Passive or Spontaneous Logs

(SP, GR, SPECTRA GR, CALIPER)

By

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Lecture Outline

- Introduction
- Spontaneous Potential (SP) Log
  - Tool Physics
  - Measurement and Interpretation, Rw
- Gamma Ray Log
  - Tool Physics
  - Measurement and Interpretation
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  - Tool Physics
  - Measurement and Interpretation
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Introduction

- We'll start looking at specific logging tools in detail
- We'll start by looking at Natural, Passive or Spontaneous measurements.
- These tools measure natural phenomenon in the wellbore due to the drilling activity, wellbore interactions and other natural or spontaneous property of the formation
- These tools are mostly used for correlation, identifying lithologies, indicating volume of shale, and as qualitative indicator for permeability.

Gamma Ray Log

Gamma Ray Log
(Background and Tool Physics)

- Gamma ray log is a record of the TOTAL natural gamma radiation from formation rocks through which the drill bit has drilled through.
- Natural gamma radiation is essentially from the radioactive decay of these 3 elements found in rocks (acronym ***KUTH***);
  - Potassium (^{40}K)
  - Uranium(U, ^{235}U and ^{238}U)
  - Thorium(Th)
- Each natural radioactive decay has a specific energy level, frequency and wavelength, this is applied in the Spectral tool.
- Radioactive materials are usually found abundantly in shales, although sometimes **we may have a radioactive sand or dolomite**

Sources of the Gamma Radiation in Rocks

- Largest source of formation radioactivity is potassium, and its very common in sedimentary rocks.
- Potassium is present in;
  - Evaporites e.g. Sylvite (KCl), Polyhalite etc.
  - Clay Minerals e.g. Feldspars (Orthoclase, etc.), Micas (Illite, Montmorillonite), Kaolinite
- Uranium is present in;
  - Uranium salts (Highly soluble and easily transported)
  - Organic Shales (Source rocks)
- Thorium is present in heavy minerals e.g. Monazite and Zircon

Examples of Low and High Radioactive Lithology

Low Radioactivity	High Radioactivity
Halite	Shale
Gypsum	Potassium Minerals
Anhydrite	Igneous Rocks
Limestone	
Dolomite	
Sandstone	

Tool Physics and Principle

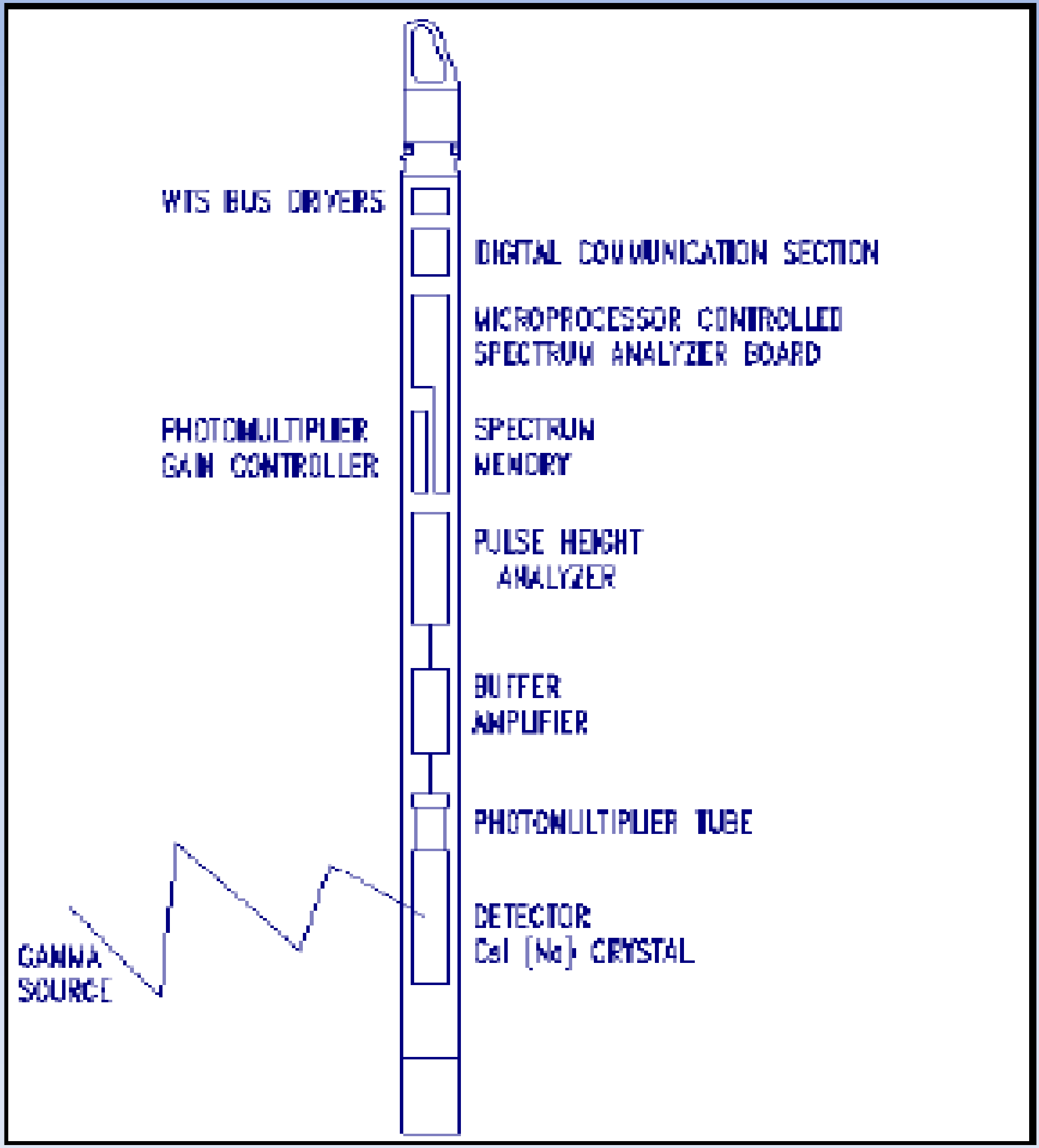
Path of incident gamma ray to recorded electrical signal.

