FORMATION EVALUATION

PETE 321

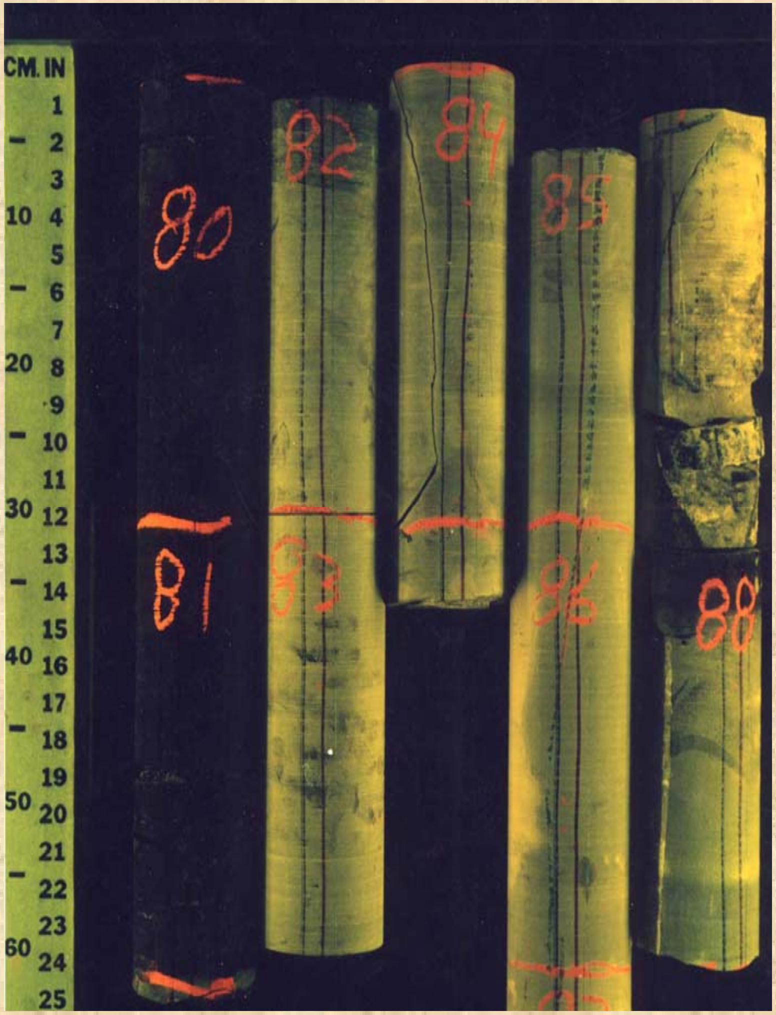
DENSITY AND NEUTRON LOGS

Summer 2010

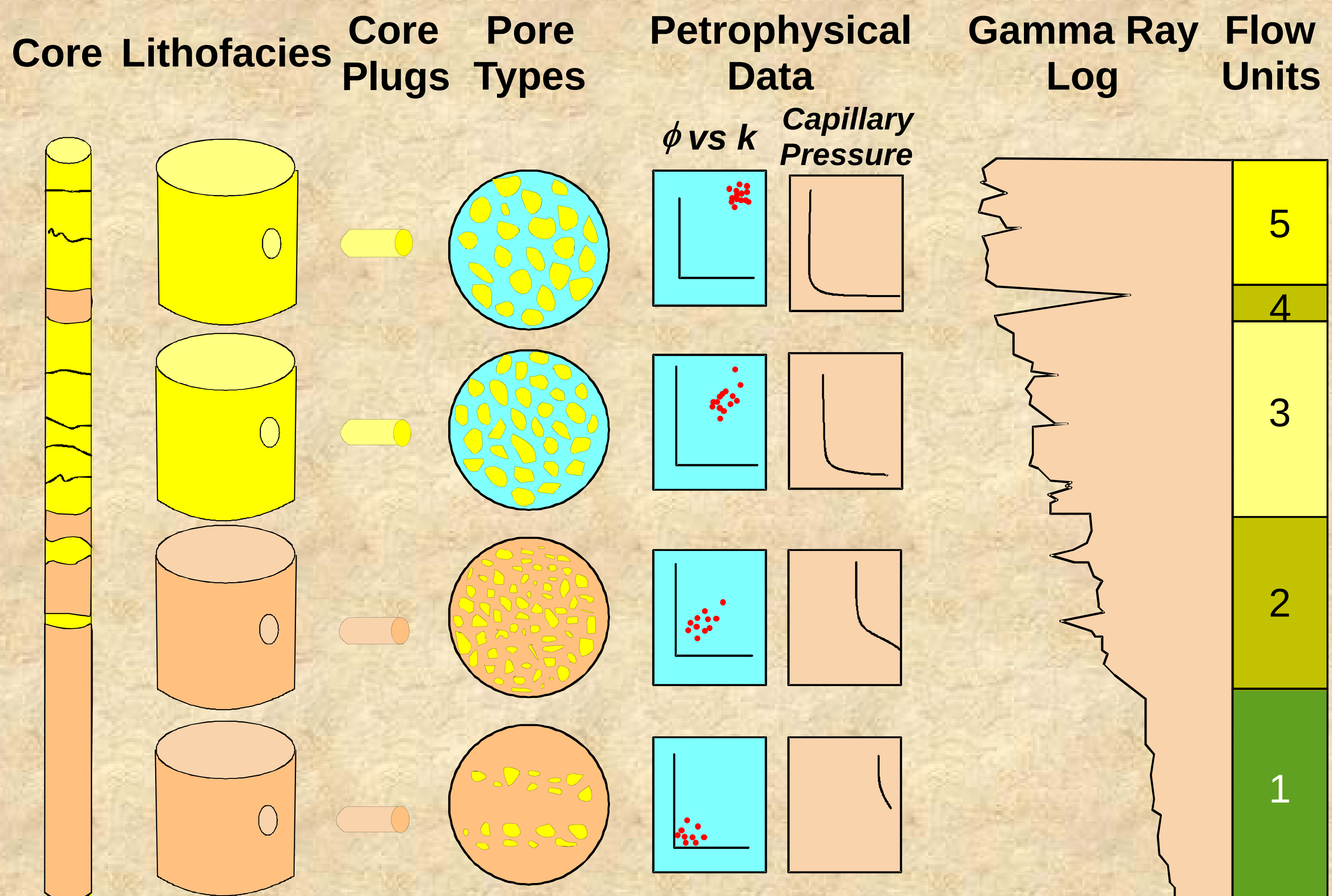
David Schechter

Fluorescent Intervals in 1U Sand

- **Sharp transition between oil saturated pay and non-pay observed by fluorescence in core samples**



