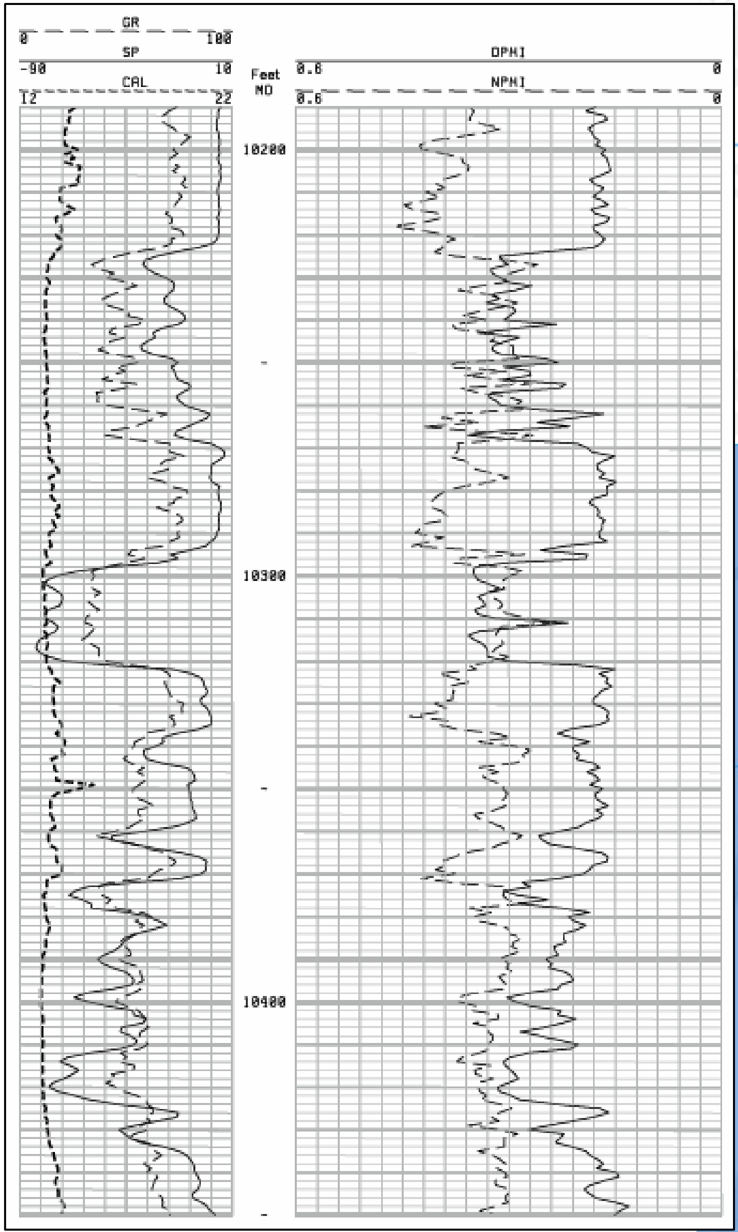
Larionov (1969) *Older rocks*

- First step is to calculate the GR Index (I_{GR})
- Successively, several non-linear relationships may be applied depending on fomation age or other local information

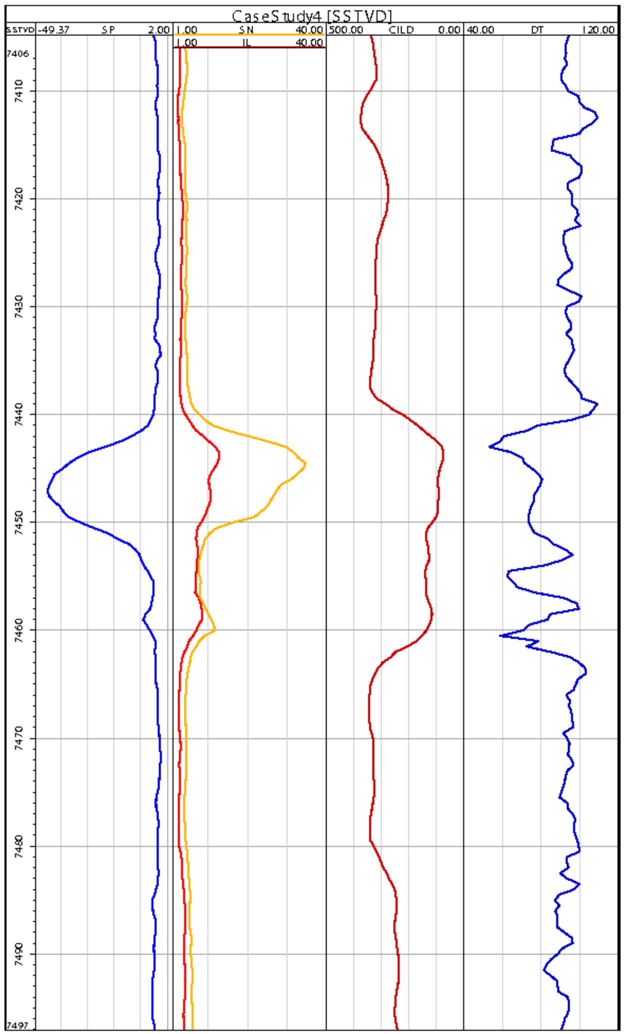
Caliper

Caliper log

- Interpretation goals:
  - Indication of hole diameter and volume
  - Qualitatice indication of permeability
  - Correlation
  - Log quality control
- Units: inches, cm
- Mnemonics: CAL, CALI



