भारतीय प्रौद्योगिकी संस्थान (भारतीय खनि विद्यापीठ) धनबाद

IIT ISM

INDIAN INSTITUTE OF TECHNOLOGY (INDIAN SCHOOL OF MINES) DHANBAD

GPC510 - Well logging

Semester - Winter 2024; Lecture - 16

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AGENDA

- Introduction
- Principles of formation density measurement
- Tool design
- Porosity calculation

INTRODUCTION

- Density of formation is one of the most important physical rock properties
- Formation density log measures the bulk density of a formation
- Bulk density refers to the overall density which includes rock matrix and pore fluids occupying the pore space
- Bulk density of a rock will change according to the porosity and the mineralogy
- For example, a quartz mineral content sandstone matrix has bulk density of 2.65 g/cm^3. With the increase of porosity, the bulk density will decrease
- Density log is the one of the most important tool used to accurately calculate total porosity

DENSITY LOG WITH ADDITIONAL LOG

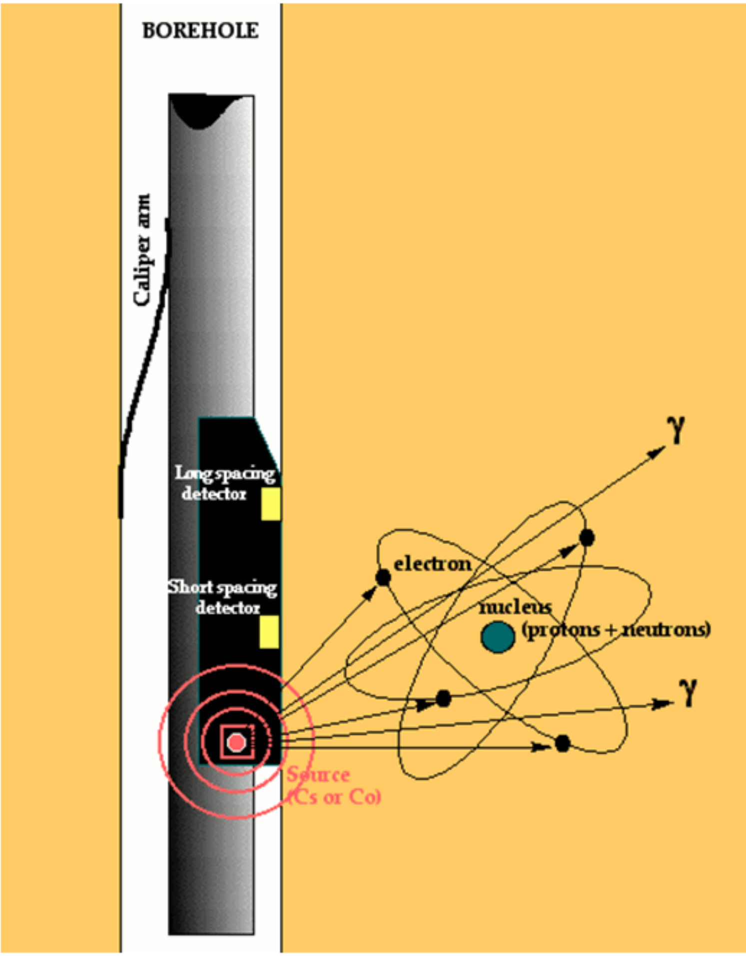
The density log is run in combination with other tools

- Litho-density, or PEF tools, which are a specialized density tool to obtain information about matrix composition of a formation
- Neutron log along with density log are used to identify lithology and locating hydrocarbon zones
- Various cross-plotting techniques combining density-neutron log for multiple application related to formation evaluation

PRINCIPLES

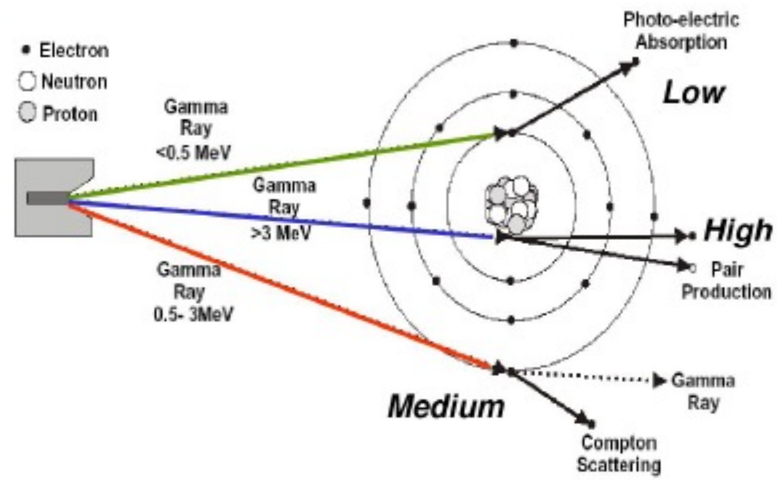
Formation density tool has:

- A gamma-ray source, which bombard the formation with radiation,
- Gamma-ray detectors
- The standard source (^{60}Co - or ^{137}Cs – 0.63 Mev) emits medium energy gamma rays between the energy range 0.2 – 2 MeV
- These gamma rays collide with the formation