1. Gamma ray from formation Rock
2. Detected by; Scintillation Chamber or Geiger Muller Counter
3. Single Photon of Light is emitted
4. Photon Strikes a Photocathode, which releases a bunch of electrons
5. Signal is amplified to a detectable level
6. Signal generates a measured voltage in a resistor

GR Detectors in Use;

- Scintillation Detector e.g. NaI
- Semiconductor Detector
- Gas-Discharge Counters

Gamma Ray Tool Layout



Gamma Ray Log

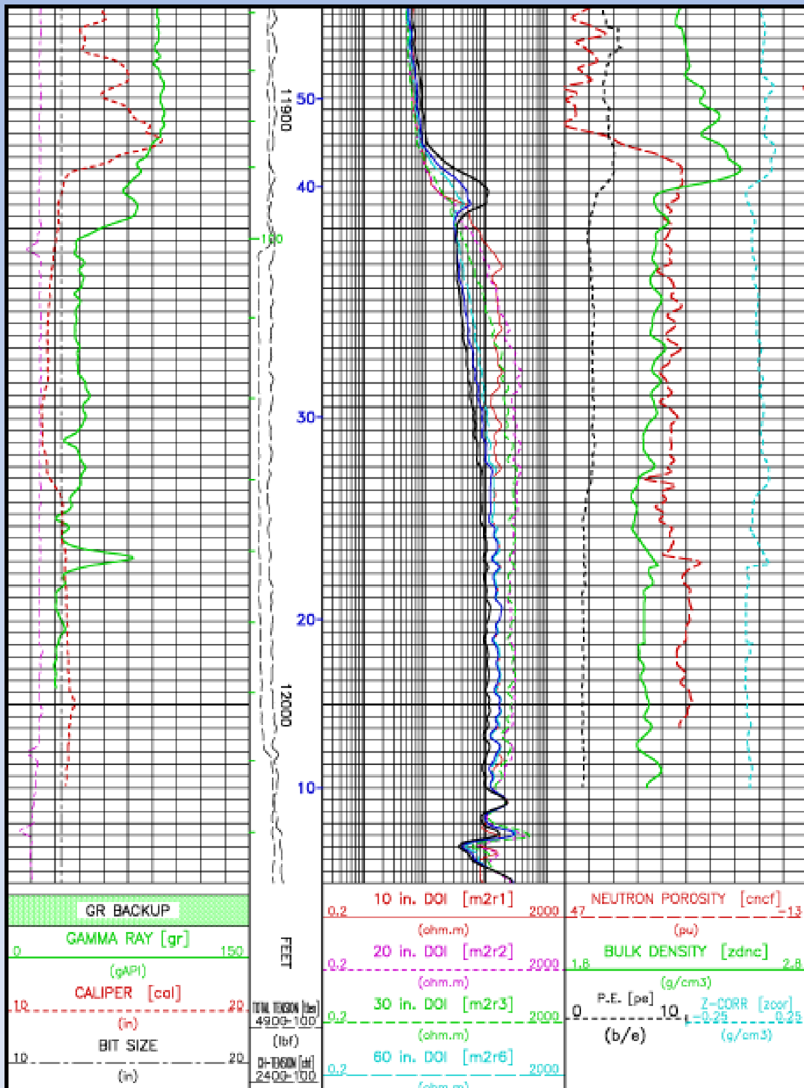
(Measurement and Interpretation)

- GR is measured in **API units** (American Petroleum Institute). The tool is calibrated to an API standard Well resident in the University of Houston, Texas. This “API Well” serves as the calibration standard to which all field calibration are referenced.

- GR log is affected by the following;
  - Bore hole size
  - Density of drilling mud
  - Tool position
  - Thickness of casing and cement in cased hole

- Limestone exhibit low GR counts, dolomites exhibit higher levels. Sandstone is usually higher than the carbonates and increases depending on the shaliness.

Example GR Log



Example log shows GR Log in Green recorded on Track 1 with linear scale, with other logs like Caliper and the bit size.

In Open holes, GR is log is usually scaled (0 – 150 API), and in Cased hole it is scaled (0-100 API).

Although this may vary from company to company and region, just ensure that you read the Scales.

Uses of Gamma Ray Logs

- Stratigraphic Correlation; We look for similarity in shape and magnitude to match logs from same well or other wells. Used to pick perforation point.

- Gross lithology-Identification of reservoir rocks; e.g. Usually Shales have high GR count, sands have less except when radioactive, hence we can distinguish shales from sandstone formation.

- Estimation of shale content;

$$I_{GR} = \frac{GR_{log} - GR_{clean}}{GR_{shale} - GR_{clean}}$$

  - Where,
  - I_{GR}=Volume of shale (Assuming a linear relationship)
  - GR_{log}= Gamma ray reading from log data
  - GR_{shale}= Gamma ray reading in shale
  - GR_{clean}= Gamma ray reading in clean sandstone

  – For non linear relationships, we have the following models;
    - Clavier: $V_{shale} = 1.7 * [3.38 * (I_{GR} + 0.7)^2]^{0.5}$
    - Steiber: $V_{shale} = \frac{I_{GR}}{3.0 - 2.0 * I_{GR}}$
    - Larionov (Tertiary Rocks): $V_{shale} = 0.083 * (2^{3.7 * I_{GR}} - 1)$
    - Larionov (Older Rocks): $V_{shale} = 0.33 * (2^{2 * I_{GR}} - 1)$

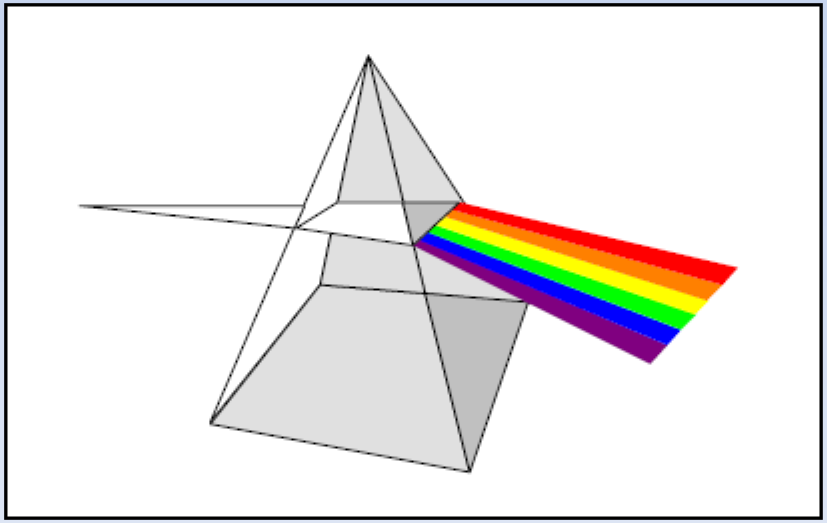
Uses of the Gamma Ray Log

- Detection of bed boundaries and stratigraphic correlations
- Estimate volume of shale
- Perforating Depth Control
- Identify mineral deposits of potash, Uranium and Coal
- Monitor movement of Injected radioactive material

Factors Affecting GR Log

- Radiation intensity of the formation
- Counter/Detector efficiency
- Time constant
- Logging Speed
- Borehole environment (Borehole size, mud weight, tool eccentricity)
- Mineralogical composition of the formation

