Tishk International University
Engineering Faculty
Petroleum and Mining Department

Well Logging I

Lecture 5: Density Logs

3rd Grade - Fall Semester 2021-2022

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Density Logs

- The Density Log or Formation Density Log
- The tool components
- Names of Modern density tools
- Density Log and Principles of measurement
- Log Presentation
- Depth of investigation and resolution.
- Formation Density Log Determination of Porosity from chart
- Principal uses
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- The Photoelectric Factor
- How dose it work
- Volumetric Photo-Electric Absorption Index
- Some Notes

The Density Log or Formation Density Log

- The formation density log measures the bulk density of the formation.
- Its main use is to derive a value for the total porosity of the formation.
- It is also useful in the detection of gas-bearing formations and in the recognition of evaporites.
- The formation density tools are induced radiation tools.
- They bombard the formation with radiation and measure how much radiation returns to a sensor.

The tool consists of:

A radioactive source. This is usually **Caesium-137** or **Cobalt-60**, and emits gamma rays of medium energy (in the range 0.2 – 2 MeV). For example, Caesium-**137** emits gamma rays with a energy of 0.662 MeV.

A short range detector. This detector is very similar to the detectors used in the natural gamma ray tools, and is placed 7 inches from the source.

A long range detector. This detector is identical to the short range detector, and is placed 16 inches from the source.

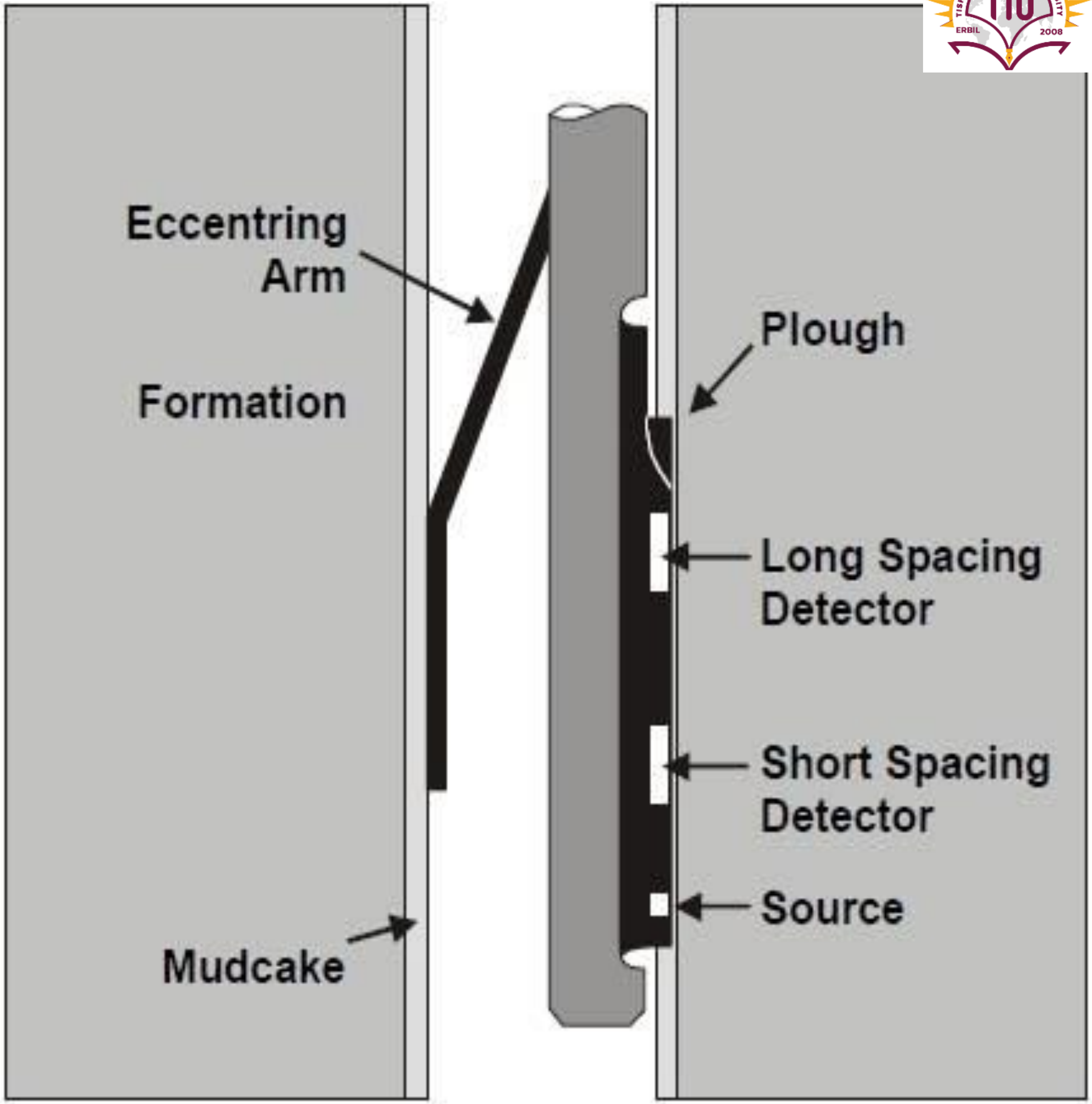


Fig. Schematic diagram of a formation density tool.

