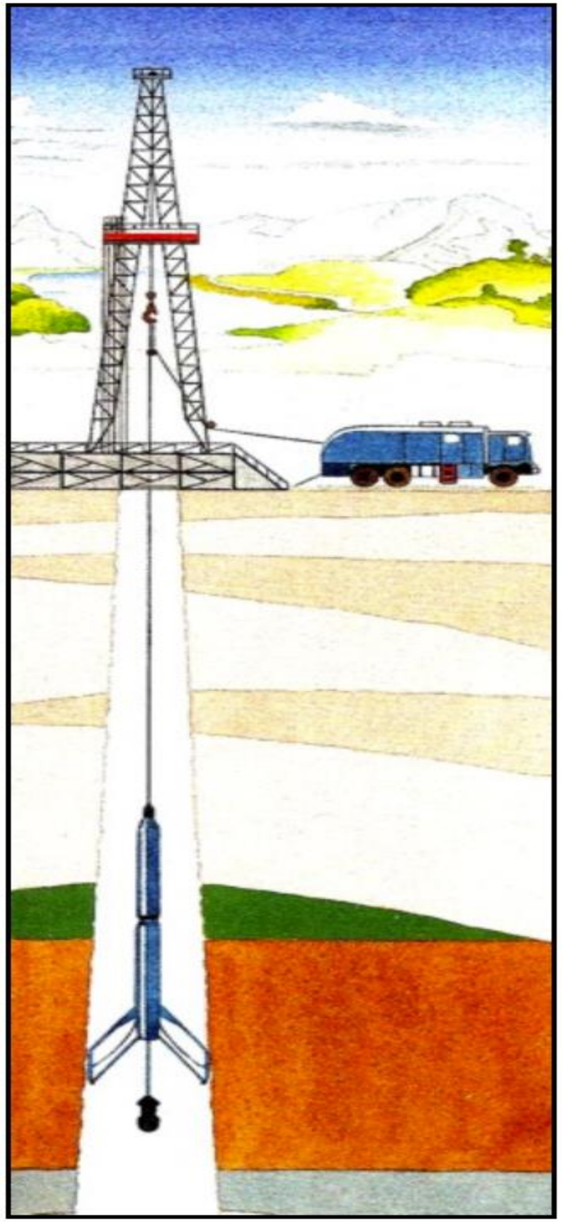
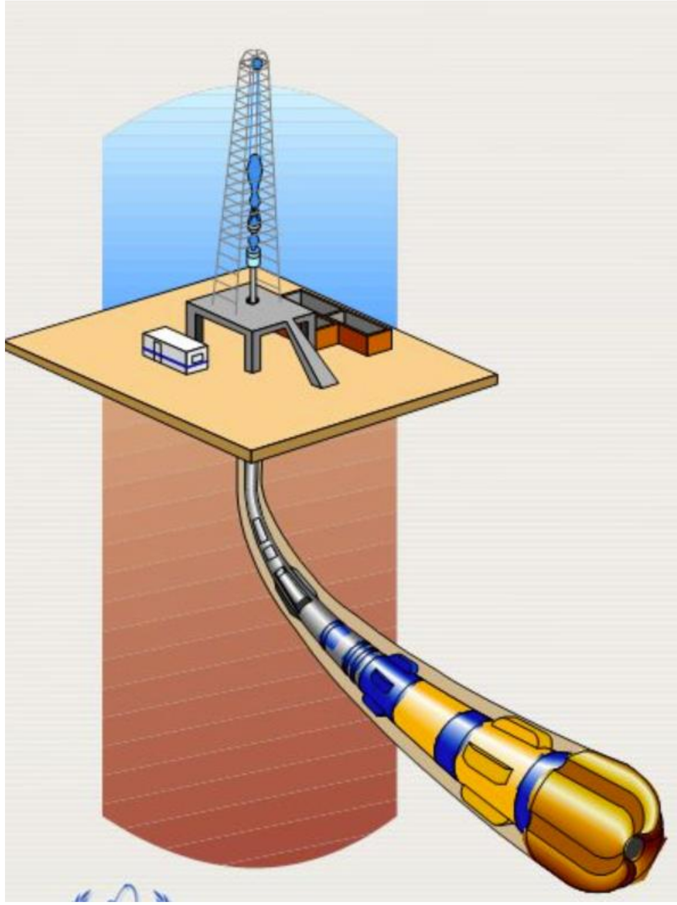
Well Logging



Wireline

MWD/LWD



Well Logging operations that occur during the drilling of the well bore and do not require that the drill stem or other equipment be removed from the well. This type of operation requires that the well logging tool contains one or more sealed sources and be located above the drilling stem to obtain information through mud telemetry communications.

Crains Handbook

IAEA

Borehole Data:

Category	Data Type and Source	Ownership
Mud Logging/Drilling	Pore pressure predictions; gas or oil shows during drilling; drilling-mud and cuttings analysis	Wellsite geologists/ reservoir engineers
Well Logging and Log Interpretation (mostly openhole wireline logs, but increasingly LWD)	Mechnical logs (calipers); electric logs (laterlog, induction, spontaneous potential, resistivity); natural-radiation logs (simple and spectral gamma rays); artificial-radiation logs (density and neutron); acoustic logs (sonic); image logs (dipmeter, micro-image resistivity); special logs (NMR); temperature log	Primarily petrophysicists
Coring and Core Analysis	Mineralogy, lithology; hydrocarbon shows, porosity, permeability; SCAL (wettability, capillary, core flooding)	Primarily petrophysicists, with geologists and reservoir engineers
Formation Testing and Sampling	Formation testing for pressure stratigraphical profile; fluid type validation and sampling; drillstem or production test	Reservoir engineers
Cased-Hole Logging	Production logging (pressure, spinner, densimeter); formation evaluation logs (neutron, acoustic, cased-hole resistivity); casing/wellbore integrity logs (bond logs, temperature, ultrasonic)	Production/reservoir engineers