GAMMA RAY INTERACTIONS

- **High energy GR** (> 3 MeV) interact with nucleus and are converted to an electron and positron (pair production). Low efficiency, small contribution
- **Medium energy GR** (0.5 – 3 MeV) undergo Compton scattering where GR interacts with an electron orbiting the nucleus, ejecting the electron and incident gamma ray loses its energy
- **Low energy GR** (< 0.5 MeV) collide with electrons, and are absorbed. GR energy is either used to promote the electron to a higher energy or to eject it from atom. The process is called photoelectric effect, and is important in the litho-density tool

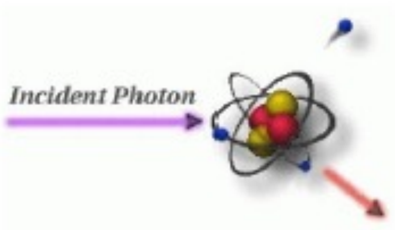


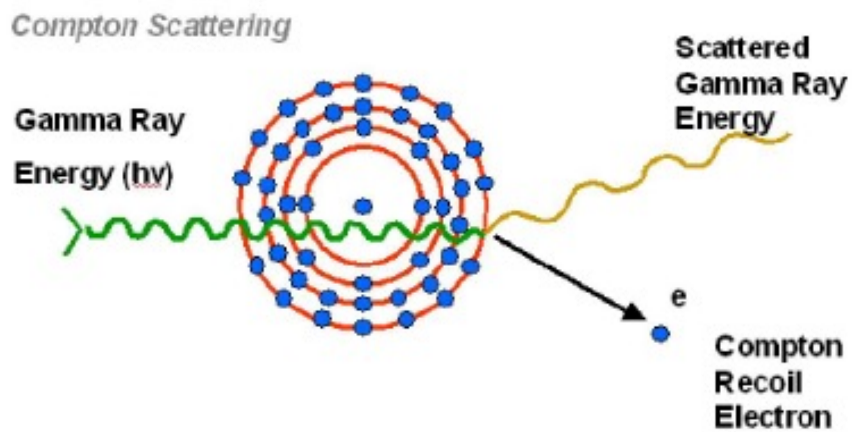
Rezaee, 2022

PRINCIPLES

Compton Scattering

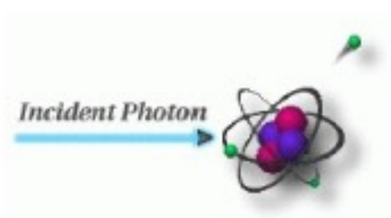
Depends on electron density

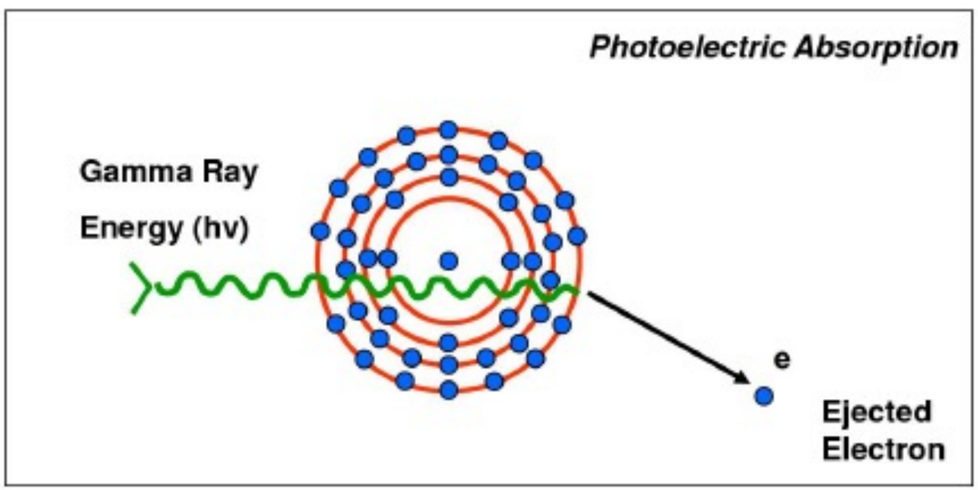




Photoelectric absorption

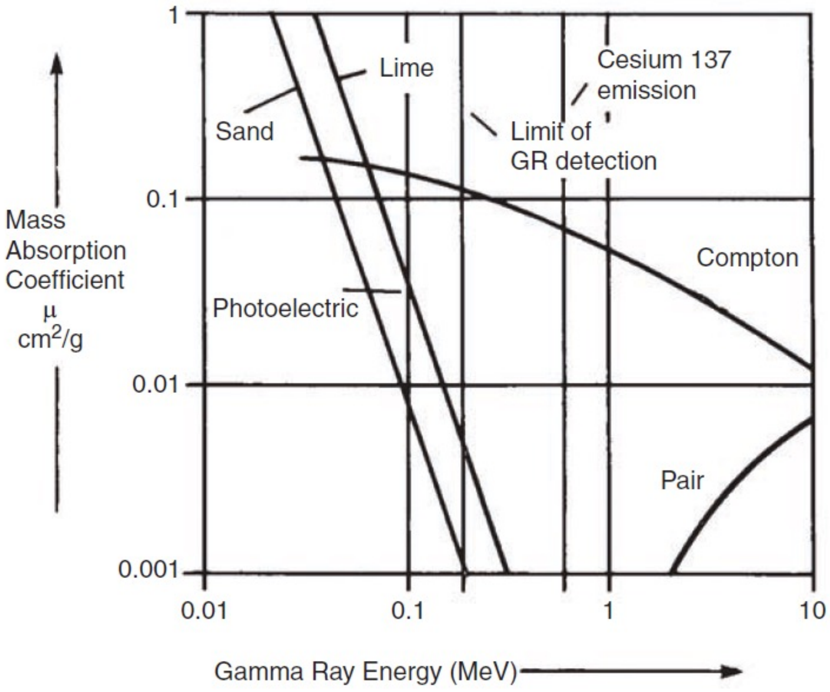
Depends on atomic number





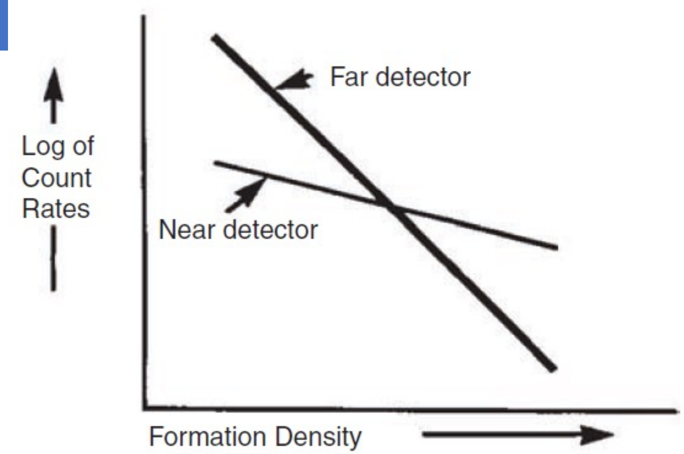
COUNT RATES AND DENSITY

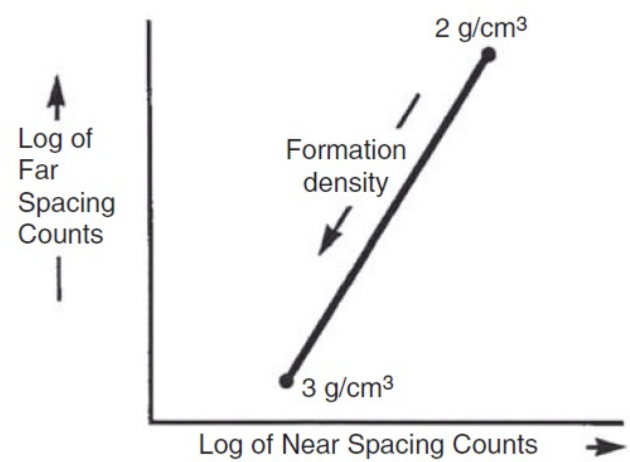