Modern density tools

1- Density measurement

Name	**Symbol**	**Company**
Formation Density Compensated	FDC	Schlumberger
Compensated Densilog	CDL	Western Atlas, Halliburton
Compensated Density	CDS	BPB

2- Photoelectric measurement

Name	**Symbol**	**Company**
Litho-Density Tool	LDT	Schlumberger
Compensated Z-Density	ZDL	Western Atlas
Photoelectric Density	PDS	BPB
Spectral Density Tool	HSDL	Halliburton

Density Log

- The density log is the continuous record of a formation's ***Bulk density*** (**g/cm^3**), and indicate by the Greek letter $\boldsymbol{\rho}$ (rho).
- This is the **overall density** of rock including solid matrix and the fluid enclosed in the pores.
- Geologically, bulk density is a function of the density of the minerals forming a rock ($\boldsymbol{\rho}_{ma}$) and the volume of the fluids which it encloses porosity ($\boldsymbol{\rho}_{fl}$).
- For example, sandstone with **no** porosity will have a bulk density of **2.65 g/cm^3**.
- At **10%** porosity the bulk density is only **2.49 g/cm^3**,
- the sum of 90% quartz grains (density 2.65 g/cm^3) and 10% water (density1.0 g/cm^3).

Pb = (0.9 * 2.65) + (0.10*1.0) = 2. 485

Principles of measurement

- The logging technique of the density tool is to subject the formation to a bombardment of focused GRs and to measure their attenuation between the tool source and detectors.
- Such attenuation (Compton scattering) is a function of the number of electrons that the formation contains (electron density) which is very closely related to its common density.
- In dense formations, Compton scattering attenuation is extreme, and few detectable GRs reach the tool's detectors,
- while in lesser density (higher porosity) the number is much higher.
- Detector counts in modern tools are converted directly to bulk density for the log printout.
- The actual values presented on the density log are transformed to give actual values of calcite (2.7g/cm^3) and pure water 1.0g/cm^3).

- The number of Gammaray reaching the detector is function of the number of electrons present in the formation (electron density ρe).

$$\rho e = \frac{2Z}{A} . \rho b$$

Z= atomic number (also known as the **proton number**)

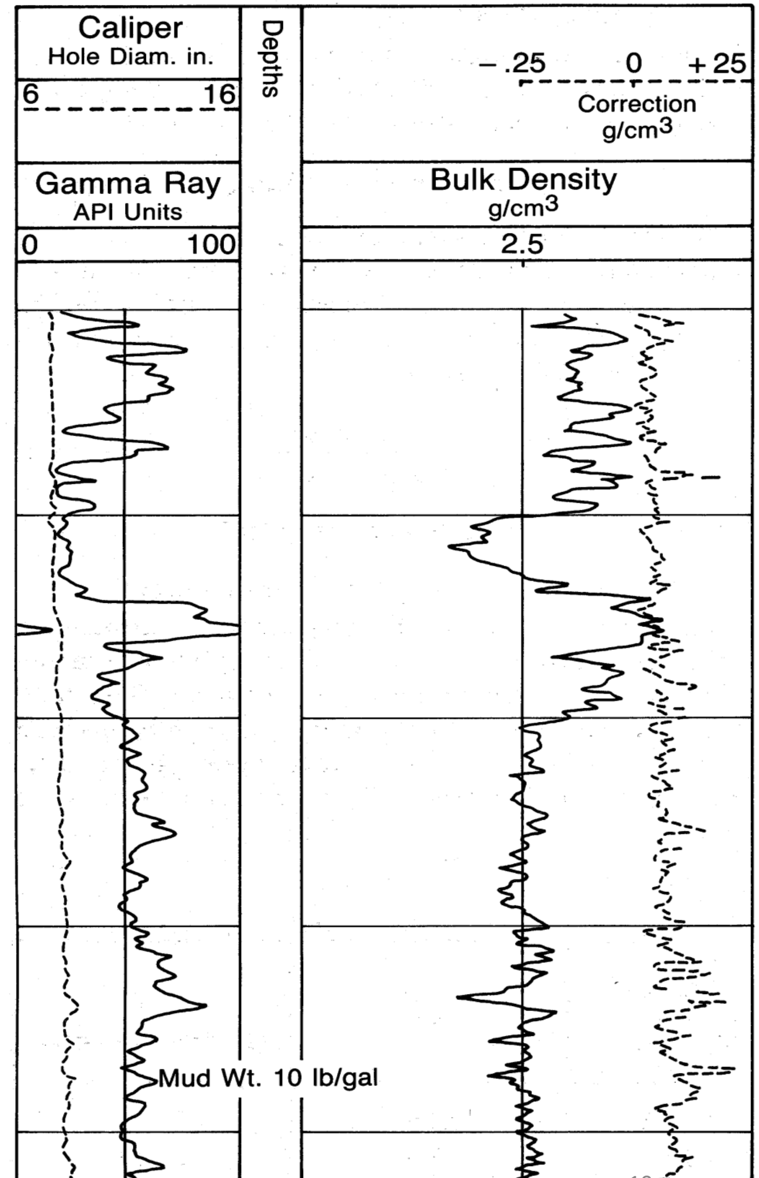
A= mass number (**protons** and **neutrons**)

Log Presentation

The formation density log is recorded in tracks 2 and 3 of the standard API log presentation on a linear scale.
The scale is in g/cm^3, and usually spans 1.95 to 2.95 g/cm^3 as this is the normal range for rocks

The automatic compensation (correction) for mud cake is often shown in either track 2 or track 3 on a linear scale.