GEOLOGICAL AND PETROPHYSICAL DATA USED TO DEFINE FLOW UNITS



Modified from Ebanks et al., 1992

POROSITY TOOLS

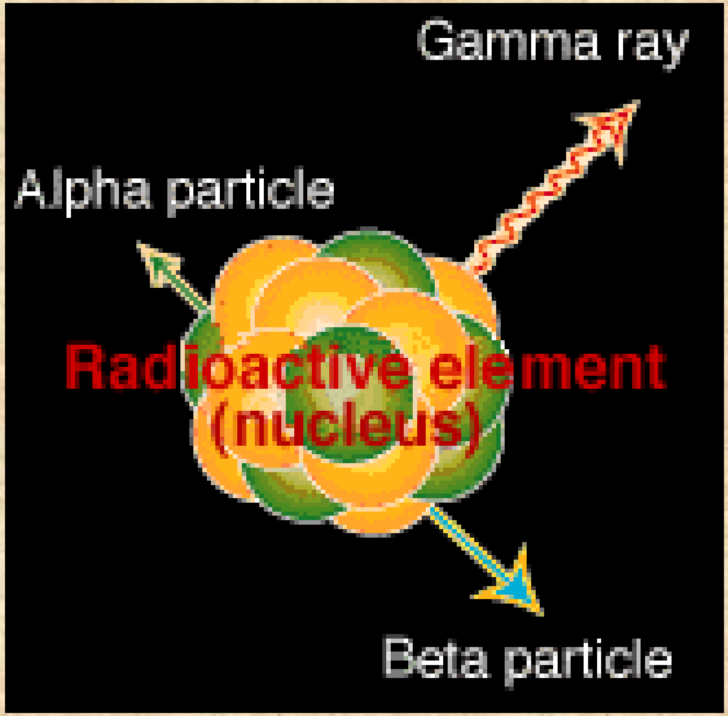
- Sonic
- Density
- Neutron

OVERVIEW

- Introduction to Nuclear logging
- Review of basic tools
  - Density Tools
  - Neutron Tools