Well Logs to Characterize Subsurface

Goals:

shale volume (Vsh)

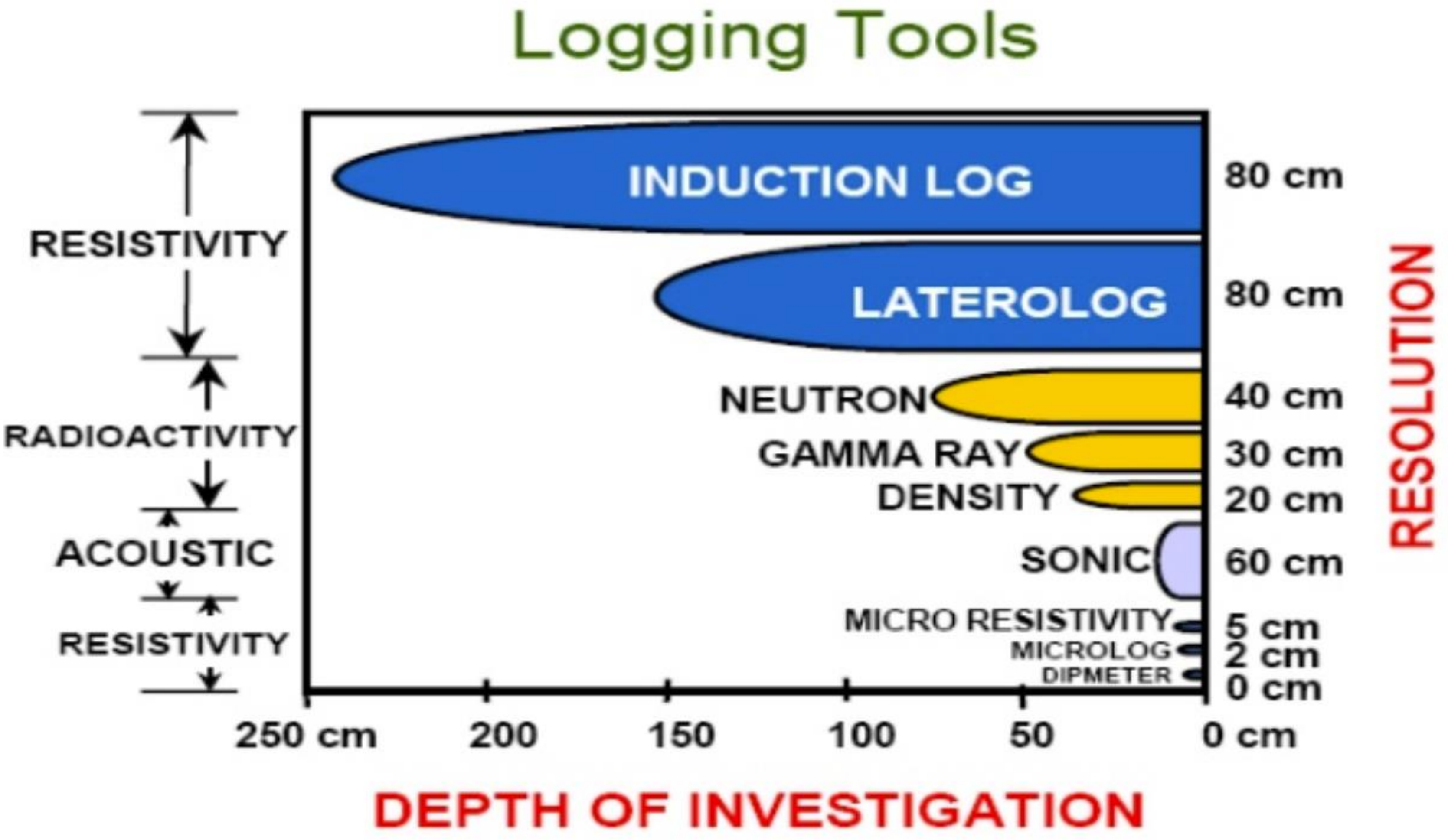
water saturation (Sw)

porosity (φ)

permeability (k)

elasticity (σ, AI, SI, etc.)

reflectivity coefficient (R)



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Well Logs and what they mean

Table 1 The functions of every log in petrophysical and rock physics properties calculation and analysis.

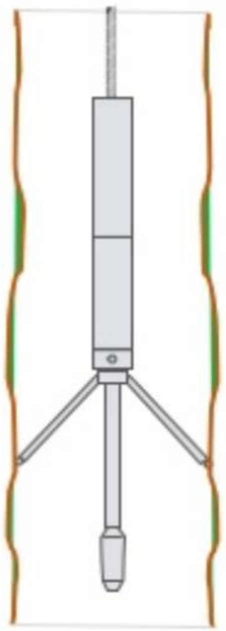
Name	Uses
Gamma Ray (GR)	Lithology interpretation, shale volume calculation, calculate clay volume, permeability calculation, porosity calculation, wave velocity calculation, etc.
Spontaneous Potential (SP)	Lithology interpretation, Rw and Rwe calculation, detect permeable zone, etc.
Caliper (CALI)	Detect permeable zone, locate a bad hole
Shallow Resistivity (LLS and ILD)	Lithology interpretation, finding hydrocarbon bearing zone, calculate water saturation, etc.
Deep Resistivity (LLD and ILD)	Lithology interpretation, finding hydrocarbon bearing zone, calculate water saturation, etc.
Density (RHOB)	Lithology interpretation, finding hydrocarbon bearing zone, porosity calculation, rock physics properties (AI, SI, σ, etc.) calculation, etc.
Neutron Porosity (NPHI)	Finding hydrocarbon bearing zone, porosity calculation, etc.
Sonic (DT)	Porosity calculation, wave velocity calculation, rock physics properties (AI, SI, σ, etc.) calculation, etc.
Photoelectric (PEF)	Mineral determination (for lithology interpretation) *not used in this article