This curve ($\Delta\ \rho$)) is included as a quality control curve. If the correction curve is greater than ±0.15 g/cm^3, the data in the main curve will not be very reliable.



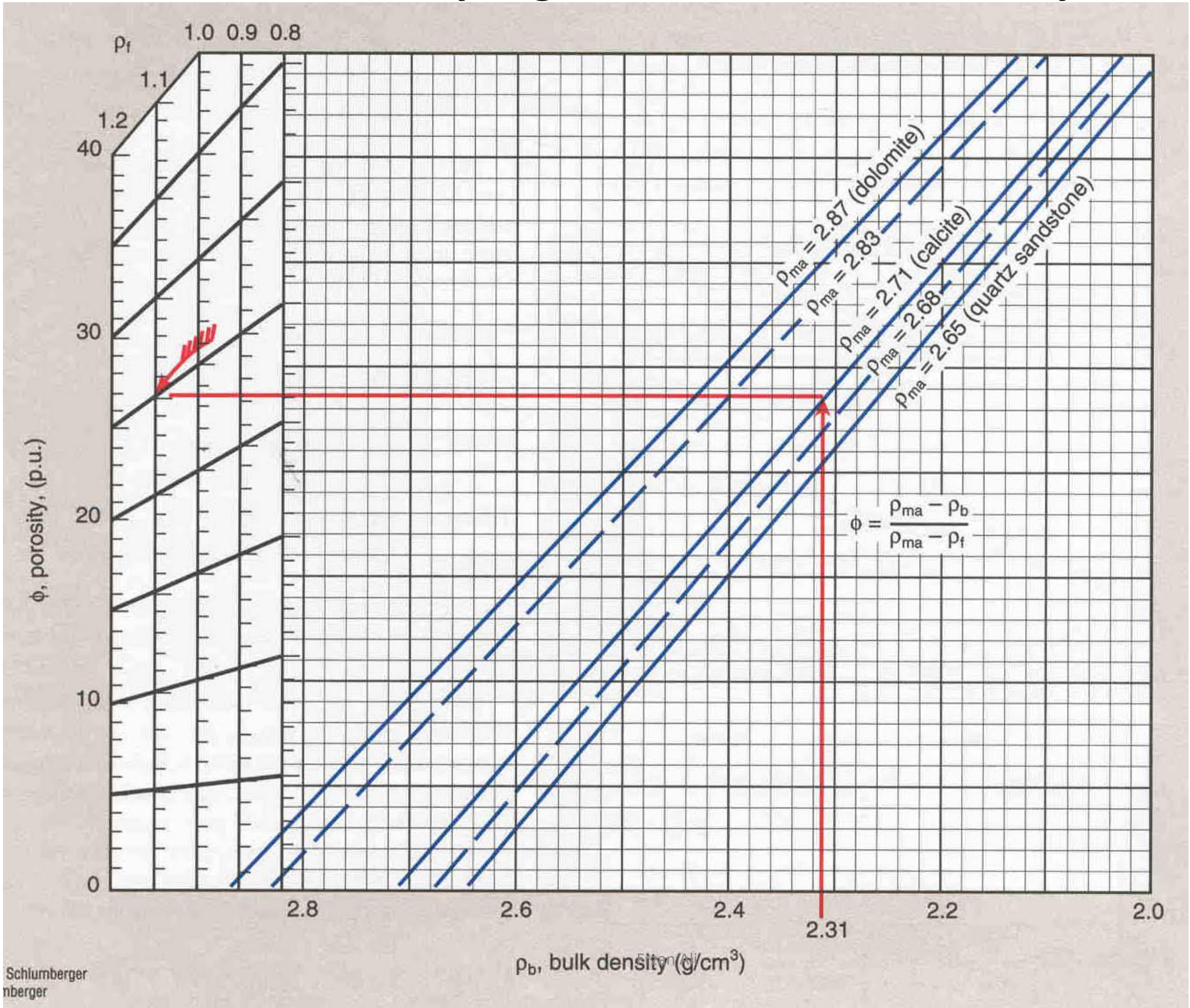
Depth of investigation

- **The depth** of investigation is very shallow (around 10 to 13cm), which makes it very susceptible to hole conditions (enlargement).

- **The bed resolution** is good, at average logging speeds (about 400m/h, 1300m/h) true densities can be read in beds down to about 60cm (2ft);

- good bed resolution makes the density log used for drawing bed boundaries

Formation Density Log Determination of Porosity



Principal uses:

<u>Quantitatively</u> the density log is used to

a- to calculate acoustic impedance in seismic interpretations.

b- Calculate porosity; to calculate porosity from density log it is necessary to know the density of rock.