- Applications/Limitations
- Log examples

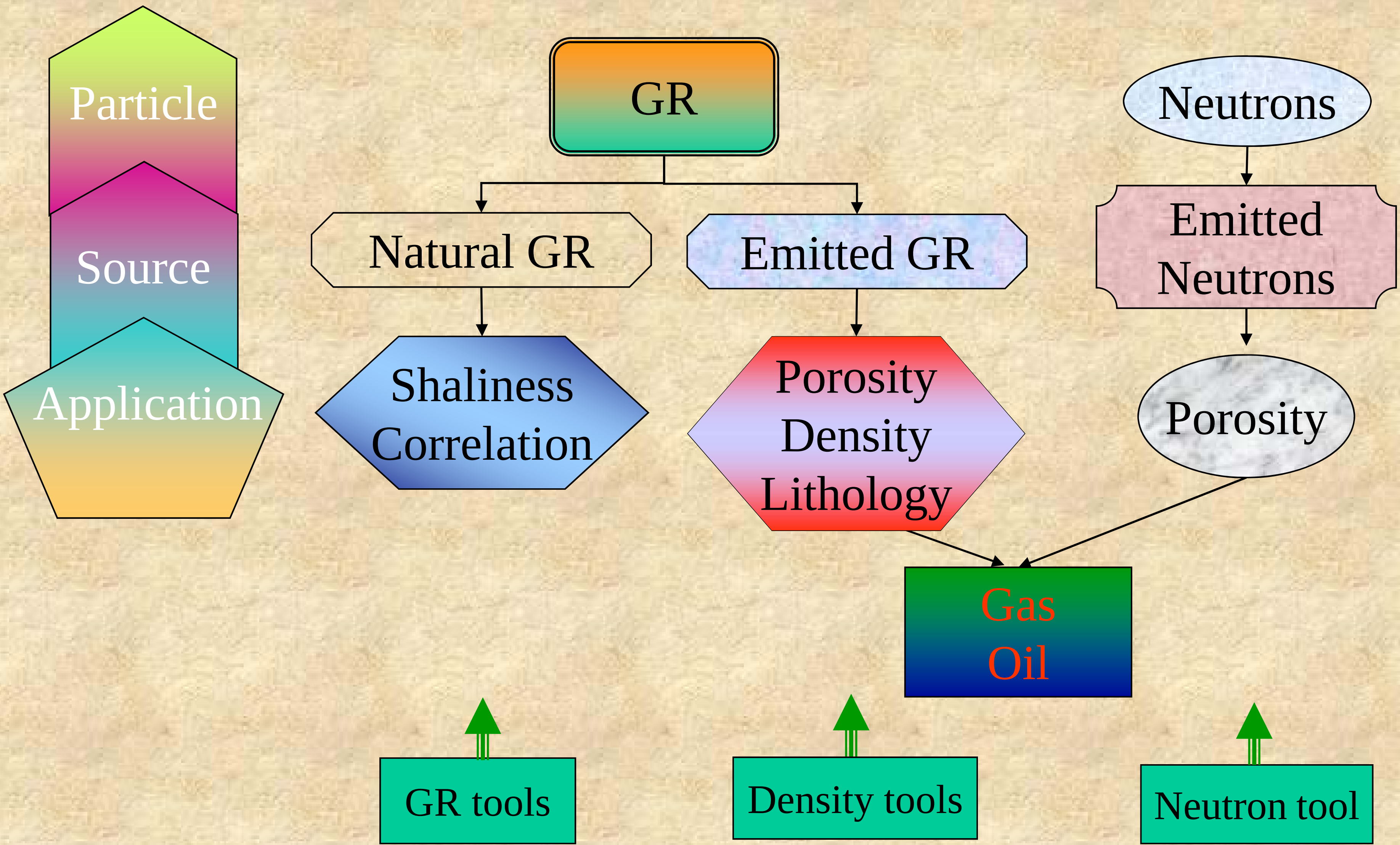
NATURAL RADIOACTIVITY



Spontaneous emission of α and β particles and γ radiation from the nucleus of a atom

- **Alpha particle** = 2 neutrons + 2 protons
  (same as helium nucleus)
- **Beta particle** = high velocity electrons
- **Gamma rays** = electromagnetic radiation
  (no mass or charge; energy in MeV)