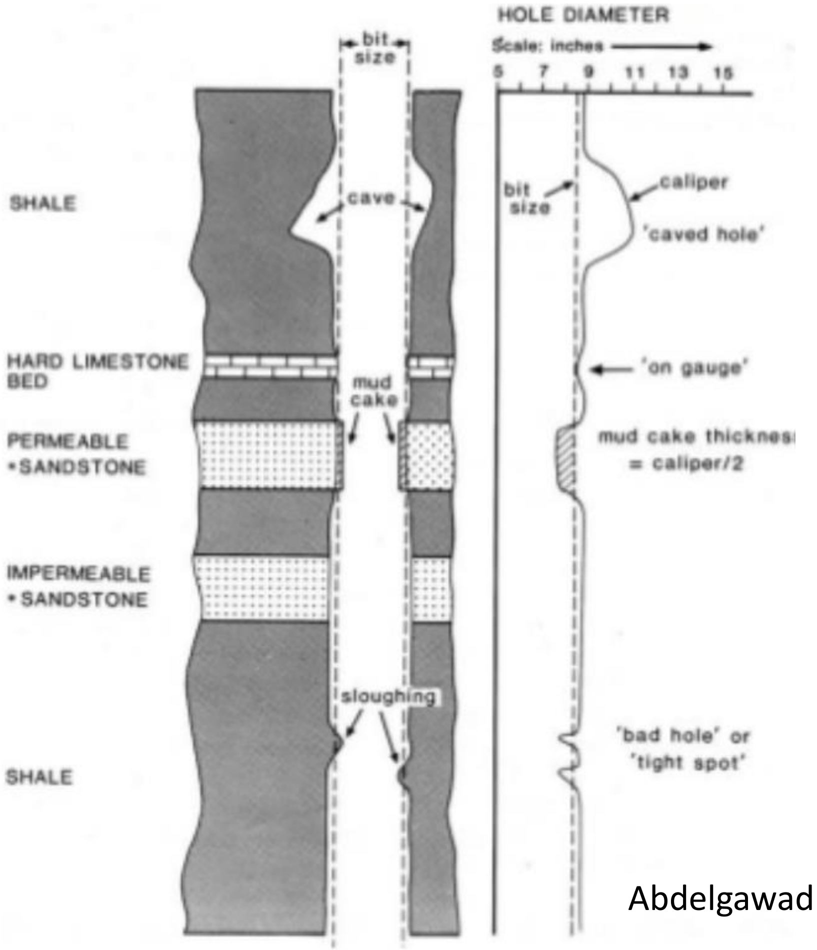
(Log Name)

Borehole size: Caliper Log – (CALI):

- The caliper tool measures the variation in borehole diameter using two or more articulated arms that push against the borehole wall
- Each arm is typically connected to a potentiometer which causes the resistance to change as the diameter of the borehole changes, creating a varying electrical signal that represents the changing shape of the borehole
- This variation in output is translated into changes of diameter after a simple calibration and the caliper log is printed as a continuous series of values of hole diameter with depth

Continuous measurement of the size and shape of a borehole along its depth.