As an example, if the tool measures a bulk density of 2.5g/ cm^3 in a saltwater bearing formation (**ρ_{fl} = 1.1g/ cm^3**), we can interpret any of the following according to the lithology:

Lithology	Grain density	porosity
Sandstone	2.65g/ cm^3	10%
Limestone	2.71g/ cm^3	13%
Dolomite	2.87g/ cm^3	21%

- Of course, if we know the grain (matrix) density and the fluid density we can solve the equation that gives the porosity from the summation of fluid and matrix composition:
- **Bulk density (ρb) = $\Phi \times \rho_{fl}$ + ρ_{ma} (1- Φ).**

- Porosity Φ_D=

$$\frac{\rho ma - \rho b}{\rho ma - \rho fl}$$

Φ_D = porosity derived from density log
ρ_{ma} = density of matrix (rock), from the table
ρ_{fl} = fluid density (fresh or salt muds).

- It also used to calculate acoustic impedance.

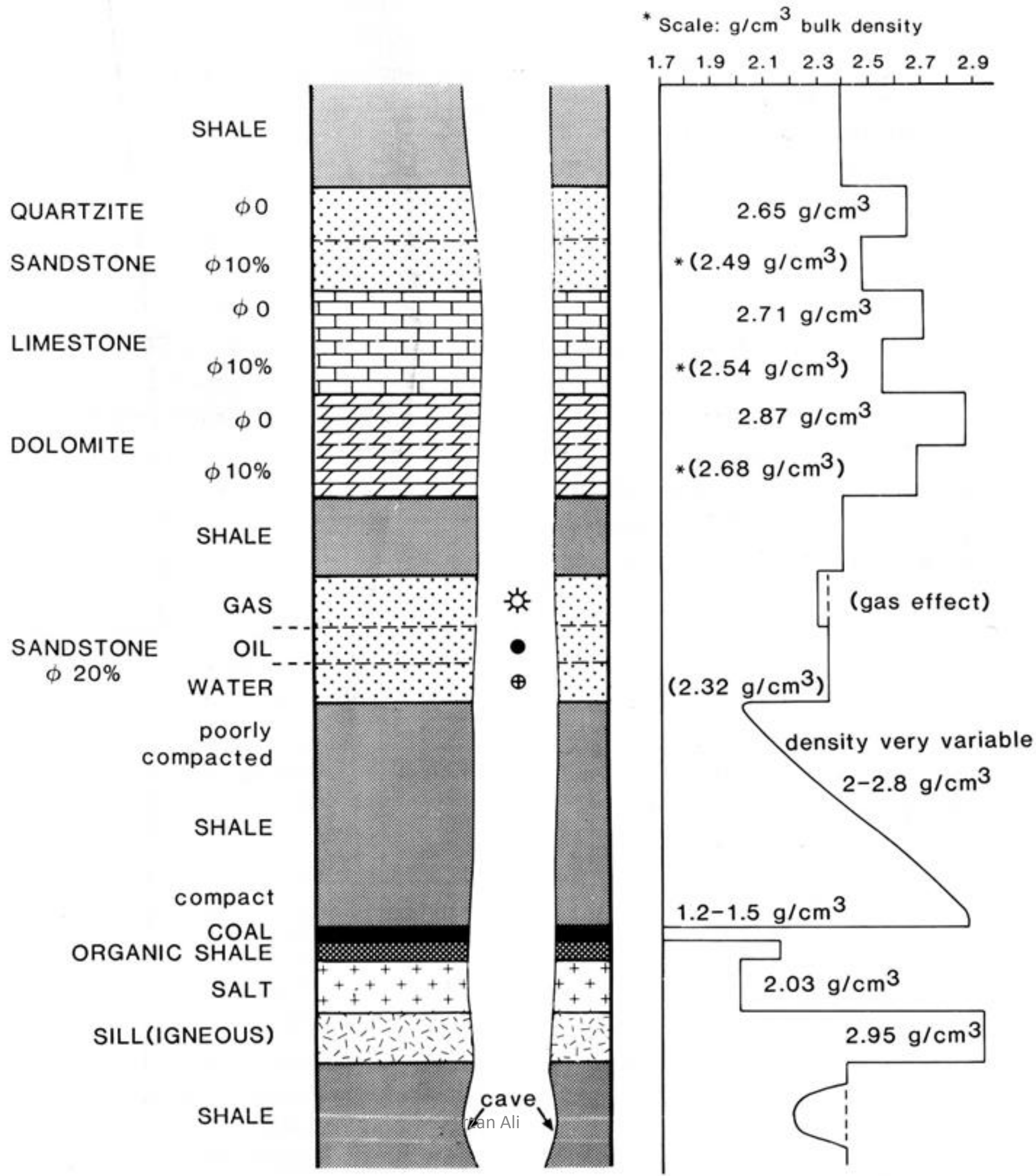
Qualitative use

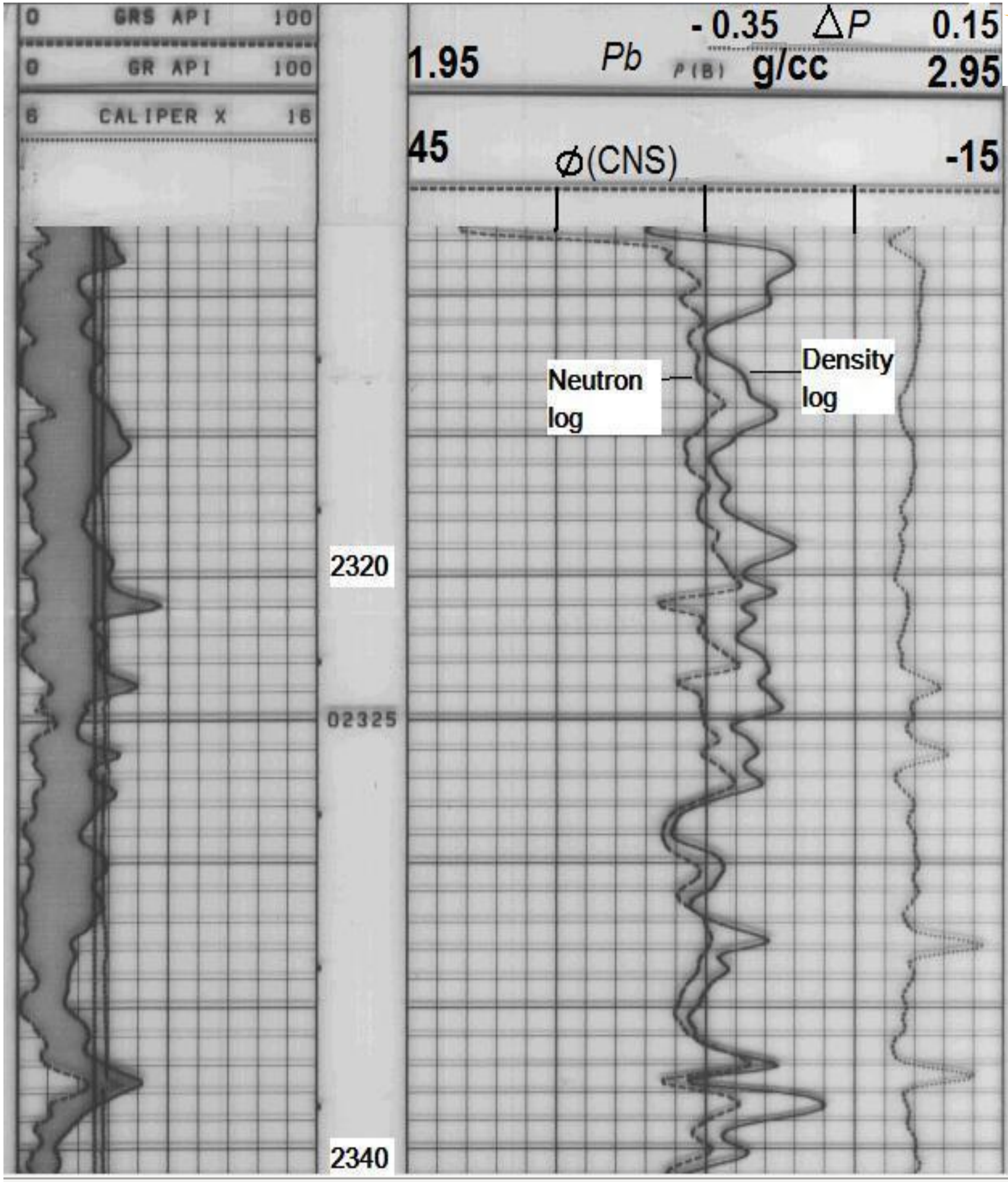
- **<u>Qualitatively</u>** the log can assist the geologist to:
- Identify evaporate minerals, most evaporates tend to be give intervals of constant densities if they are pure.
- Detect gas bearing zones
- determine hydrocarbon density
- evaluate shaly sand reservoirs and complex lithologies

Log presentation scale and units

- The density log is normally plotted on a linear scale of bulk density (figure).