- Gamma ray mass absorption coefficient μ, $I_o = I_{in}e^{-\mu n_e L}$
- Detector of conventional density tools have a lower level of energy detection
- Based on this, Compton scattering is the only form of gamma ray interaction captured by the density tool



COUNT RATES AND DENSITY

- Count rate seen at detector is logarithmically propositional to the formation density
- Log(count rate) = A + B*formation density
- Lower count rates with increasing formation density





COUNT RATES AND DENSITY

- The attenuation of gamma-ray energy due to Compton Scattering is governed by the electron density (n_e) of the formation i.e., number of electrons per unit volume, from which the bulk density ρ_b (g/cm3) can be relate via below equation

$$n_e = \rho_b \left(\frac{Nz}{A} \right)$$

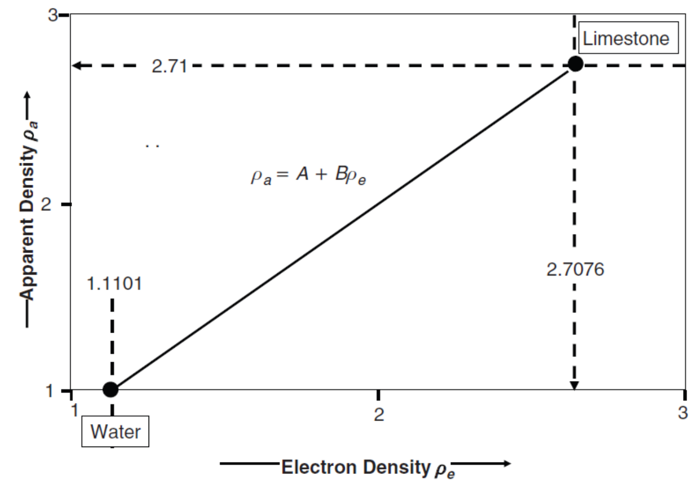
Where Z is the atomic number (number of electrons per atom), and A is the atomic weight. Given for majority of element and constituents of rock Z/A ~0.5 except hydrogen. electron density index is defined as $\rho_e = \frac{2n_e}{N}$