SPECTRA Gamma Ray Log



SPECTRAL GAMMA RAY LOG

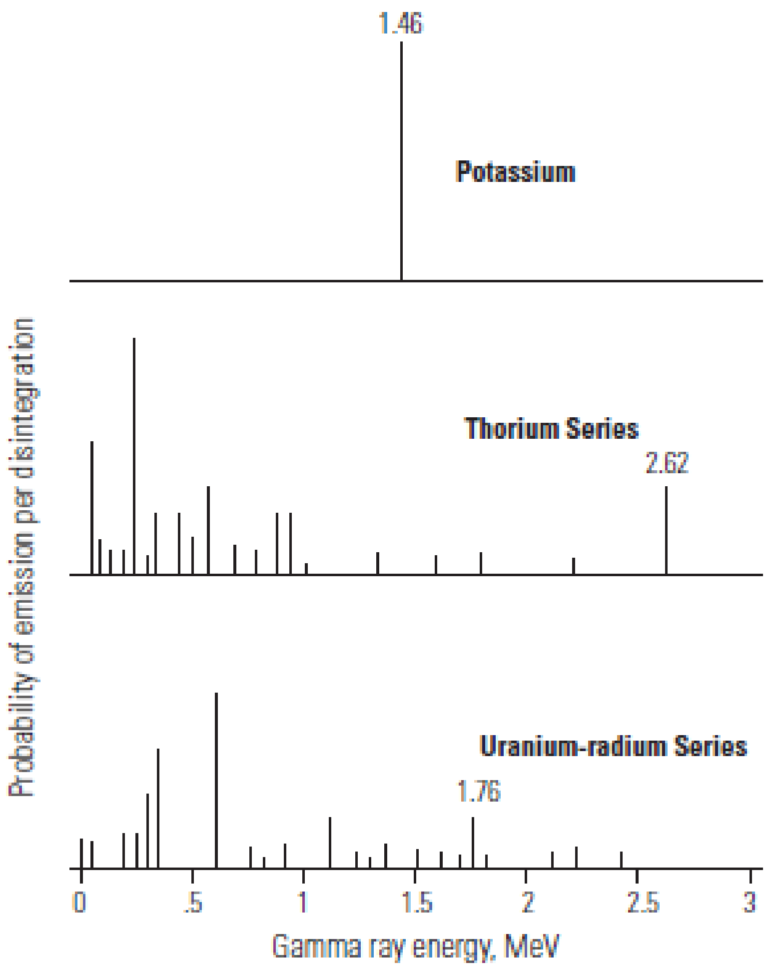
(Tool Physics)

- As discussed earlier, each natural radioactive decay has a specific energy level, frequency and wavelength and color. This characteristic is then used to separate the radiation into distinct energy levels that reflects each element.

- It is different from GR because the data are differentiated into elemental energy levels viz. Potassium, Uranium and Thorium, hence it is NOT the Total GR count.

SPECTRAL GAMMA RAY LOG

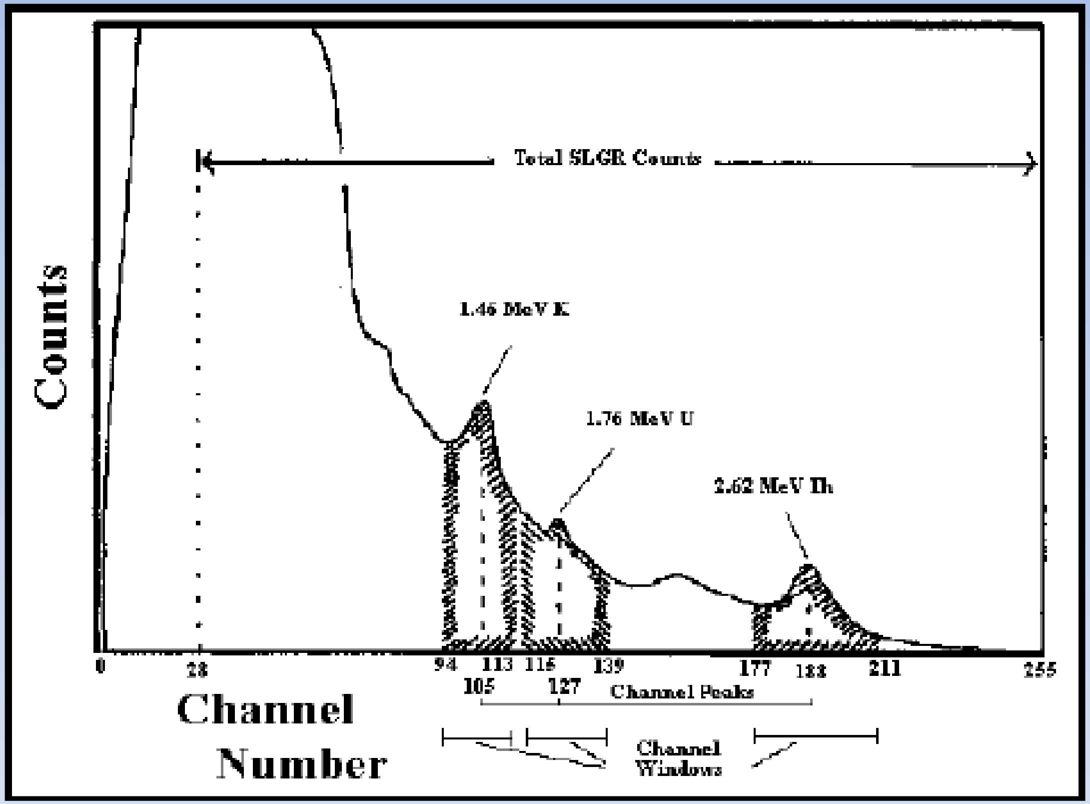
(Energy Levels of K,U,Th Series))



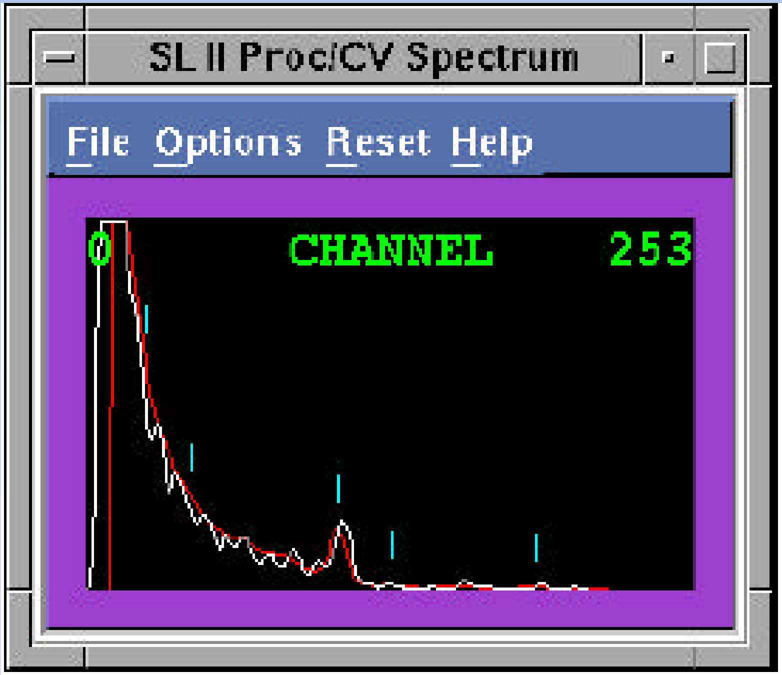
Radioactive Decay

Potassium decays into Argon, while Thorium and Uranium decay into several daughter elements before finally stabilizing at lead. Hence the several lines in their energy level diagram.