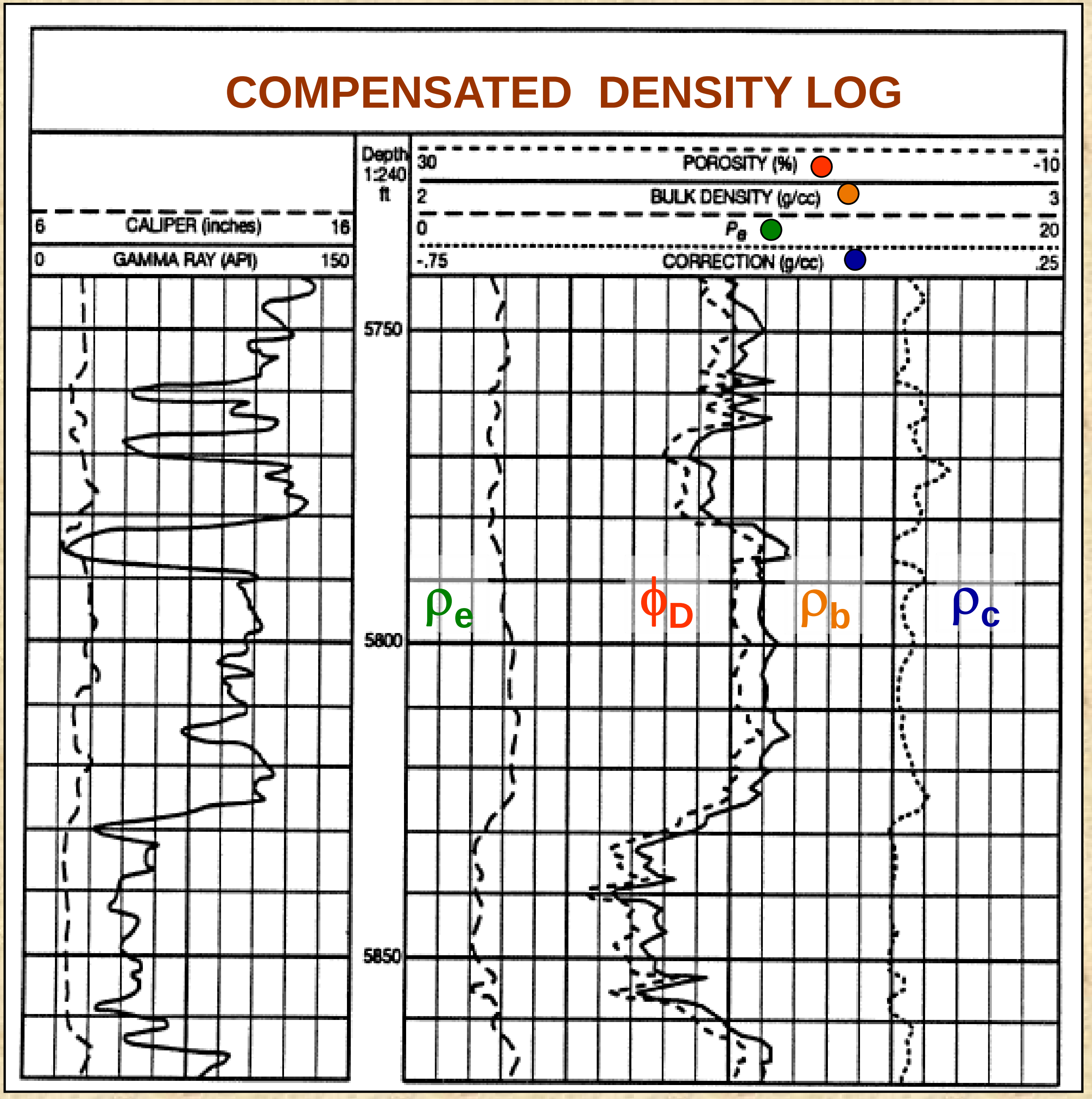
FAMILY OF NUCLEAR TOOLS



DENSITY LOGS

DENSITY & POROSITY MEASUREMENTS

- **Uses**
  - **Density**
  - **Porosity**