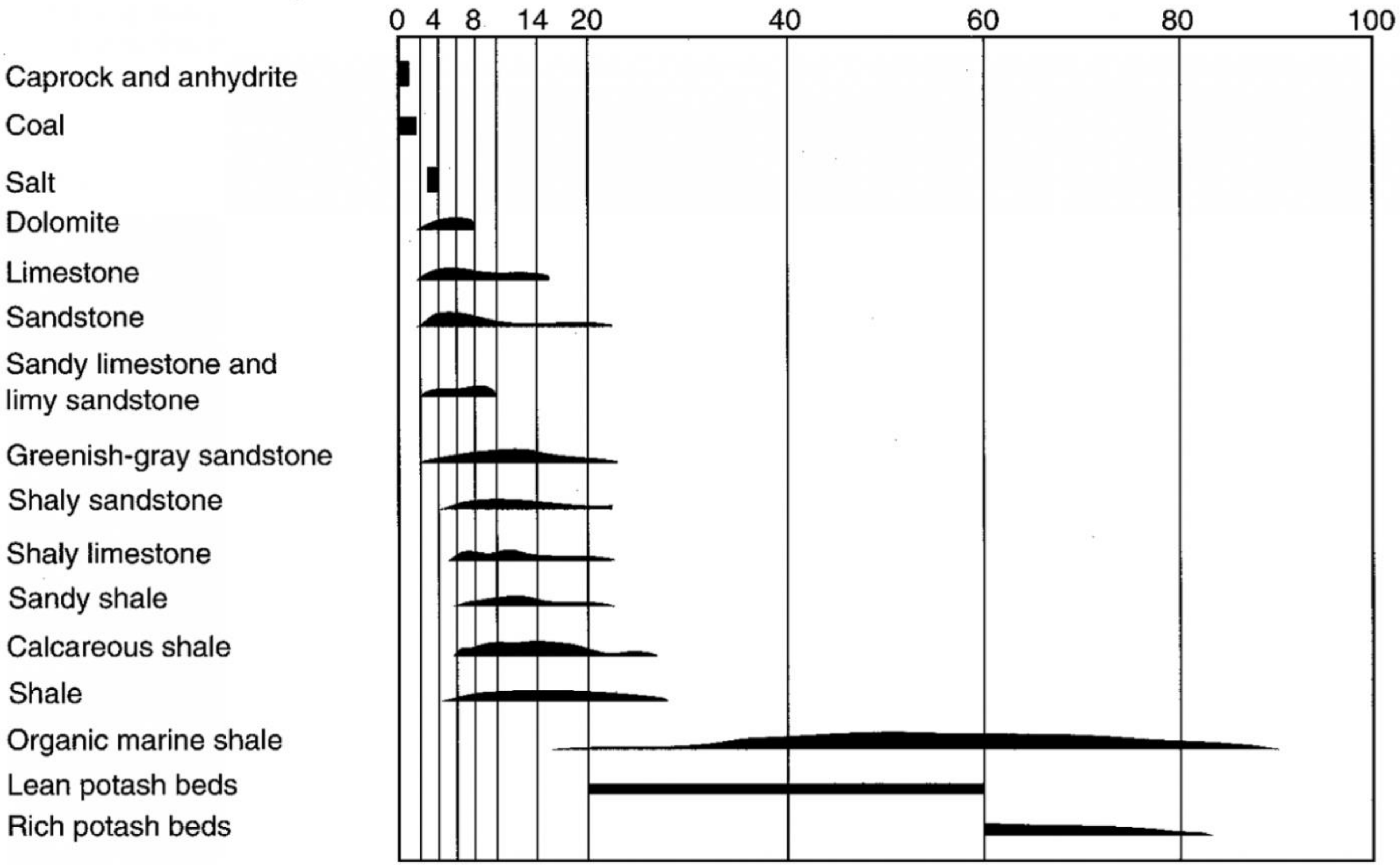


Abdelgawad

Shale Volume: Gamma Ray Log – (GR):

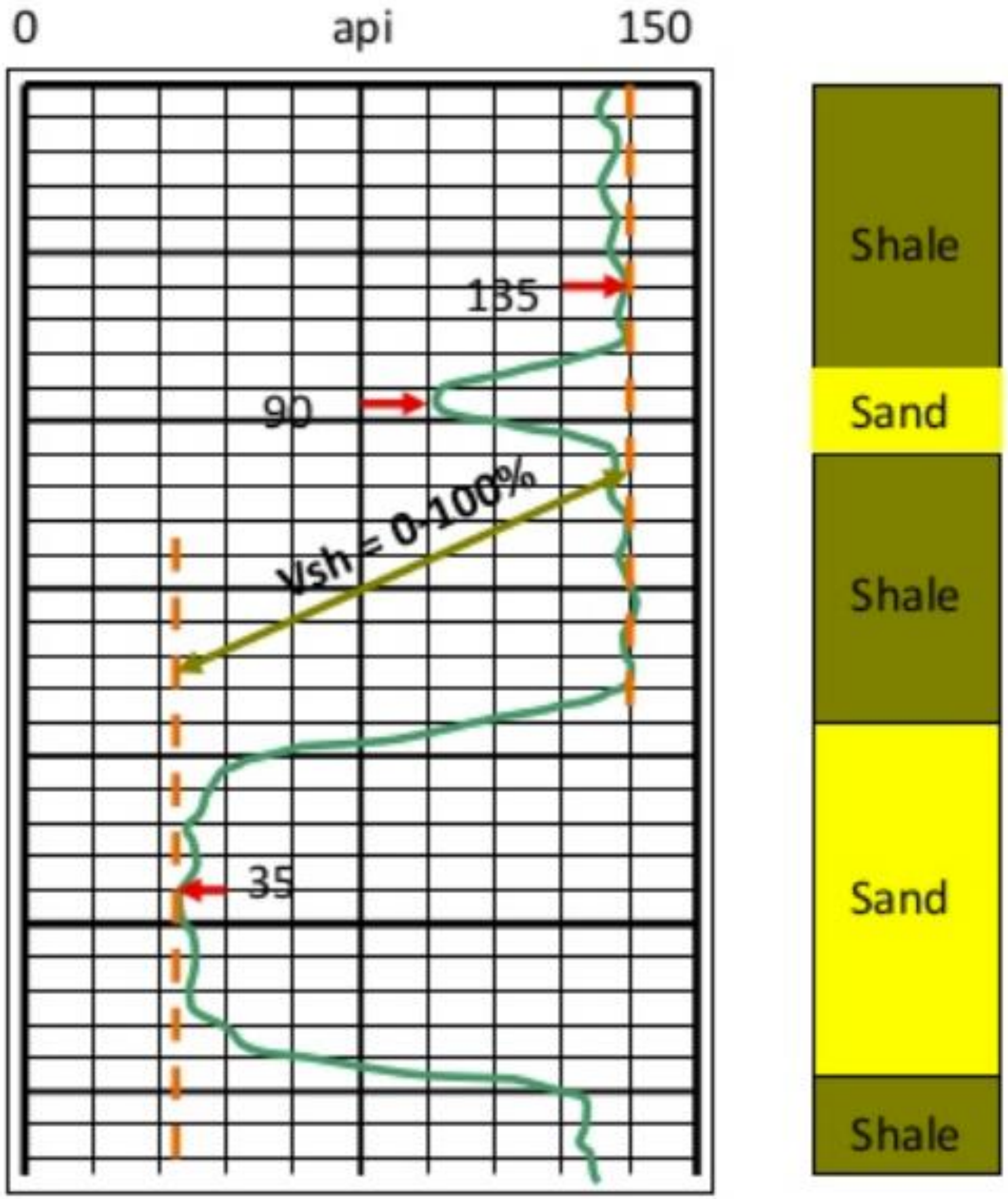
- Measures naturally occurring gamma radiation to characterize the rock or sediment
- Three elements and their decay chains are responsible for the radiation emitted by rock: potassium, thorium and uranium
- Different types of rock emit different amounts and different spectra of natural gamma radiation
- In particular, shales usually emit more gamma rays than other sedimentary rocks, such as sandstone, gypsum, salt, coal, dolomite, or limestone because radioactive potassium is a common component in their clay content
- This difference in radioactivity between shales and sandstones/carbonate rocks allows the gamma ray tool to distinguish between shales and non-shales.
- But it cannot distinguish between carbonates and sandstone as they both have similar deflections on the gamma ray log
- Gamma radiation is usually recorded in API units, a measurement originated by the petroleum industry

Radioactivity (GR) Level For Rock Types



Bigelow, 1992

Shale Volume: Gamma Ray Log – (GR):