- The log is run across track 2 and 3 with Neutron log (dashed line), most often with scale of **1.95** and **2.95** g/cm^3.

Lithology	ρmagm/cm^3	**Pe (b/e)**
Sandstone	2.64	1.81
Limestone	2.71	5.08
Dolomite	2.88	3.14
Anhydrite	2.96	5.05
Salt	2.04	4.65
Fresh water	1.0	…
Salt water	1.15±	…
Barite (mud additive)	…	267


* Scale: g/cm3 bulk density
1.7 1.9 2.1 2.3 2.5 2.7 2.9
SHALE
QUARTZITE φ0
SANDSTONE φ10%
φ 0
LIMESTONE
φ10%
φ 0
DOLOMITE
φ10%
SHALE
GAS
SANDSTONE φ 20%
OIL
WATER
poorly compacted
SHALE
compact
COAL
ORGANIC SHALE
SALT
SILL(IGNEOUS)
SHALE
cave
2.65 g/cm3
*(2.49 g/cm3)
2.71 g/cm3
*(2.54 g/cm3)
2.87 g/cm3
*(2.68 g/cm3)
(gas effect)
(2.32 g/cm3)
density very variable
2-2.8 g/cm3
1.2-1.5 g/cm3
2.03 g/cm3
2.95 g/cm3


0 GRS API 100
0 GR API 100
6 CALIPER X 16
- 0.35 ΔP 0.15
1.95 Pb P(B) g/cc 2.95
45 ϕ(CNS) -15
Neutron log
Density log
2320
02325
2340

The Photoelectric Factor

- The Photoelectric Factor (or PEF) log

  (the **Litho-Density log** of Schlumberger) is a continuous record of the effective photoelectric absorption cross section index or **Pe** of a formation,

- it is strongly depend on the average atomic number, **Z** (chemical composition and indirectly lithology), the effect of porosity are kept minimum.