  - **Lithology**
- **Curves**
  - **Bulk density** (ρ_b and $\Delta\rho$)
  - **Pe**



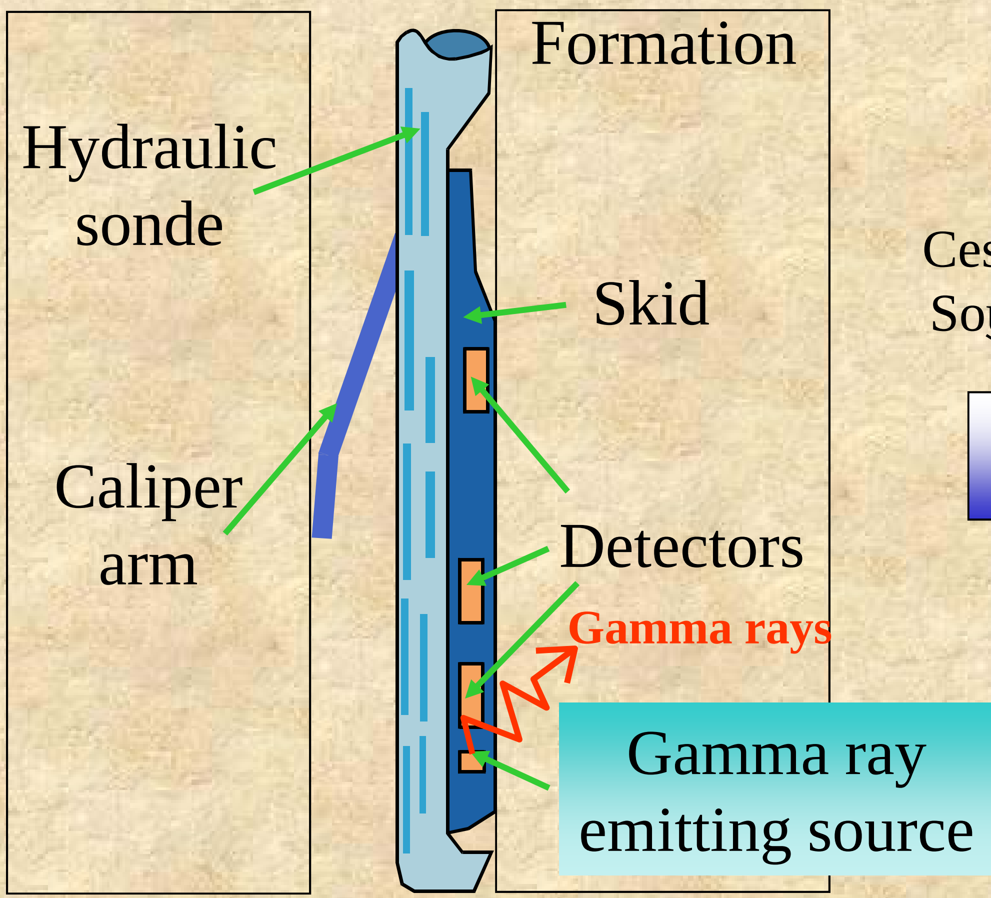
From Halliburton (EL – 1007)