1) Pick a clean GR response

2) Pick a shale GR response

3) Scale between

$$Vsh = \frac{GR_{log} - Gr_{clean}}{GR_{shale} - Gr_{clean}}$$

GR 90 -> Vsh = 55%

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Density: Density Logging – (RHOB):

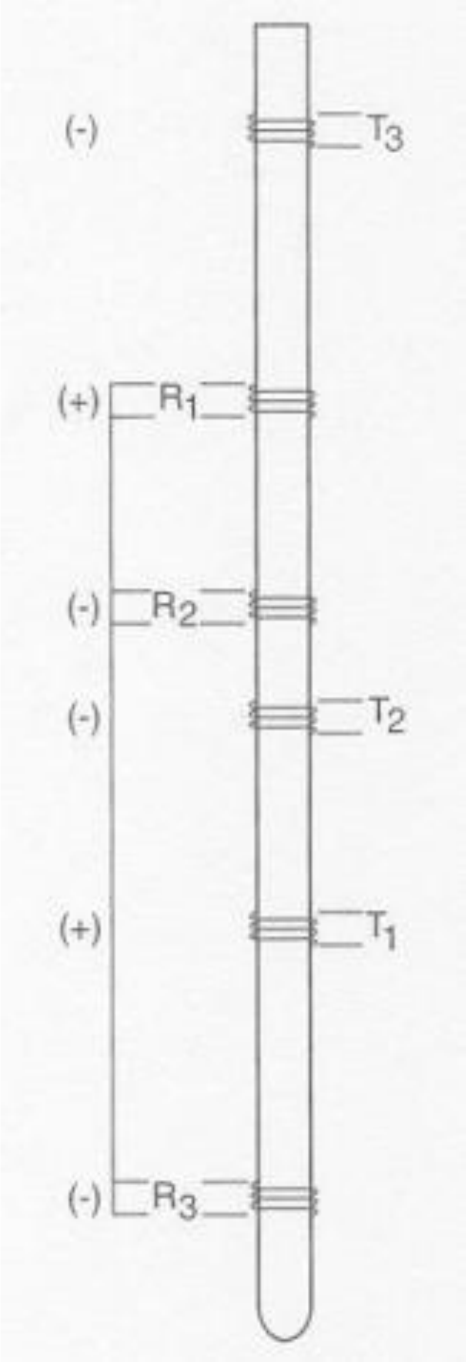
- A type of active nuclear tool: a radioactive source and detector
- The source emits medium-energy gamma rays into the formation
- These gamma rays interact with electrons in the formation and are scattered in an interaction known as Compton scattering
- The number of scattered gamma rays that reach the detector, placed at a set distance from the emitter, is related to the formation's electron density
- Formation's bulk density is calculated from the electron density

Porosity: Neutron Porosity Log – (NPHI):

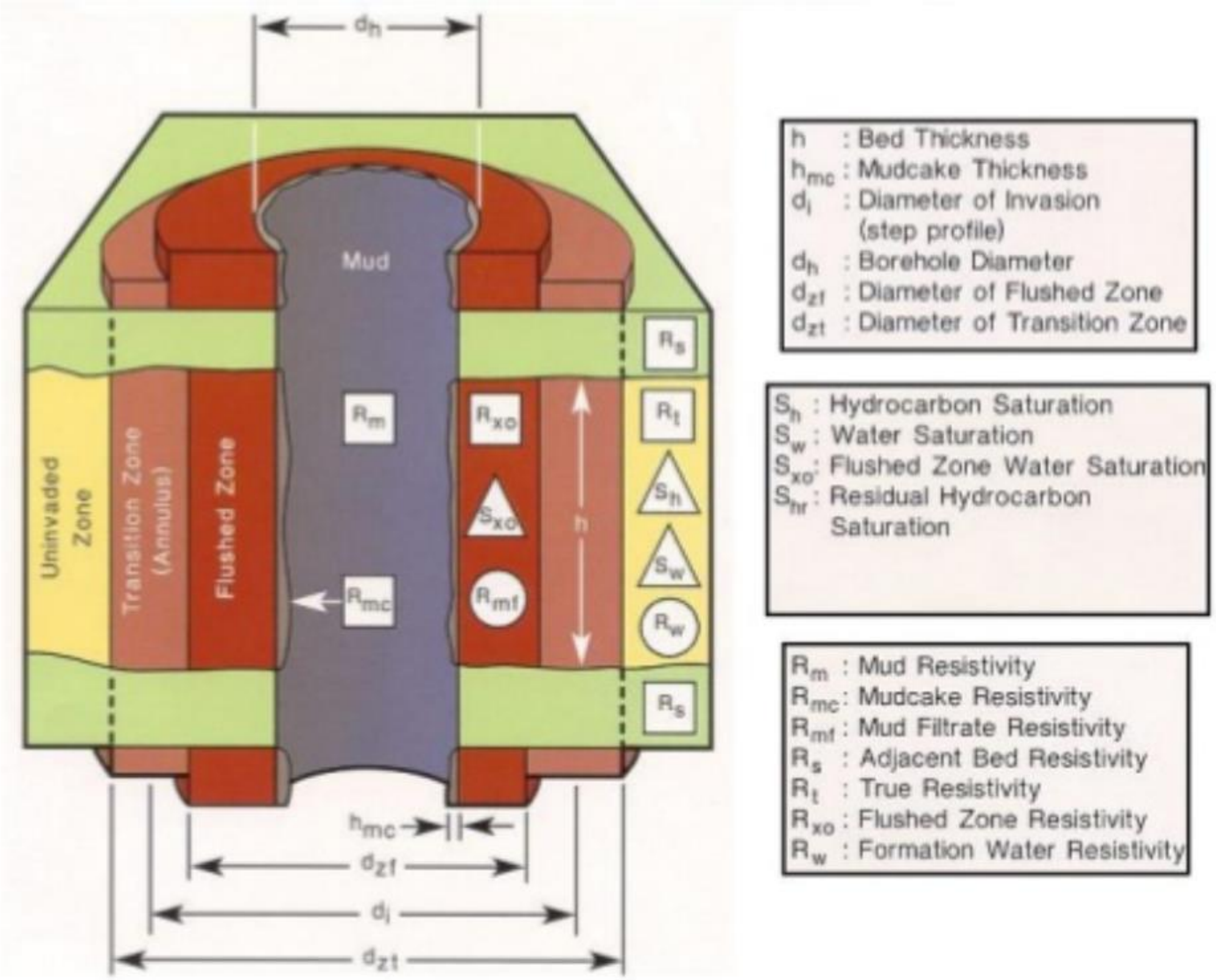
- Neutron source to measure the hydrogen index in a reservoir
- Hydrogen index is directly related to porosity
- As hydrogen atoms are present in both water and oil filled reservoirs, measurement of the amount allows estimation of the amount of liquid-filled porosity
- A hydrogen atom will cause a neutron to slow down the most, as they are of roughly equal mass.
- As hydrogen is fundamentally associated to the amount of water and/or oil present in the pore space, measurement of neutron population within the investigated volume is directly linked to porosity