ELECTRON DENSITY

- For most of the rocks, the bracketed portion is very close to unity, thus when the tool is calibrated in a freshwater-saturated limestone , the apparent global density ρ_a is linked to the electron density index ρ_e as

$$\rho_a = 1.0704\rho_e - 0.1833$$

- Therefore, for liquid filled reservoirs (sandstone, limestone, dolomite), ρ_a is practically equal to ρ_b , correction is required for gas saturated formation

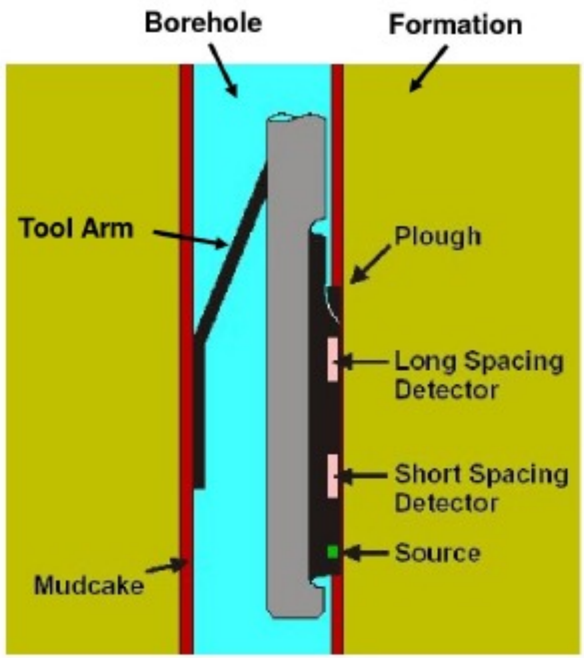


Bulk density (ρ_b), 2Z/A, ρ_e, ρ_a values for common minerals and formation fluids.

Compound	ρ_b	2Z/A	ρ_e	ρ_a (Equ.)
Quartz	2.654	0.9985	2.65	2.648
Calcite	2.710	0.9991	2.708	2.710
Dolomite	2.870	0.9977	2.863	2.876
Anhydrite	2.960	0.9990	2.957	2.977
Gypsum	2.320	1.0222	2.372	2.351
Halite	2.165	0.9581	2.074	2.032
Coal	1.500	1.040	1.600	1.400
Fresh water	1.000	1.1101	1.110	1.00
Salt water	1.146	1.0797	1.237	1.135
Oil	0.850	1.1407	0.970	0.850

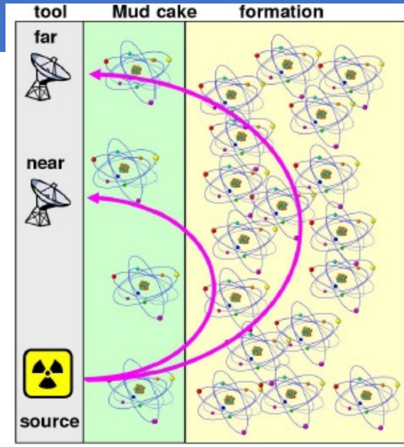
COMPENSATED DENSITY TOOL (FDC)

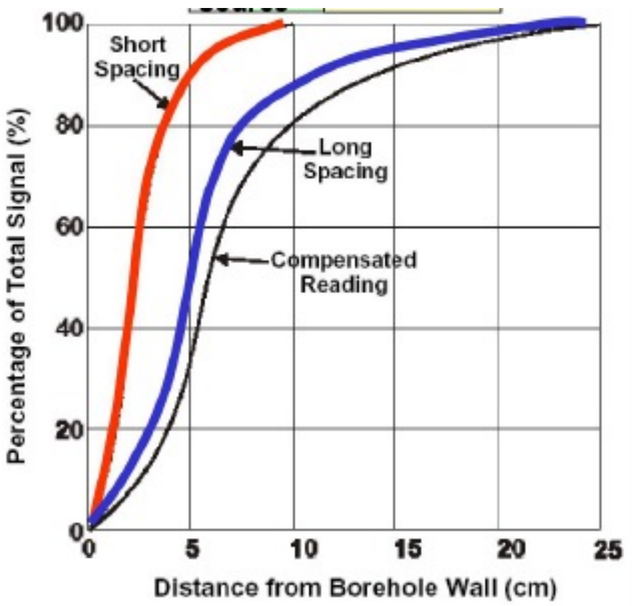
- The first tools used only one detector. However, the measurement impacted by mud cake, its thickness, density
- Formation compensated density tool use double detectors (long spacing -16'' and short spacing -7'' from source)
- The tool is pushed against the one side of the wellbore with sufficient force by an extendable arm
- The tool contains a small plough that scrapes off the mudcake as the it moves
- Detectors are scintillation detector which convert gamma ray energy into electrical signal



MUD-CAKE COMPENSATION

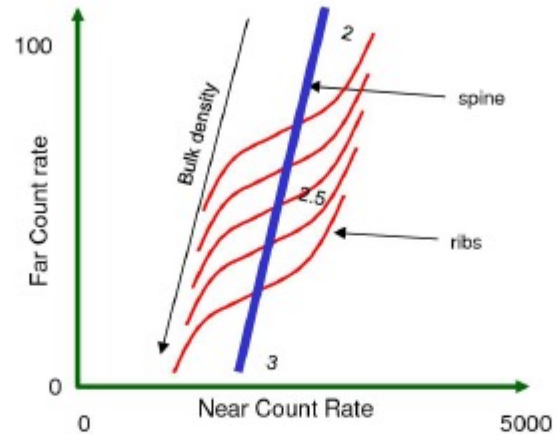
- Gamma rays measured by the short spacing detector have only penetrated a short distance into the formation and mostly measured mudcake and a very shallow into the formation
- Gamma rays measured by the long-spacing detector penetrated deeper into the formation