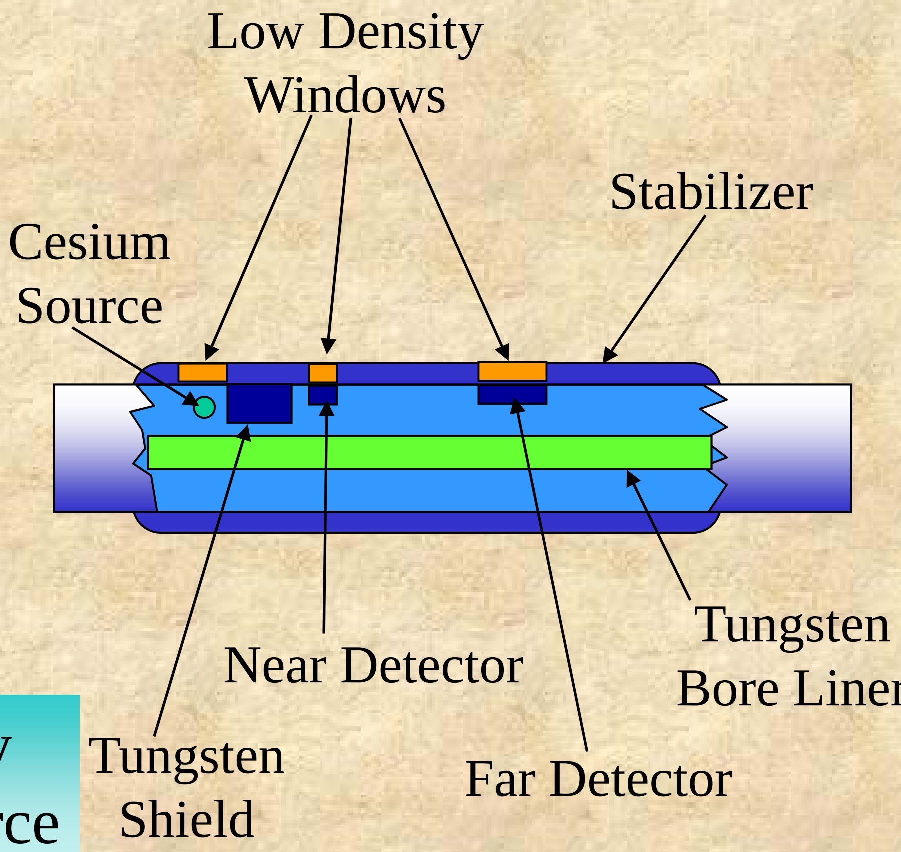
Why has Sonic been displaced as phi tool

- Porosity can be determined without precise knowledge of rock matrix
- No need for compaction correction
- Overlay of density-neutron excellent indicator of gas
- Transitions from one rock type to another detected
- Shale effects more evident

DENSITY PRINCIPLE

- **Detect GR's from the source which have been scattered back by the formation**





PRINCIPLE

- **Gamma rays emitted from radioactive source**
- **Gamma rays collide with electrons in formation, losing energy**
- **Detectors measure intensity of backscattered gamma rays**
  - **<u>High energy</u> GR relate to - Density**
  - **<u>Low energy</u> GR relate to - Lithology**