Fluid Type: Resistivity Log – (IL, AIT, RES):

- Measures its electrical resistivity. When a formation is porous and contains salty water, the overall resistivity will be low. When the formation contains hydrocarbon, or contains very low porosity, its resistivity will be high.
- Mixed Resistivity and Induction tools are used to induce a current in the formation and measure the conductivity:
  - DIL (Dual Induction Logging); ILM: Induction Mid, ILD: Induction Deep, SFL: Shallow Focused Laterolog (electrodes)
  - AIT: Array Induction Image Tool – newer
- Usually while drilling, drilling fluids invade the formation:
  - If *water based mud* is used and oil is displaced, deeper resistivity logs will show lower conductivity than the invaded zone
  - If *oil based mud* is used and water is displaced, deeper resistivity logs will show higher conductivity than the invaded zone
- Resistivity is used to *identify permeable areas*, *estimate the porosity of a formation*, and *estimate fluid saturation*. Archie's equation can be used to calculate porosity and fluid saturation from resistivity logs
- Also, by distinguishing between water and hydrocarbon saturation, resistivity logs can be used to identify oil-water contacts



Borehole Environment:



Read **apparent** resistivity from well log, R_a

Correct for **borehole** effect (if necessary)

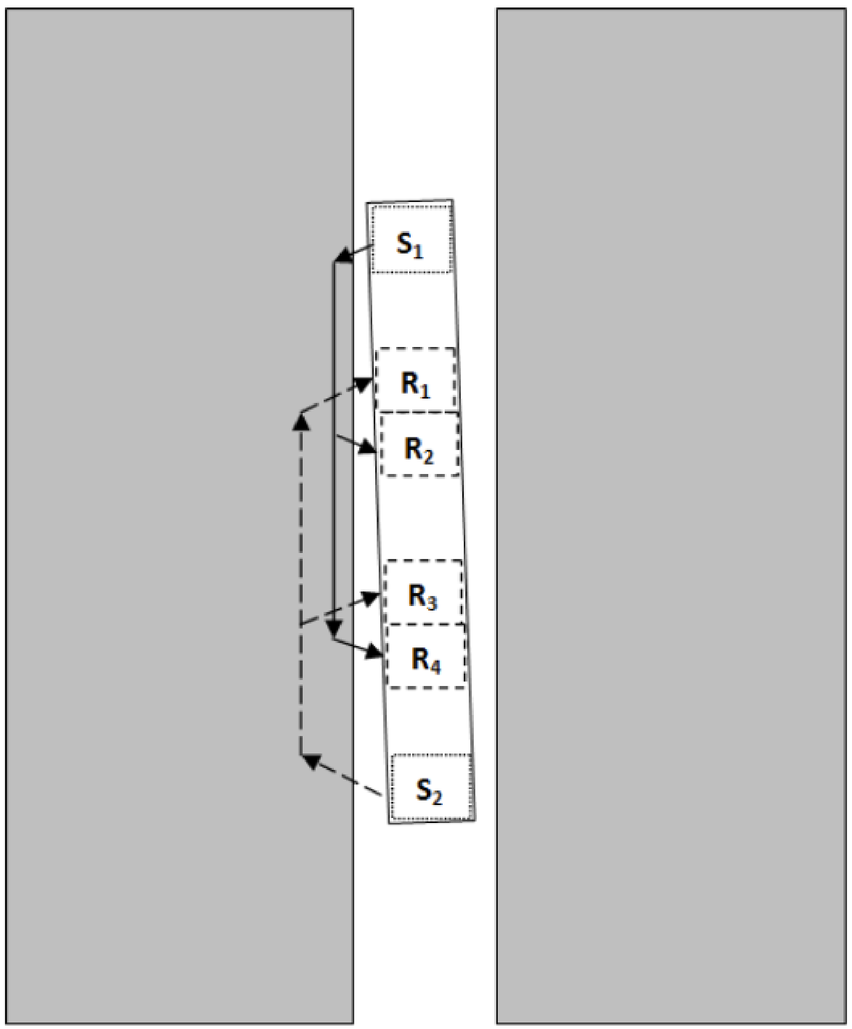
Correct for **bed thickness** effect (if necessary)

Correct for **invasion** effect (if three curves are present)

True formation resistivity, R_t

P- & S-wave velocity: Sonic Log – (DTC/DTS):