Spectrum Channel Windows

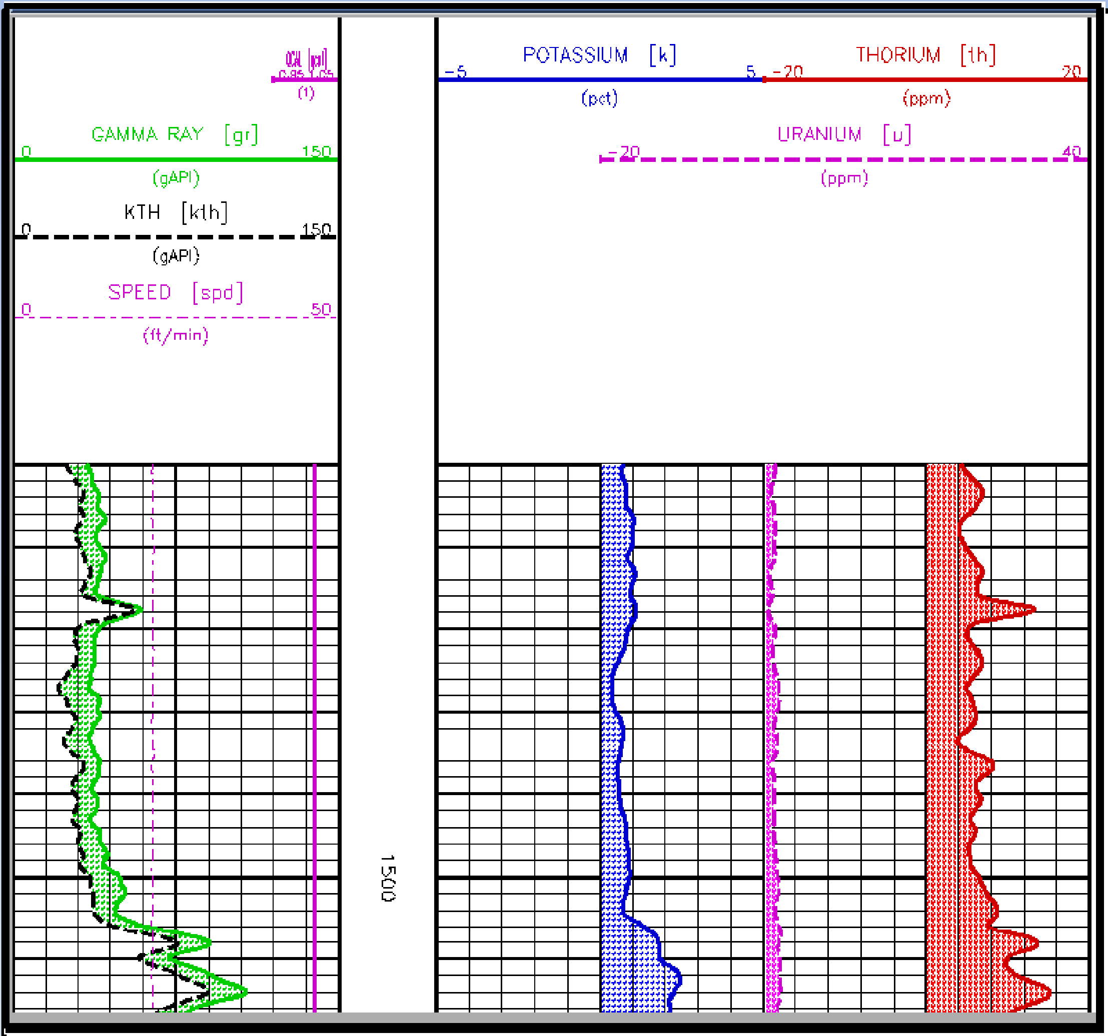


Spectrum Channels and Energy Levels



Digital Spectralog Display Window While Logging (Baker Atlas)

Example Spectral Log



Total gamma ray log is presented in green on track 1. The Spectra log data is presented in track 2, on a linear scale. It shows the different amount and contributions from K, U and Th (Potassium, Uranium and Thorium).

Uses of Gamma Ray Spectral Log

- **Clay and mineral Typing**: Gives and indication of what elements are contributing to the gamma ray signal and in what proportion, also any anomalies due to “hot” formations

- **Detection of Mobile Water behind Casing**: High Uranium reading especially in cased holes can indicate movement of water behind the casing.

- **Fracture Identification**: Spikes to higher Uranium values may indicate fractures due to the soluble uranium compounds in reservoir fluids