Examples



Well log data for Case Study 4 in Basic Well Log Analysis by Asquith and Krygowski

- **Detemine the R_w from the SP log**
- Given:
  - R_{mf} = 0.51 ohmm at 135°F (BHT)
  - R_m = 0.91 ohmm at 135°F (BHT)
  - Surface Temperature = 60°F
  - Total Depth (TD) = 8007 ft
  - Bottom Hole Temperature (BHT) = 135°F
- From the log:
  - Formation Depth at SP_{max} = 7446 ft
  - Bed Thickness = 7450 – 7442 = 8 ft
  - Short normal resistivity (Ri = Resistivity of the invaded zone) = 33 ohmm

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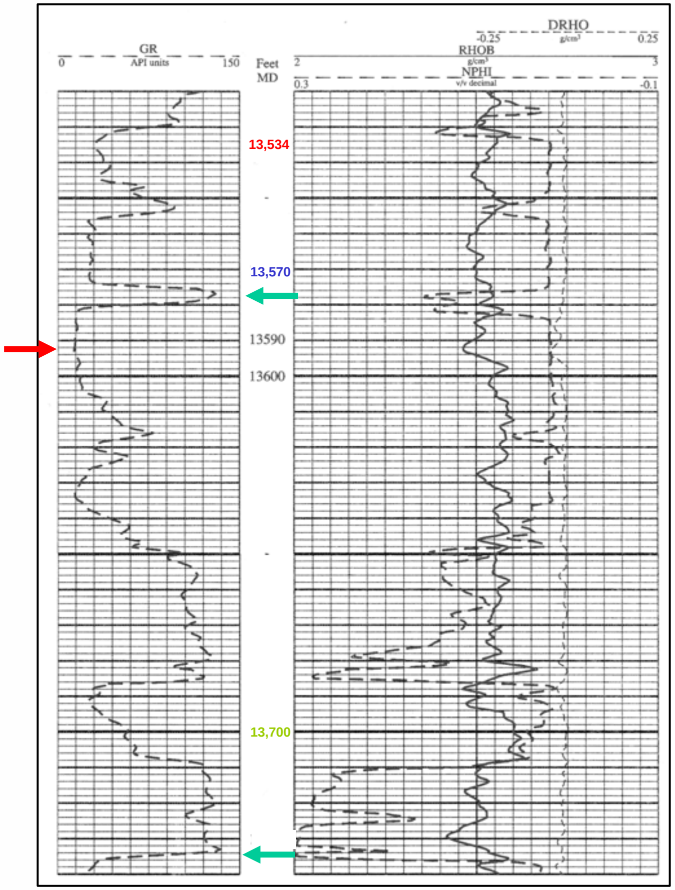
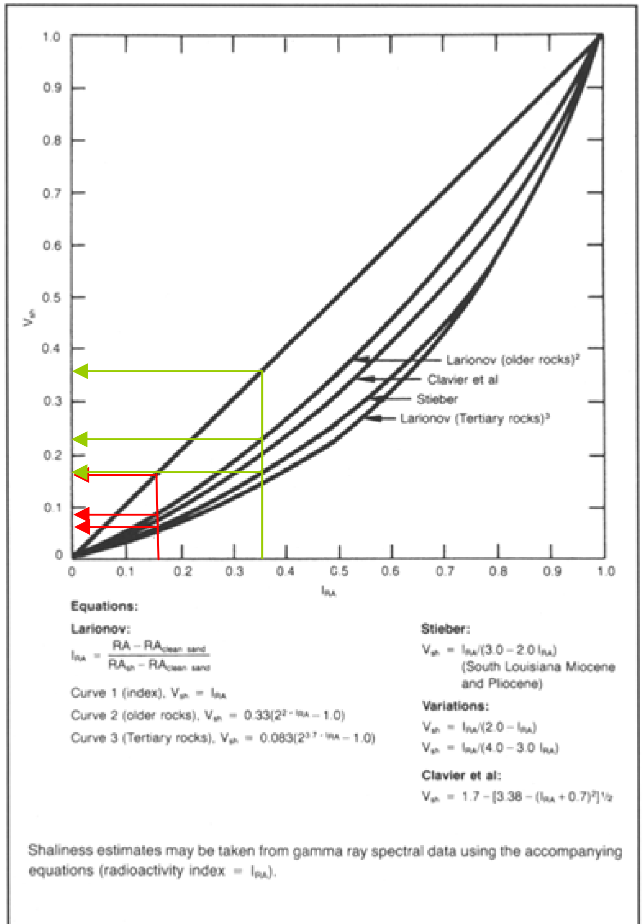
Examples



- Determine V_{sh} from GR
- From the log:
  - GR_{min} = 14 API at 13593 ft
  - GR_{max} = 130 API at 13577 ft and 13733 ft

Depth (ft)	GR_{log}	I_{GR}
13,534	32	0.16
13,570	28	0.12
13,700	55	0.35

Examples



Determine Vsh from GR

Depth	GR_{log}	I_{GR}	Shale Volume		
			Linear	Larionov (older rocks)	Steiber
13,534	*32*	*0.16*	*0.16*	*0.08*	*0.06*
13,570	*28*	*0.12*	*0.12*	*0.06*	*0.04*
13,700	*55*	*0.35*	*0.35*	*0.23*	*0.16*

Exercise