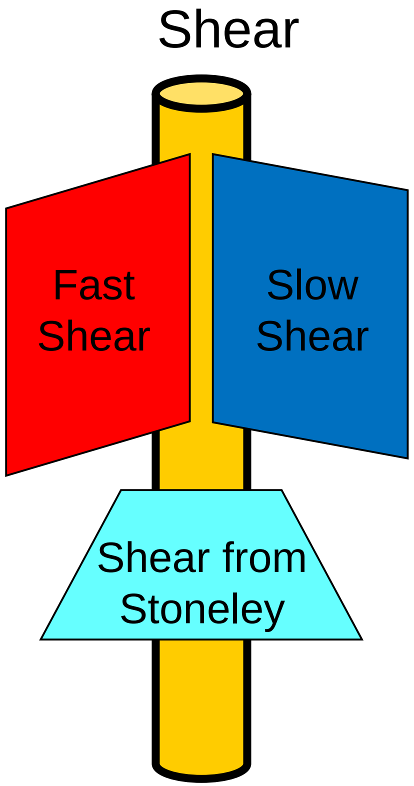
- Sonic logging measures the travel time from the piezoelectric transmitter to the receiver (usec/ft). The formation velocity is the inverse
- To compensate for the variations in the drilling mud thickness, there are two or more receivers
- Increasing or decreasing the separation between the source and receivers gives deeper penetration and overcomes the problem of low velocity zones posed by borehole wall damage
- Both up-down and down-up arrays can be used and an average calculated to compensate for tool tilt and variations in the borehole width
- Sonic logs can be used to calculate the *porosity* of a formation if the seismic velocity of the rock matrix and pore fluid are known

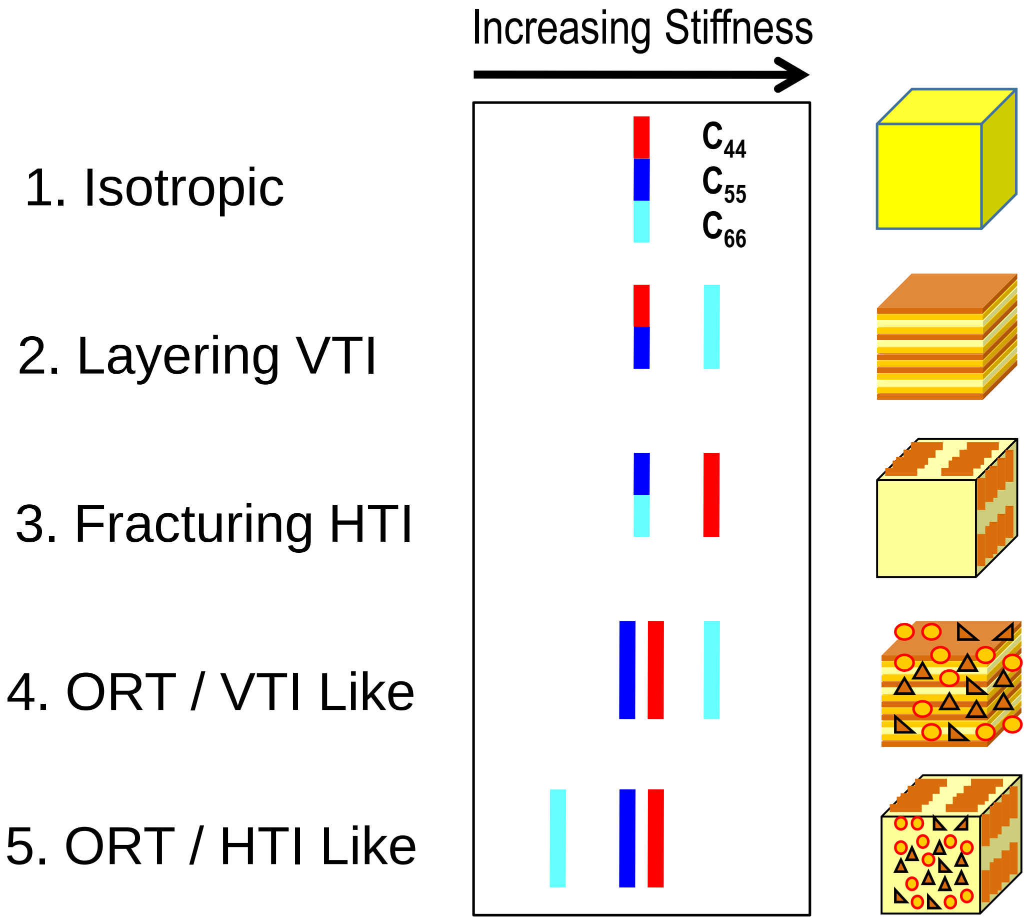


S_1 = Upper source, detected by R_2 and R_4.
S_2 = Lower source, detected by R_1 and R_3.

Dipole Sonic Measurements

- Isotropic
  - Property identical in all 3 directions
- Transverse isotropic
  - Property identical in 2 directions, 1 direction is different
  - VTI – vertical property different
  - HTI – one horizontal property different
- Orthotropic
  - Property different 3 directions
  - VTI_Like – VTI stronger than HTI
  - HTI_Like – HTI stronger than VTI