How dose it work?

- When the GRs pass through matter, at most energies they degrade through collision or Compton scattering .
- In addition, at low energies, below about 100 keV, the phenomenon known as photoelectric absorption takes effect.
- Photoelectric absorption occurs when GRs have lost sufficient energy to be captured by electrons electrically bound to atoms.
- The capturing electron acquires energy, leaves its atomic orbit and becomes ionized.
- The degree of absorption depends on both the atomic number **Z (**Protons) and the electron density (ρ_e) of the atoms.

Volumetric Photo-Electric Absorption Index

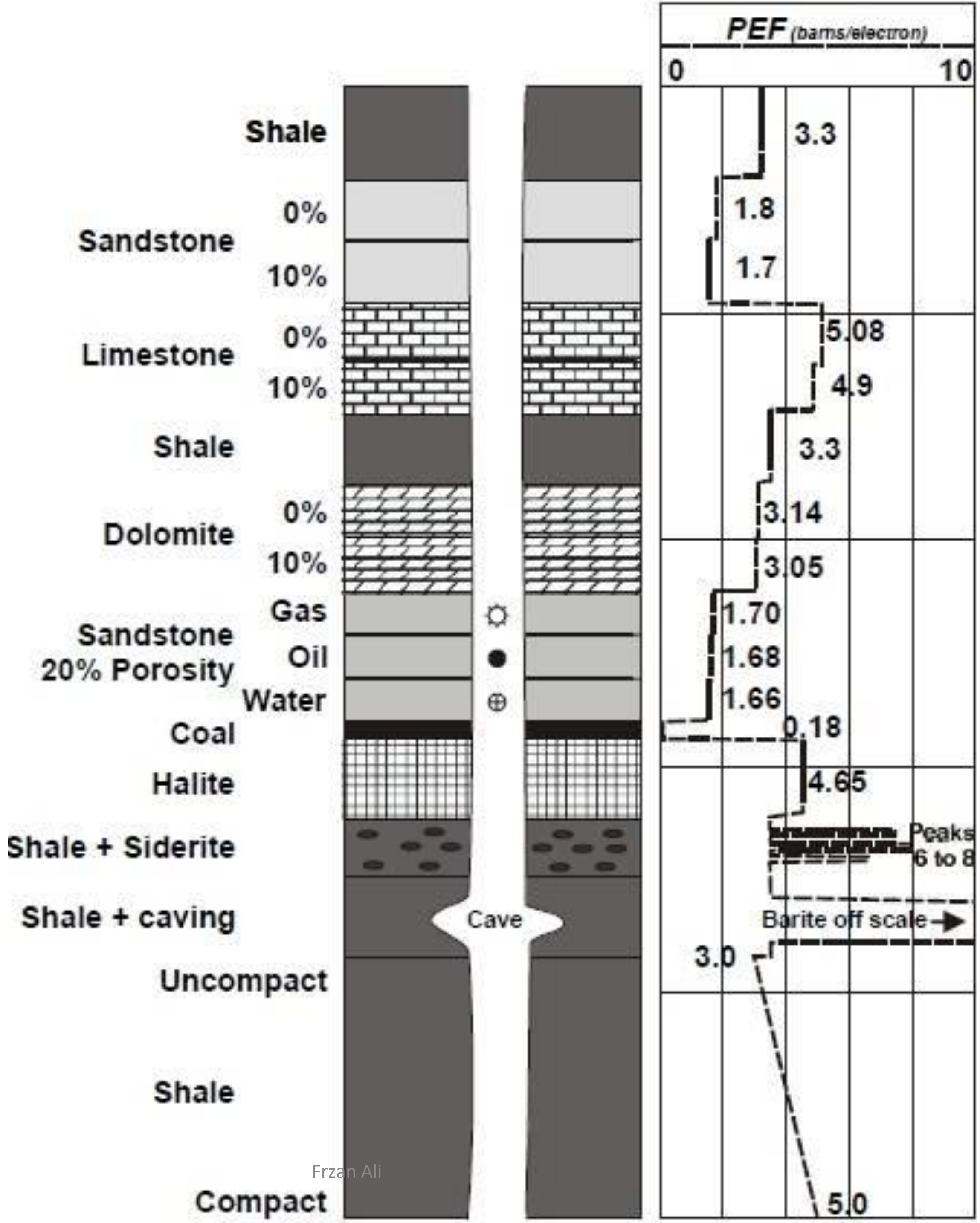
- The Volumetric photo-electric absorption index **U** *of a material describes the likelihood that a gamma* ray will be photo-electrically absorbed per unit volume of the material.
- It can be written in terms of the specific photo-electric absorption index as