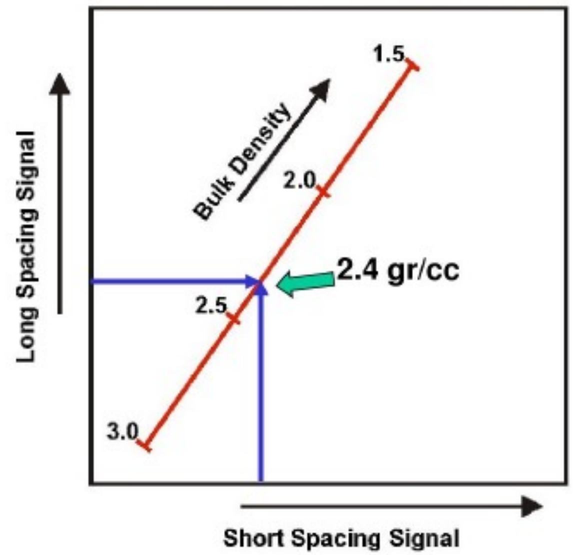




MUDCAKE COMPENSATION

- Far counts – depends on electron density (formation and fluid density)
- Near counts – depends on mud properties
- Spine and Ribs plot to compensate for mudcake effect faced by the density tool
- An example of mudcake correction plot when no mud cake formed, all data falls on the spine