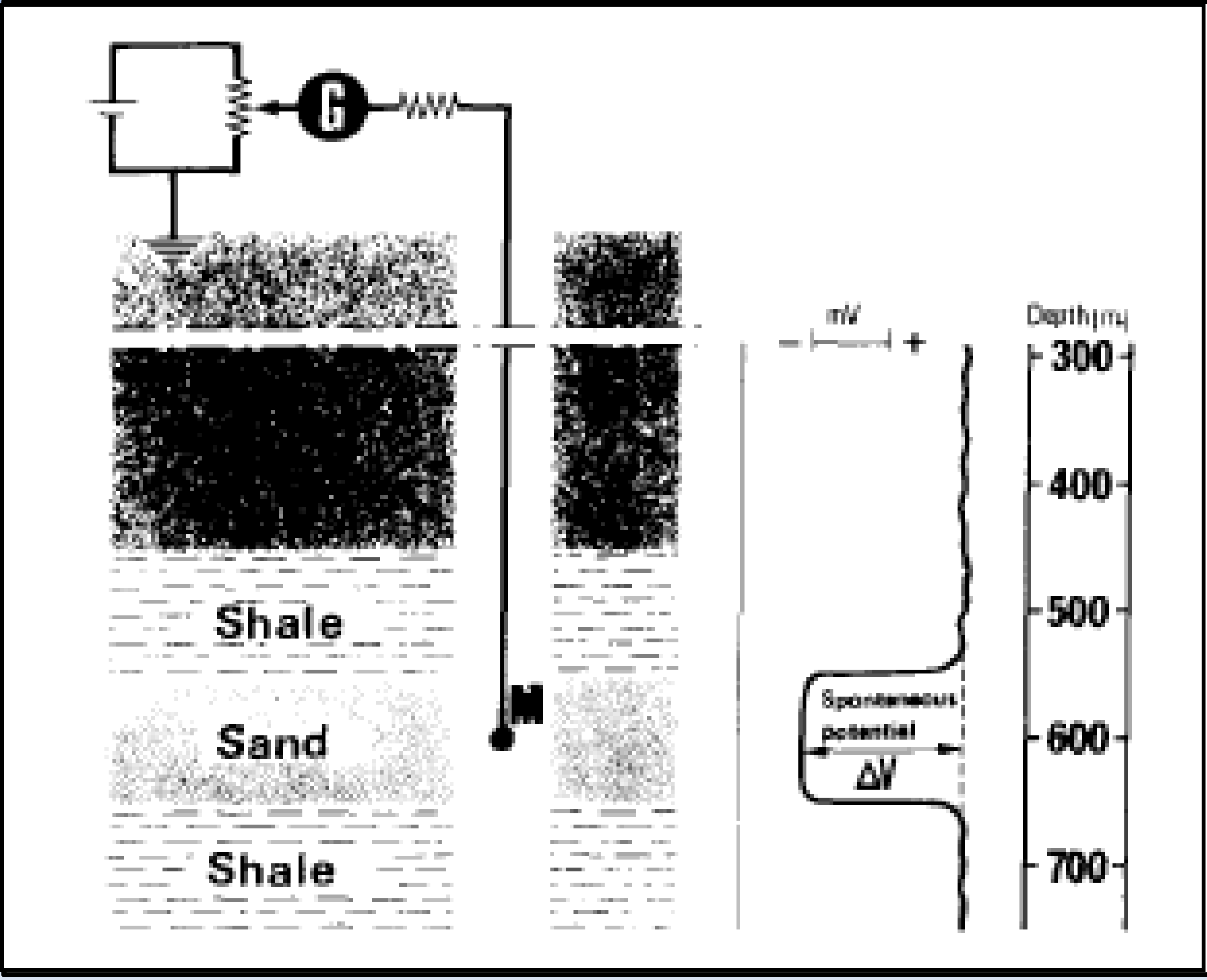
- **Source Rock Identification**: High Uranium readings in shales may give indication of the source rock potential, since organic materials usually have high uranium content. This presently has high potential application in Shale gas formation evaluation.
  - Black organic shale, oil shale and phosphorite usually have high organic content.

SPONTANEOUS POTENTIAL

Spontaneous Potential (SP) Log
(Tool Physics and Origin)

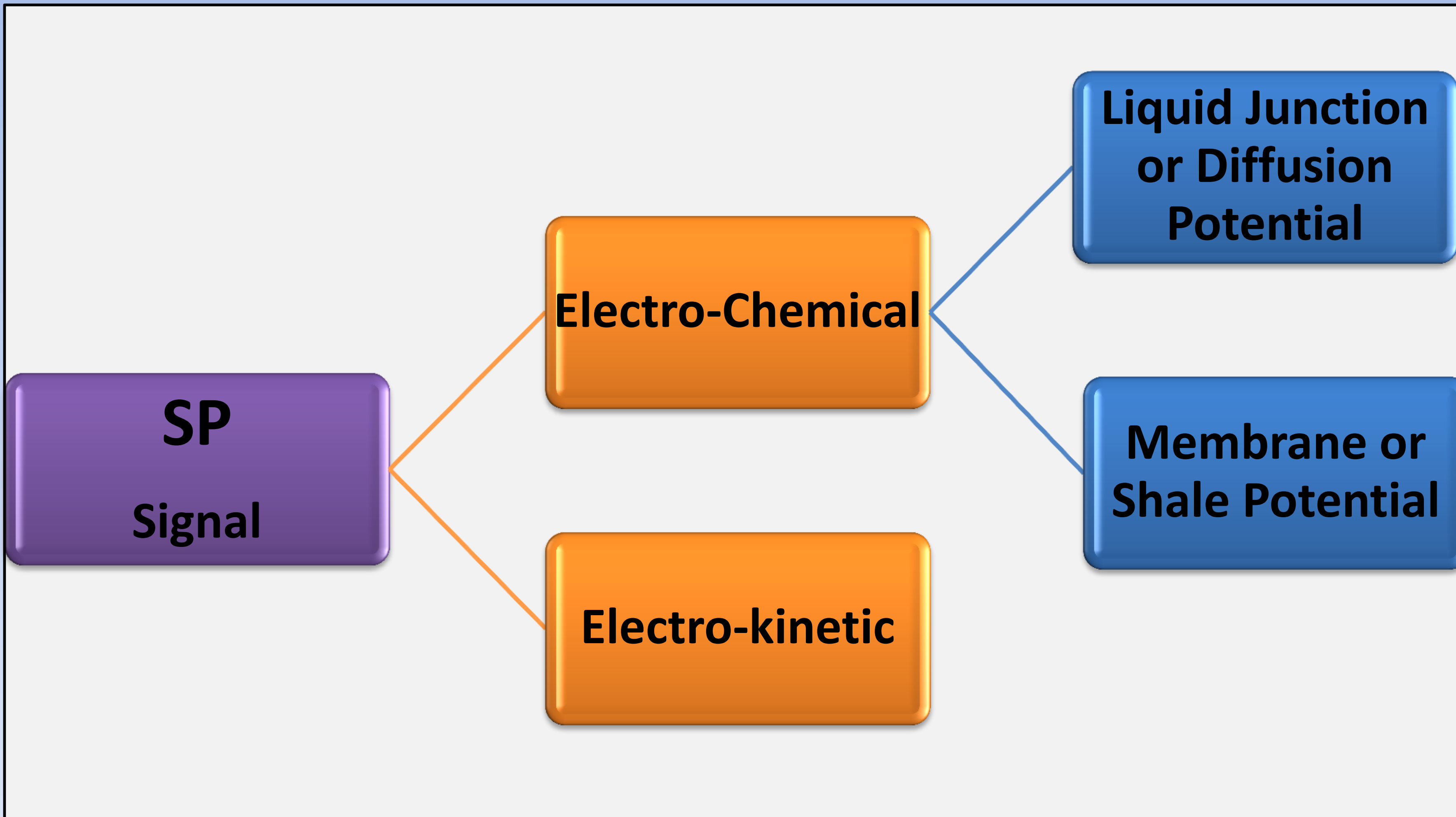
- Discovered in 1928 by the Schlumberger brothers.
- A spontaneous electrical potential difference exists between an electrode in the borehole and a remote reference electrode at the surface.
- The electrical current is generated by the diffusion and movement of aqueous (dissolved) ions, which are present in the borehole fluid (drilling mud) and formation fluids.
- It is a dc voltage measurement, in millivolts (mV)
- The potential varies from formation to formation.
- A conductive mud is required before SP signal can be generated and measured (hence this measurement is not possible in Oil Based Muds (OBM) muds)
- Shales will normally give constant readings, thus providing a shale base line, which serves as a reference. Sands or permeable beds will show a movement either to the right (+) or left (-), depending on the salinity of the drilling fluid and formation waters.