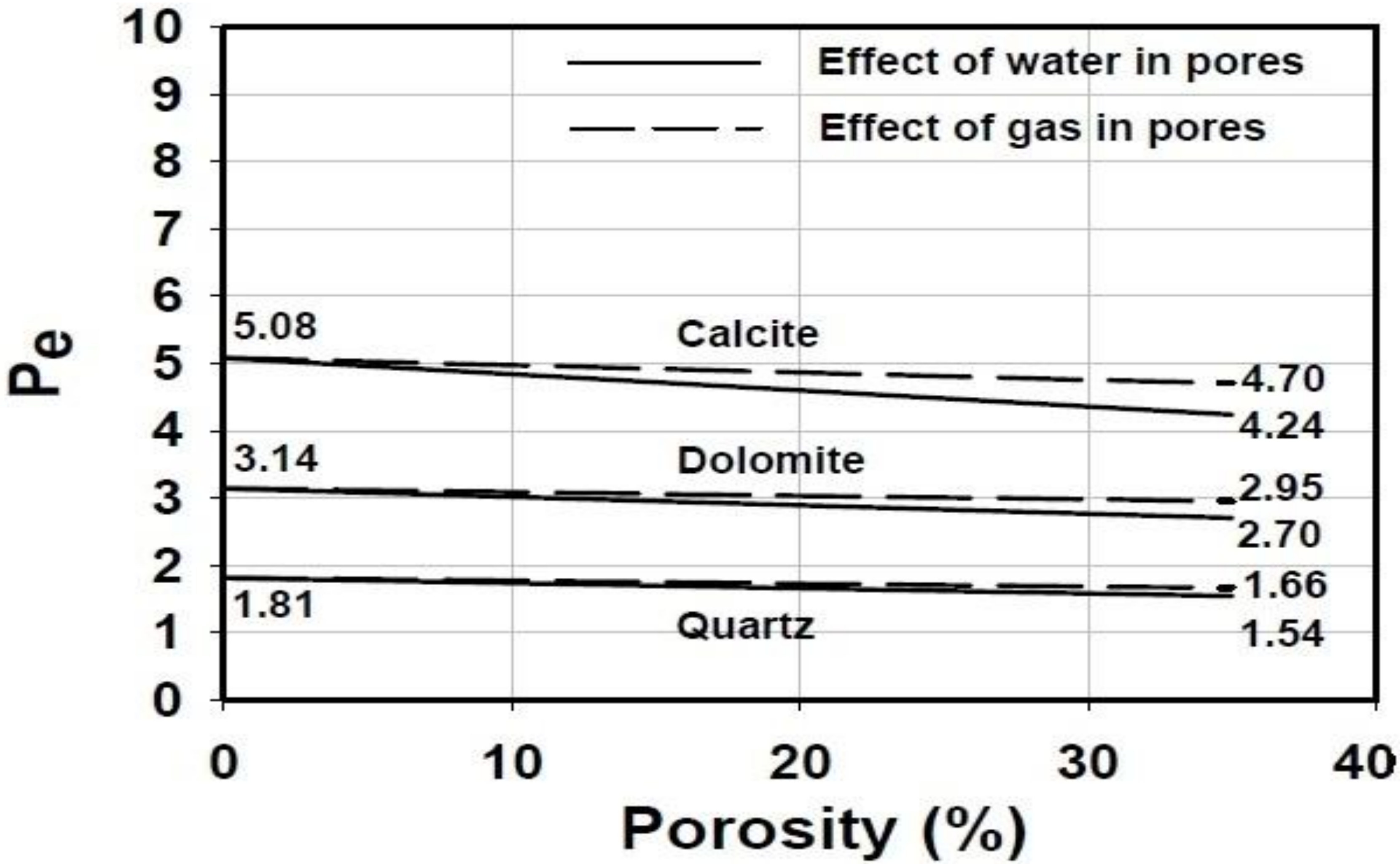
$$U = Pe\, \rho e$$

Table; **Photo-electric** data for common minerals and fluids.

Mineral	Formula	*Pe*	*Z*	$\rho\beta$	$\rho\varepsilon$	U
Anhydrite	$CaSO_4$	5.055	15.69	2.960	2.957	14.93
Barite	$BaSO_4$	**266.82**	47.2	4.500	4.01	**1070**
Biotite		6.30				21.03
Calcite	$CaCO_3$	5.084	15.71	2.710	2.708	13.77
Dolomite	$CaCO_3.MgCO_3$	3.142	3.74	2.870	2.864	9.0
K Feldspar		2.86				7.51
Gypsum	$CaSO_4.2H_2O$	3.420	14.07	2.320	2.372	9.37
Quartz	SiO_2	1.806	11.78	2.654	2.650	4.79
Zircon	$ZrSiO_4$	69.10	32.45	4.560	4.279	311
Pure Water	H_2O	0.358	7.52	1.000	1.110	0.398
Oil	$(CH_2)n$	0.119	5.53	0.850	0.948	$0.136\text{x}\rho_{oil}$