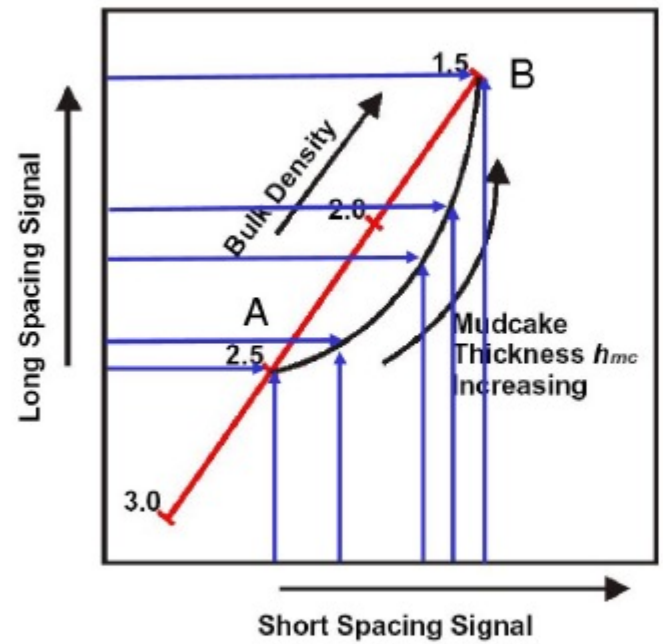


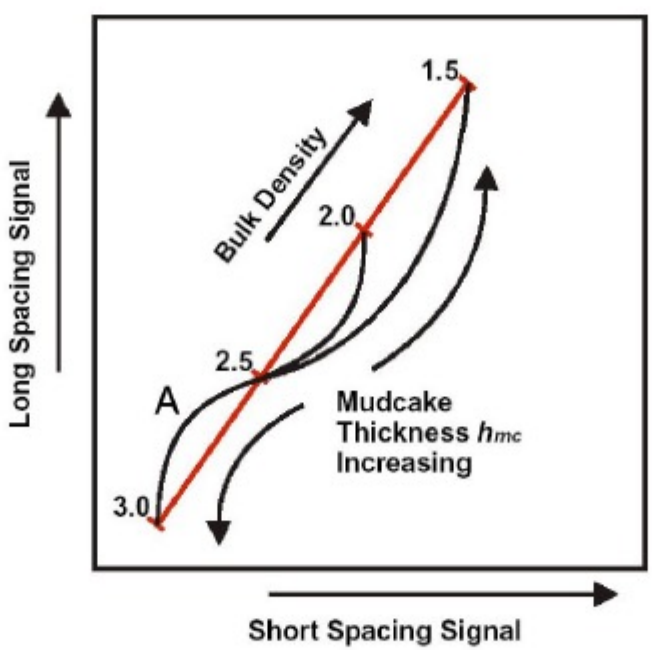
MUDCAKE COMPENSATION

A- mudcake thickness zero

B – mudcake thickness infinity

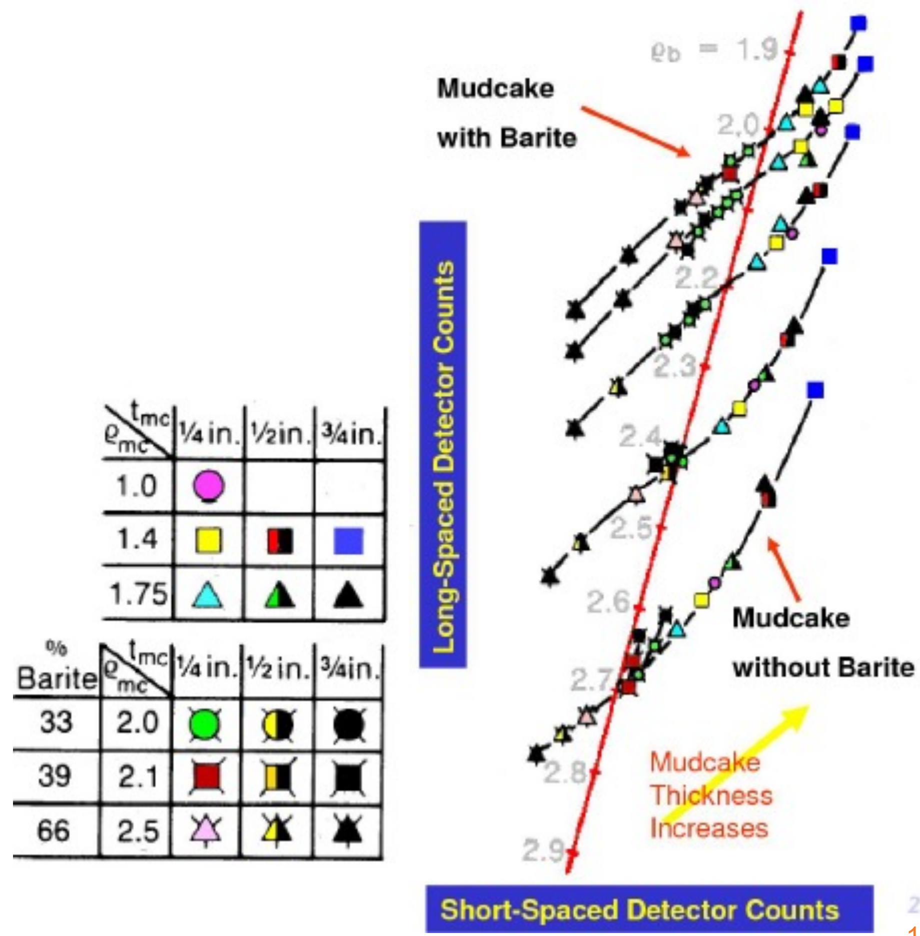
- Mudcake thickness - variable





SPINE AND RIB PLOT

- The spine and rib plot illustrates that for a given formation density, there is only one rib for all normal mudcake densities and thickness
- Surface equipment computes the position of the point on the plot, then moves the point down the rib to intercept the spine



DEPTH OF INVESTIGATION

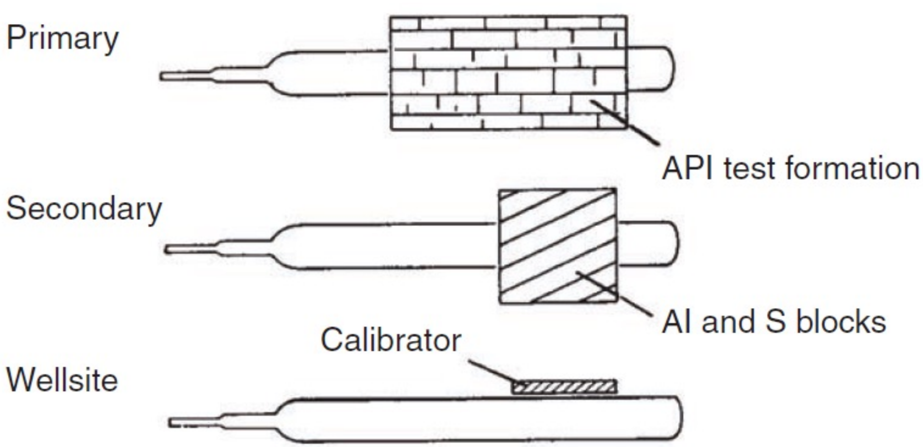
- The depth of investigation is very shallow and do not cross above 6 inch
- In porous and permeable formations, the tool investigated the invaded zone and, the fluid filling pore space will be mud filtrate
- The tool is highly influenced by bad borehole conditions, there it is required to interpret in combination with Caliper log
- The tool cannot differentiate between oil and mud filtrate because of invasion and displacement. Although the tool is impacted by gas

VERTICAL RESOLUTION

- Bed resolution is relative good despite shallow depth of investigation
- At average logging speed of 1300 ft/hr, true formation densities can be read down to vertical resolution of 2ft (60 cm)
- At lower speed and higher sampling allows improved resolution of beds up to thickness of 15 cm
- Calcareous nodules as thin as 5 -10 cm can be seen as peaks on the density logs