SP Principle



Spontaneous generation of voltage as tool moves from shale formation to sand formation.

Sources of SP Signal



Spontaneous Potentials

Electrochemical Potential (E_c)

Diffusion or Liquid Junction Potential: This arises when two electrolytes of different chemical activities are separated by a clean porous medium. Activity is related to both the amount and type of ions present. Denoted by E_d.

Membrane Potential: This is also known as shale potential, it arises when two electrolytes are separated by a porous medium where the pore walls carry an electrical double layer. Clay minerals have such a layer, and because they are present in Shales, Shales constitute such a membrane. This membrane selectively allows the positive ions to pass through while restricting the negative ions. It is denoted by E_m.

Therefore, the summation of E_d and E_m gives the composite electrochemical potential,

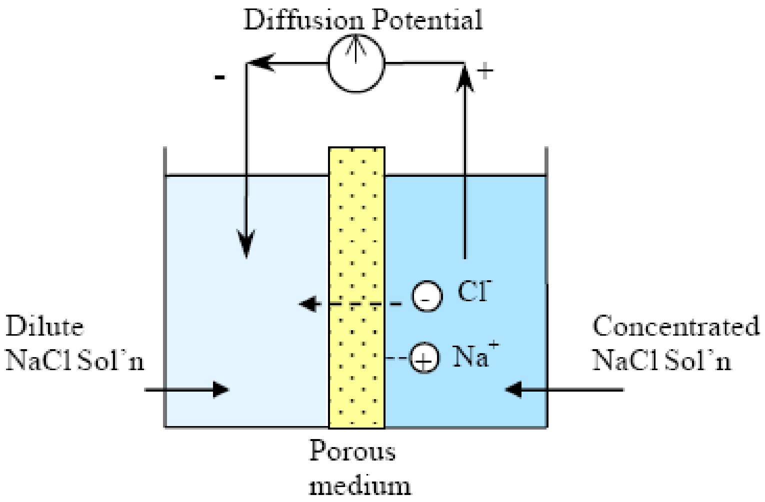
$$E_c = E_d + E_m$$

Electrokinetic Potential

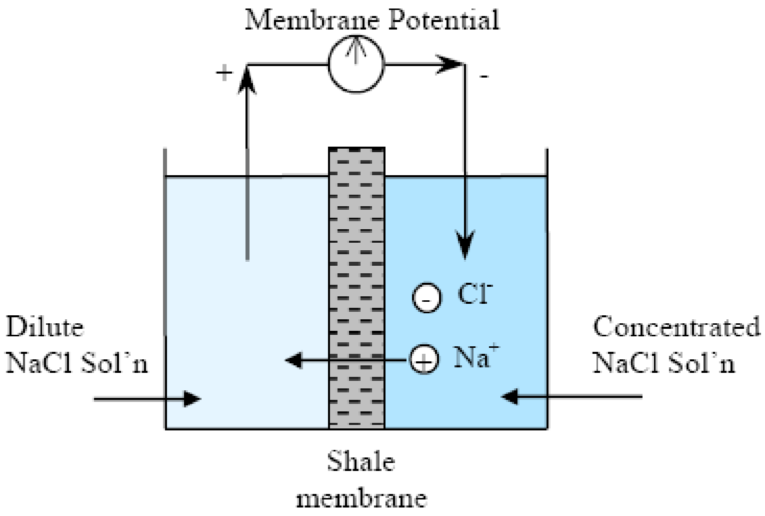
The is a result of the filtration process of the drilling mud invading the formation. It is also called the streaming potential. It is due to the potential difference between the bound clay water in the mud cake and free water across permeable formation. As the water filtrate moves into the formation across the mudcake, it carries the charges.