Figure 3.2.2 Measurements of the photo-electric absorption (*PEF*) litho-density log for common lithologies



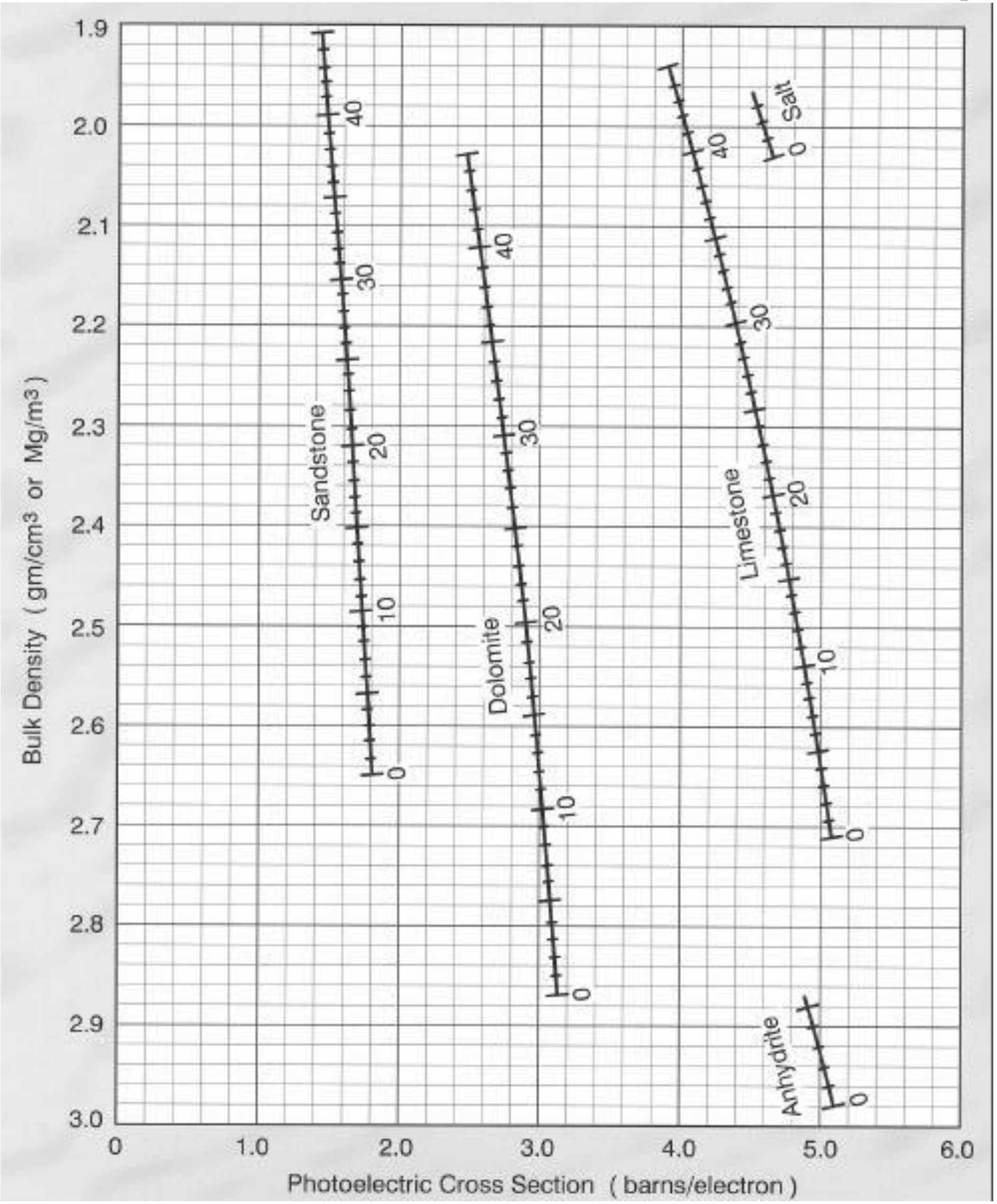


Pe as a function of porosity and fluid content.

The figure shows how little influence up to 35% porosity changes have on the *Pe values for quartz, limestone and* dolomite.

Matrix identification using the PEF and density log

data for a formation saturated with a fluid of density equal to 1.0 g/cm³.



Some Notes:

- If the formation's actual **ρma** is less than the **ρma** used to calculate **Φ, (equation).** Ex: (sandstone bed **ρma** = 2.64 g/cm^3) using a limestone (**ρma** = 2.71 g/cm^3), the calculated porosity higher than the actual porosity.
- The heavy minerals show negative porosity (its **ρb** > **ρma**)
- If the formation's actual fluid density is greater than the fluid density used to calculate the **Φ, ex:** (**ρfl=1.1** g/cm^3) using freshwater value (**ρfl=1.0** g/cm^3), the calculated porosity lower than the actual porosity, and vas versa.
- A correction curve (**Δρ** in g/cm^3) is also displayed in track 2 or 3, this curve indicates how much correction has been added to the **ρb** curve during processing due to borehole effects.
- When (**Δρ**) exceeds 0.2 g/cm^3 the values of (**ρb**) obtained from the density log considered invalid.