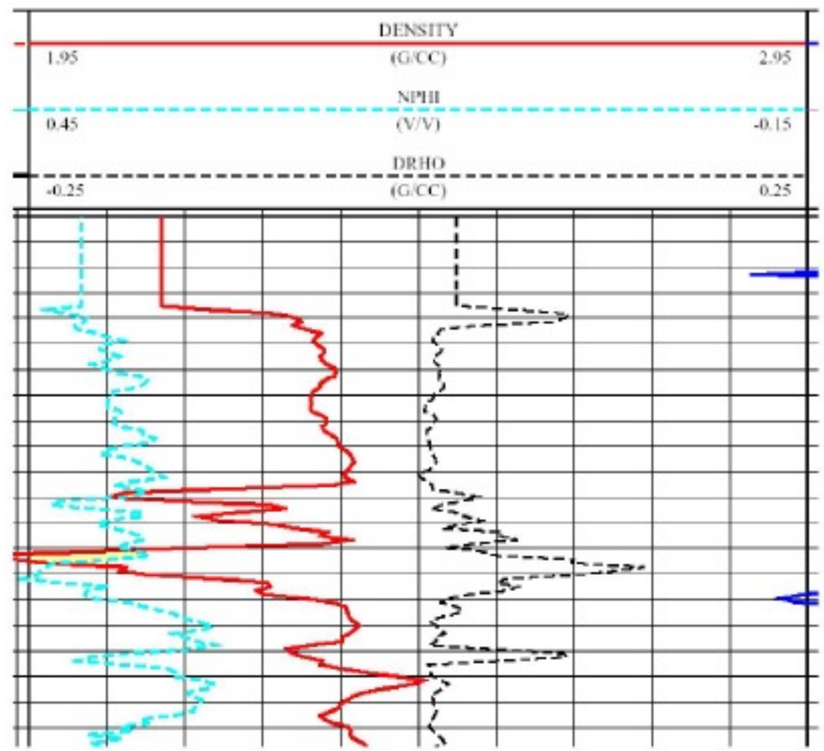
CALIBRATION

- Primary calibration in the lab under limestone saturated formation with freshwater where density is known
- Secondary calibration are made in blocks of aluminium and sulphur or magnesium with accurately known density and geometry
- At field, a calibration jig is used that gives a radioactive level of known intensity designed to test the detection system

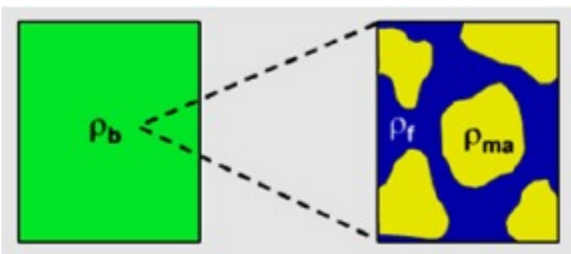


DATA PRESENTATION

- The density log is normally plotted on a linear scale of bulk density, which ranges from 1.95 to 2.95 g/cm3 (from left to right)
- The main density log is often accompanied by a curve indicating the borehole and mudcake corrections that have been applied (DRHO)
- A record of cable tension may also be included because the tool is prone to sticking in poor holes
- The tool is typically run as a density-neutron combination with a gamma ray and caliper log



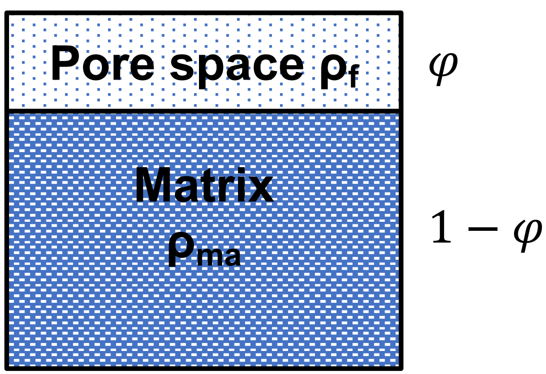
POROSITY CALCULATION



- Rock = Solid matrix + Fluid filled pores;

$$\rho_b = \rho_{ma} \times (1 - \varphi) + \rho_f \times \varphi$$

$$\varphi = \frac{\rho_{ma} - \rho_b}{\rho_{ma} - \rho_f}$$



Where,

ρ_{ma} = the density of the rock matrix

ρ_b = the bulk density of formation [from log]

ρ_f = the density of pore fluid

Φ = total porosity

POROSITY CALCULATION

- The density tool has a very shallow depth of investigation and it measured flushed zone. If the formation is hydrocarbon-bearing, the fluid density can be calculated by;