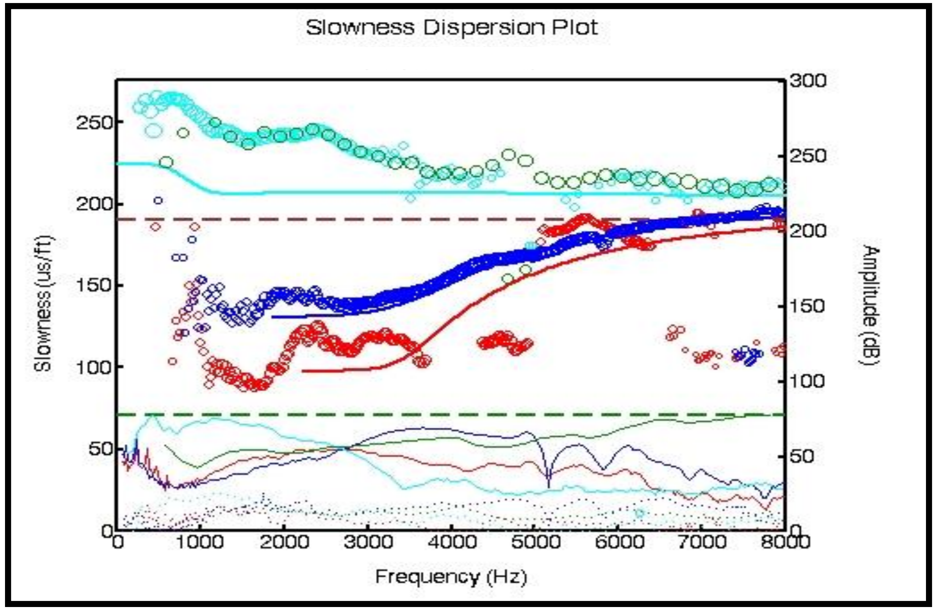




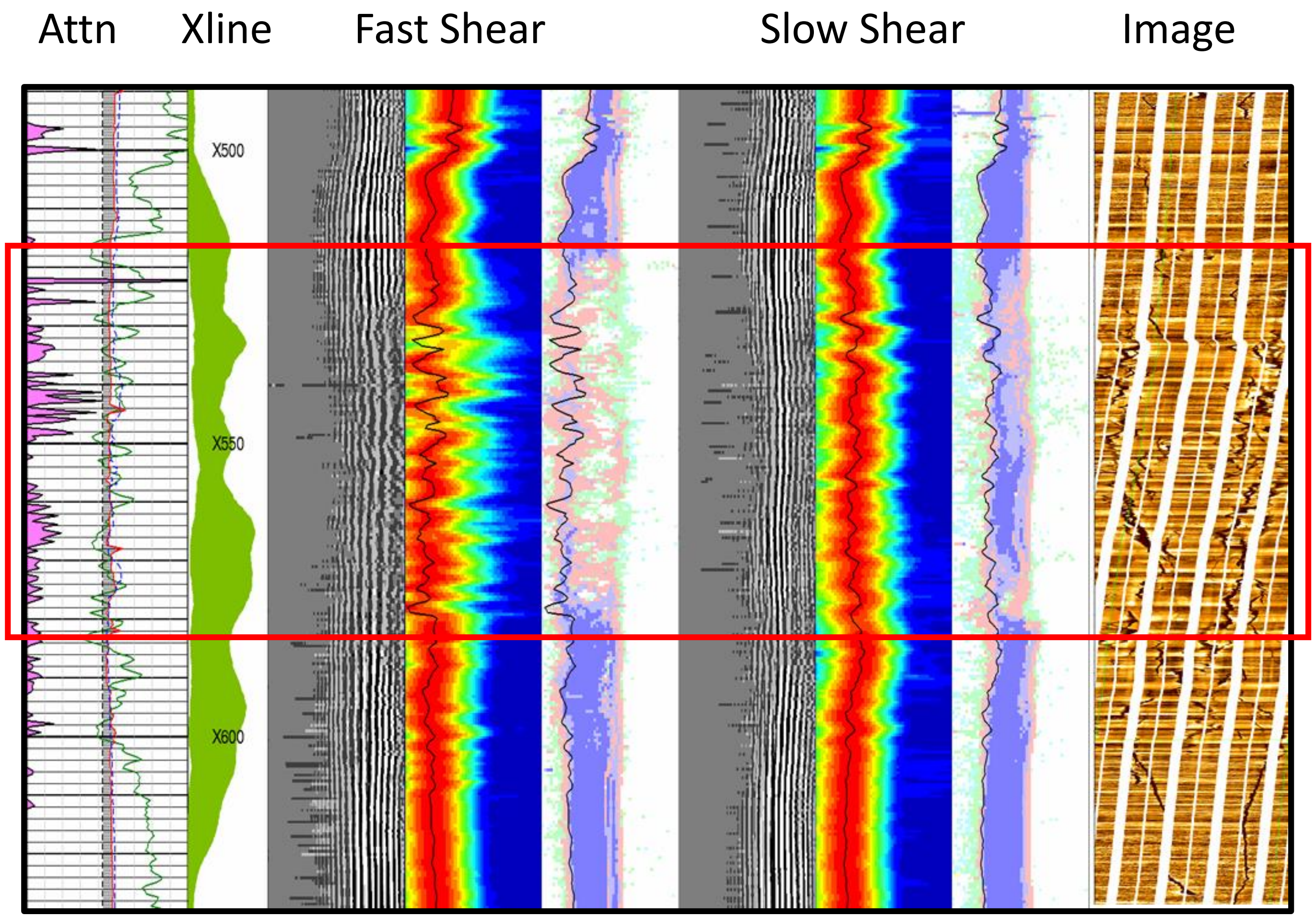
Bratton, 2017

HTI - Anisotropy due to fractures

- Sonic attenuation
- Poor minimization on Xline energy
- Natural fractures on image
- Parallel dispersion curves
- Stoneley added slowness



Bratton, 2017



Donald, A., et al. SPWLA (2006)

Spontaneous Potential Log – (SP)

- The SP log works by measuring small electric potentials (millivolts) between depths in the borehole and a grounded electrode at the surface. The change in voltage is caused by a buildup of charge on the borehole wall
- The SP curve is usually 'flat' opposite shale formations because there is no ion exchange due to the low permeability, low porosity properties thus creating a baseline
- Generally if the ionic concentration of the well bore fluid is less than the formation fluid then the SP reading will be more negative (usually plotted as a deflection to the left). If the formation fluid has an ionic concentration less than the well bore fluid, the voltage deflection will be positive (usually plotted as an excursion to the right)
- The presence of hydrocarbons will reduce the response on an SP log because the interstitial water contact with the well bore fluid is reduced
- Conductive bore hole fluids are necessary to create a SP response, so the SP log cannot be used in nonconductive (oil-based) drilling muds
- **SP data can be used to find:**
    - Depths of permeable formations
    - The boundaries of these formations
    - Correlation of formations when compared with data from other analogue wells
    - Values for the formation-water resistivity
- Many factors can cause changes in the SP log. Expertise is necessary