Spontaneous Potentials

Definition of Potential Cells

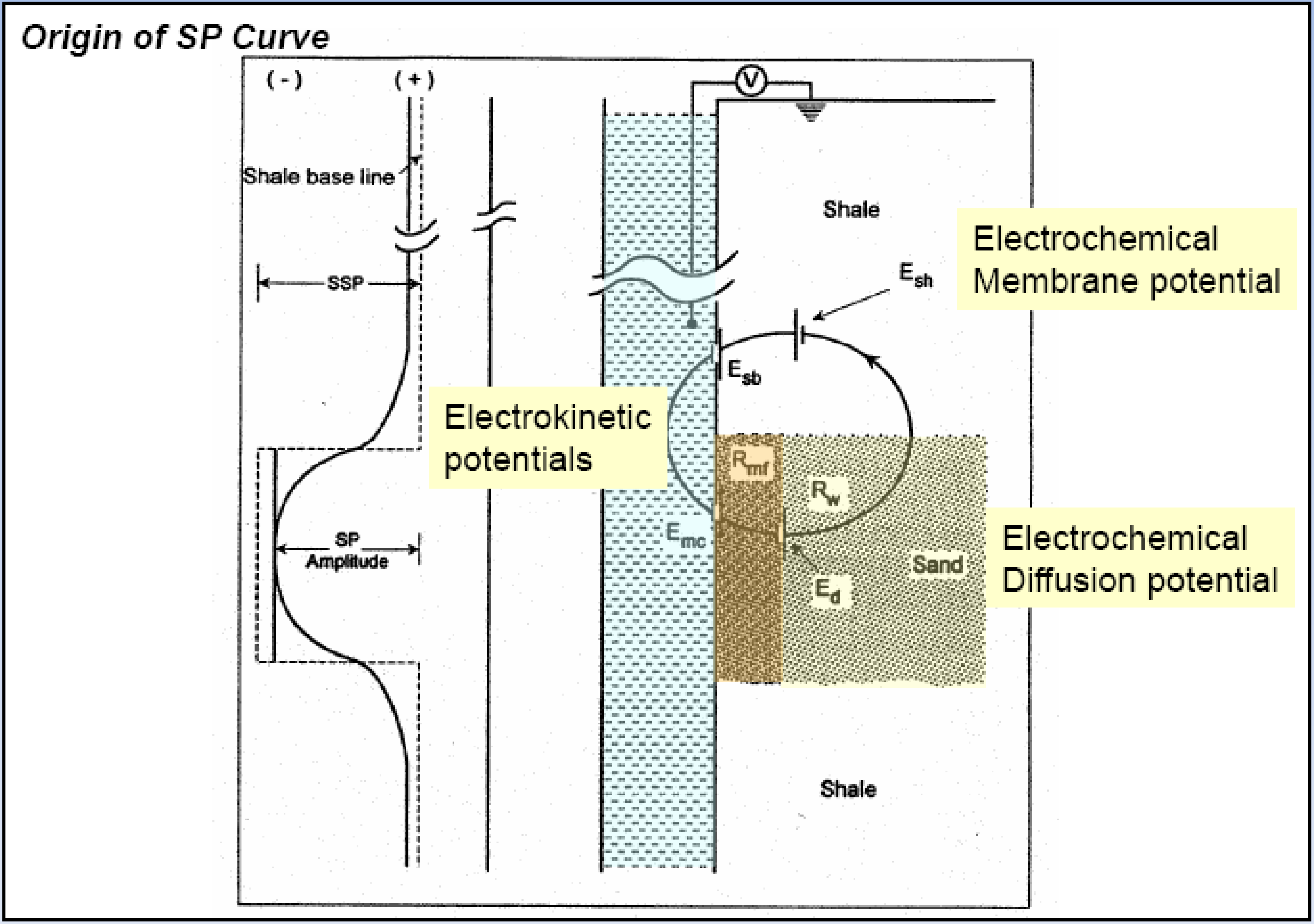


Schematic of diffusion-potential generating cell



Schematic of a membrane-potential generating cell

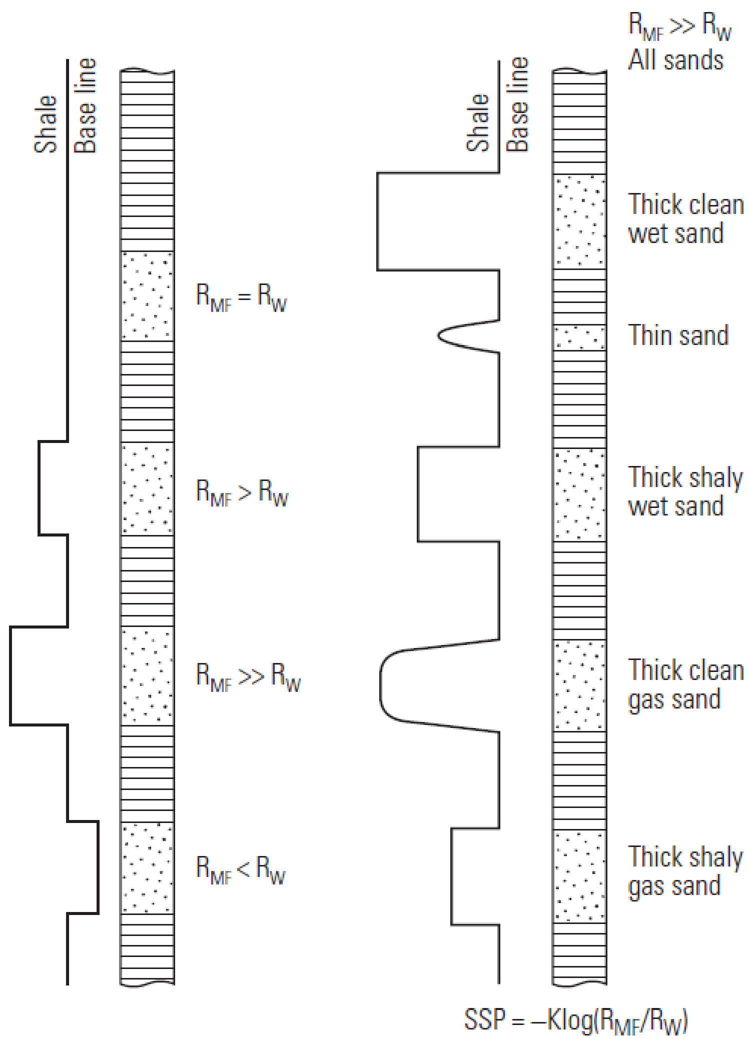
Origin of the SP Curve



SP Log
(Measurement and Interpretation)

- Some SP Log Definitions
  - **Clean Sand**: Sandstone lithology with no mix of shale, it will be the zone with the maximum **SSP** deflection. This signal is best seen in a thick clean water zone.
  - **Shaly Sand**: A sandstone formation mixed with shales. The full SP signal will be suppressed (*smaller deflection*) due to the presence of shale, here the SP is denoted PSP (Pseudo static SP, i.e. the SP of a shaly formation
  - **Oil or Gas Sand**: This is a sandstone formation with the presence of hydrocarbon.
  - **Shale Base Line**: This is the reference datum selected during SP log, that indicates a zero reading in shale
  - **Static SP (SSP):** This is the ideal SP generated when passing from shale to a clean thick porous sand if no current flows.

SP Log: Response in Formations



- $$SSP = -K * log\left[\frac{(R_{mf})_{eq}}{(R_w)_{eq}}\right]$$

- Rmf =Resistivity of mud filtrate
- Rw = Formation water resistivity
- K= $(0.133*T_f) + 60$

- **Note**
- If the R_{mf} is greater than R_w, the SP curve will deflect to the left (**-ve**) opposite non-shales
- If the R_{mf} is less than R_w, the SP curve will deflect to the right (**+ve**) opposite non-shales
- If the R_{mf} is equal to R_w, the SP curve will be a straight line, no deflection opposite non-shales.

SP Log: Applications and Corrections

- Applications of the SP Log
  - Detection of permeable zones
  - Calculation of R_w (formation water resistivity)
  - Well to well correlation
  - Qualitative indication of clay or shale volume/content
  - Determination of patterns in sedimentation
  - Stratigraphic Correlation

- Corrections to the SP Log

  The SP log is corrected for the following;
  - Thin beds
  - Hydrocarbon suppression

Class Examples

- Estimation of shale/clay volume
  - $V_{clay} = V_{shale} = \left(\frac{SP_{clean} - SP_{log}}{SP_{clean} - SP_{shale}}\right)$
  - *Where,*
  - $V_{clay} = V_{shale}$
  - SP_{log}= SP in the zone of interest read from the log
  - SP_{clean}= Maximum SP deflection in a clean water (wet) zone in the same well
  - SP_{shale}= SP value at the shale base line

Procedure for Calculating R_w from SP Log

1. Identify zone on the log which is clean, wet and permeable (This is a water zone) and the shale base line on the SP log.
2. Read the SP value at the depth of maximum deflection
3. Calculate the formation temperature at depth of interest
4. Convert R_{mf} from surface temperature to formation temperature (Using charts or equations)
5. If necessary correct SP for bed thickness and invasion effects. Read bed thickness h and invaded resistivity, R_i, obtain SSP
6. Convert R_{mf} @ formation temperature to R_{mfeq} using equations
7. Using SP value, formation temperature and R_{mfeq} calculate R_{weq} (Using chart or equations)
8. Convert R_{weq} to R_w using chart