$$\rho_f = \rho_{mf} \times S_{xo} + \rho_{hc} \times (1 - S_{xo})$$

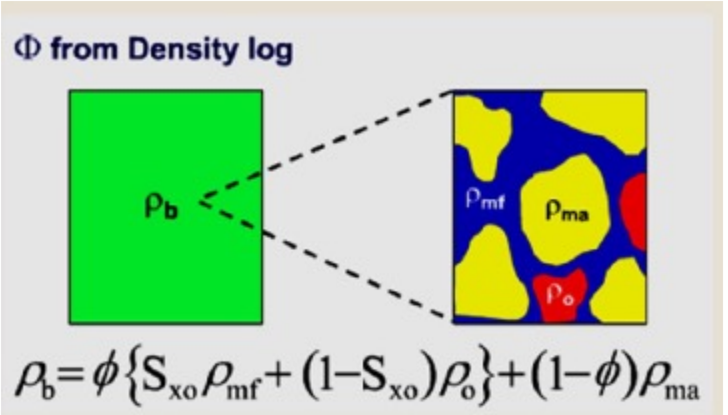
where,

ρ_{mf} = the density of mud filtrate

ρ_{hc} = the density of hydrocarbon

ρ_f = the density of pore fluid

S_{xo} = water saturation in the invaded zone

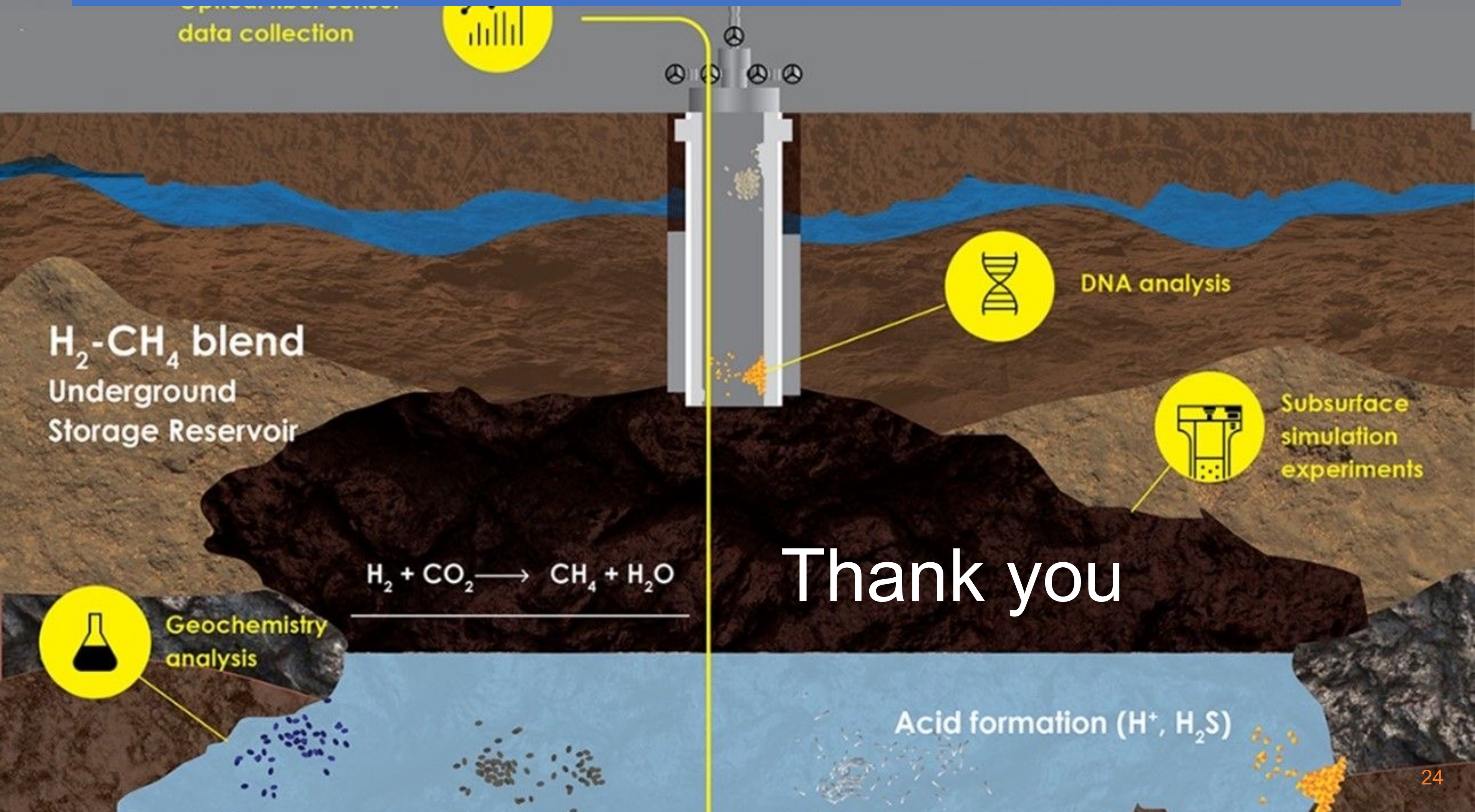


PROPERTIES OF MATRIX

Lithology		GR	Density	Neutron	Acoustic	Resistivity	PE
Sandstone		Low (Unless RA min)	2.65	-4	53	High	1.81
Limestone		Low	2.71	0	47.5	High	5.08
Shale		High	2.2-2.7 (water content)	High (water content)	50-150 (water content)	low (water content)	1-5
Dolomite		Low (higher if U)	2.87	+4	43	High	3.14
Anhydrite		V.Low	2.98	-1	50	V.High	5.06
Salt		Low (Unless K salt)	2.03 (1.87)	-3 (-2)	67 (74)	V.High	4.65
Water		0	1-1.1 (salt & temp)	100	180-190	0 - infinite (salt & temp)	0.36 (+salt)
Oil		0	0.6-1.0 (api)	70-100 (H2 index)	210-240 (api)	V.High	Low
Gas		0	0.2-0.5 (pressure)	10-50 (H2 index)	~1000	V.High	Low

(Baker Hughes, 2002)

END OF LECTURE



Thank you