Factors Determining Magnitude of the SP Signal

- The magnitude and direction of the SP curve is controlled by;
  - Resistivity of the mud filtrate, $R_{mf,}$ hole diameter
  - Resistivity of the formation water, R_w
  - Shaliness of the formation
  - The thickness and resistivity of the permeable bed, e.g. Maximum signal will not be attained in thin beds
  - The resistivity and diameter of invaded zone
  - The Resistivity of surrounding formation
  - SP has less amplitude in hydrocarbon bearing zones

Limitations of the SP Log

- These are the common problems encountered in SP logging;
  - Spurious Spikes-Caused by lightening, arc welding or short wave transmission
  - Electrical noise e.g. road noise, stray electrical signals from electrical equipment e.g. pumps, rig voltage, improper grounding
  - High resistive formation
  - Small amplitude sine wave riding on the SP signal, caused by magnetized mobile parts of the cable drum

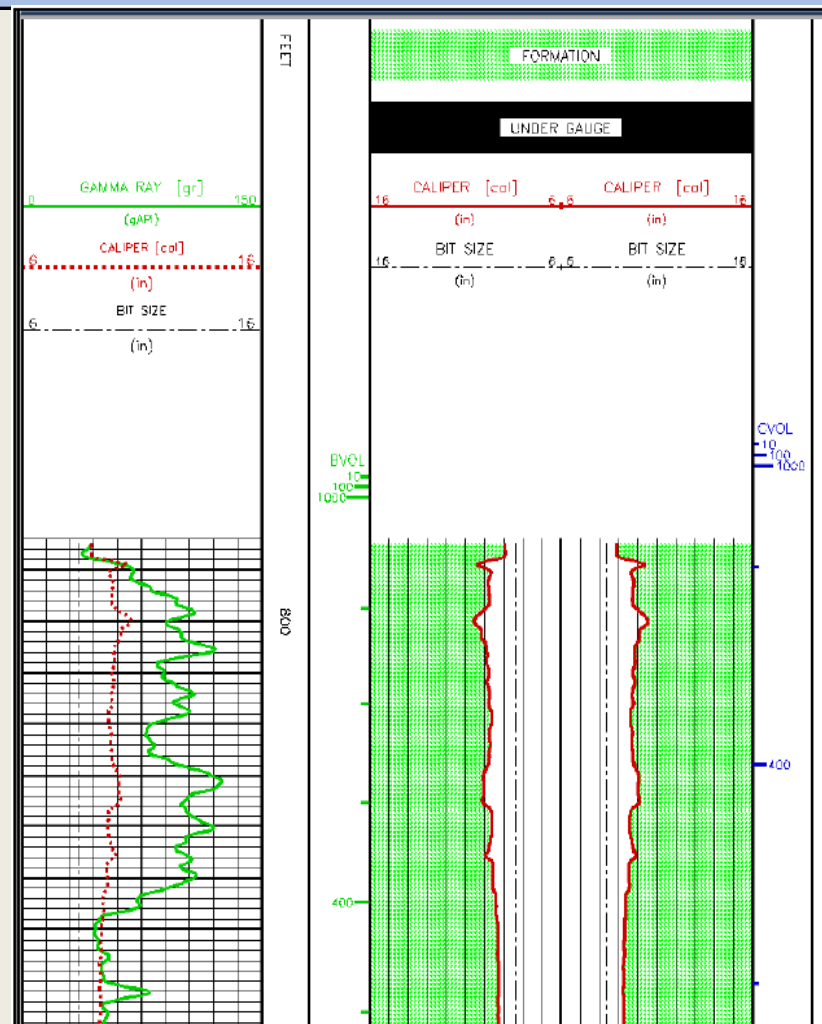
CALIPER LOG

Caliper Log
(Tool Physics)

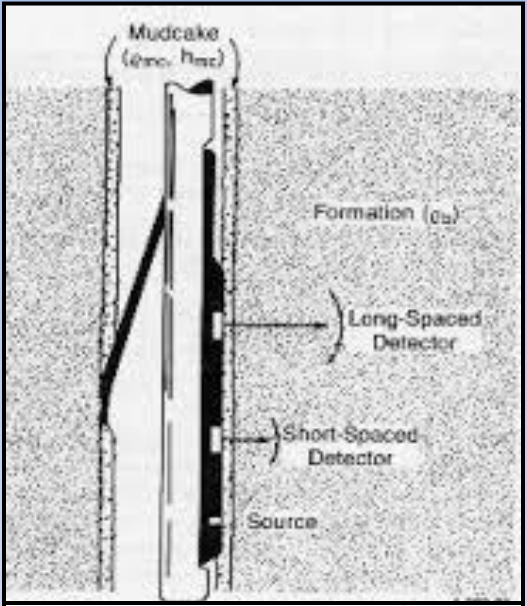
Physical movement of the tool is converted into electrical signal.

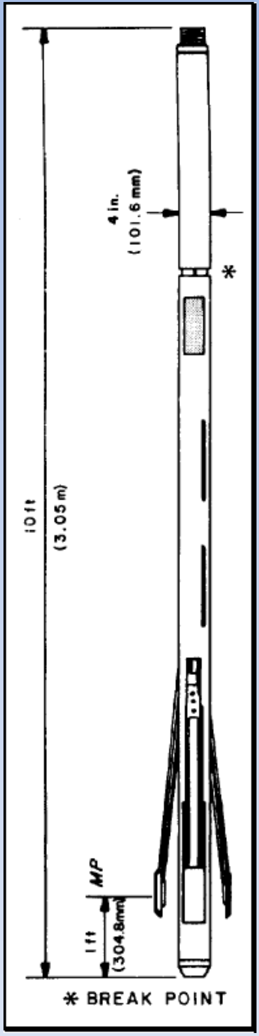
The arms are attached to a rheostat whose movement gives off a particular voltage, this voltage is recorded and based on the calibration it is converted into inches.

Some LWD devices use ultrasonic acoustic pulses to detect the diameter of the well bore.



Types of Caliper Tools





Types of Caliper Logging Tools

2-arm caliper

3-arm caliper

4-arm caliper

6-arm caliper

Tool is usually opened in the casing to measure the internal diameter of the casing. This serves as a before log verification for the tool, to ensure tool is functioning properly.

The wellbore diameter data is presented in **inches.**

Uses of Caliper Log

- Indication of hole diameter and volume-used in cement volume calculation
- Input for environmental correction of other tools
- Qualitative indication or permeability due to the formation of mud cake, implying hole size will be less than bit size.
- Correlation-comparison with offset logs to see regional problematic zones
- Log quality control- gives idea of wellbore condition and quality of data from other tool e.g. Watch-outs and borehole rugosity.

Summary

- We looked at the main lithology and correlation logs available in the industry
- Uses and peculiarities of each log
- Differentiated between GR and Spectra GR log
- Practice examples at reading and interpreting the logs.
- Presented Caliper log and its importance in log analysis.

References

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- Baker Atlas, Montrose Training Center Manual
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