GAMMA-RAY GENERATION

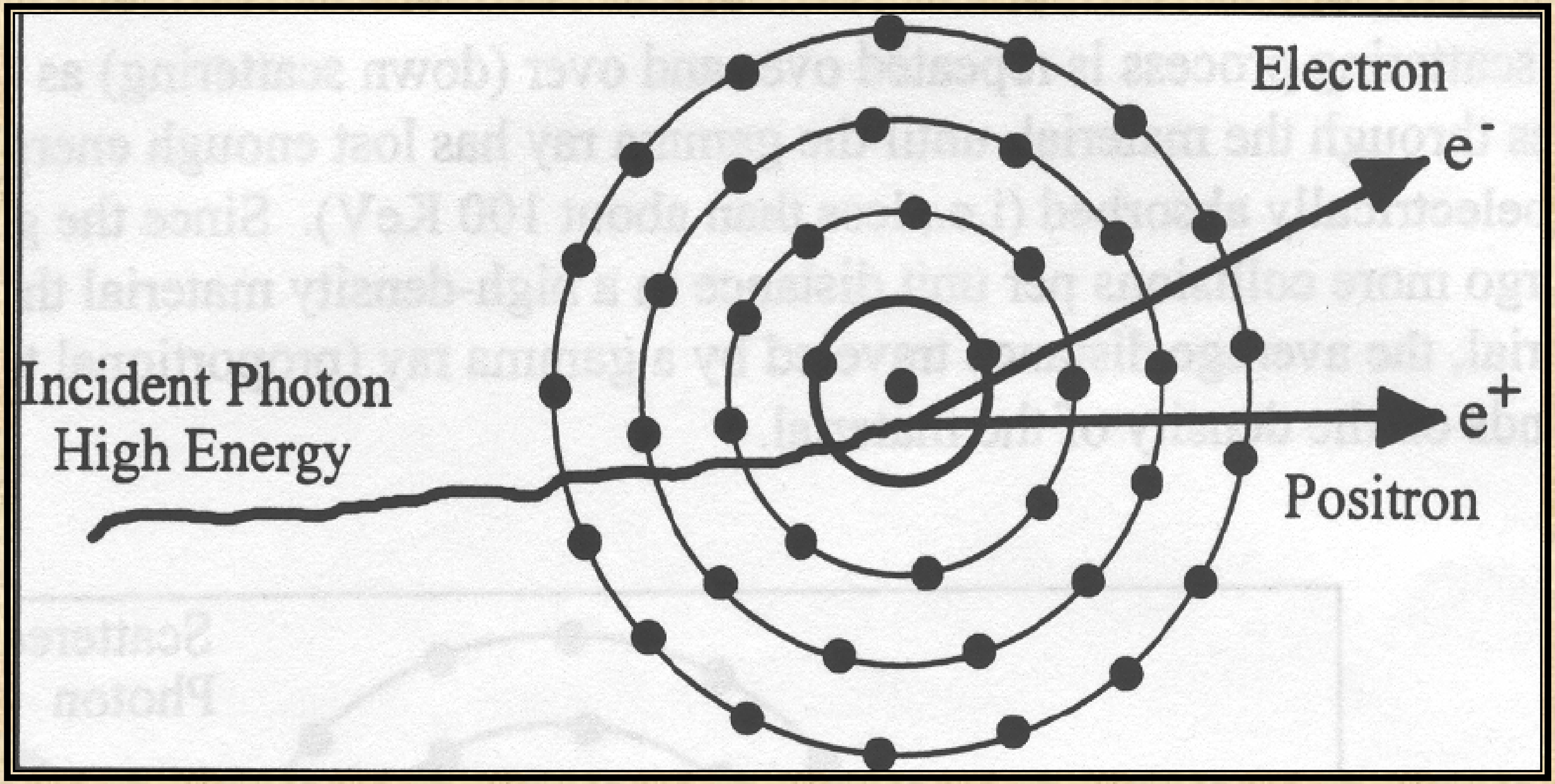
Chemical source

- Focused
- Typical properties
    - Cesium -137 material
    - 1.7 Curie strength
    - 33 year half-life
    - 662 keV gamma-ray energy

GAMMA RAY INTERACTIONS WITH MATTER

- **Pair Production**
- **Compton Scattering**
- **Photoelectric Adsorption**

PAIR PRODUCTION



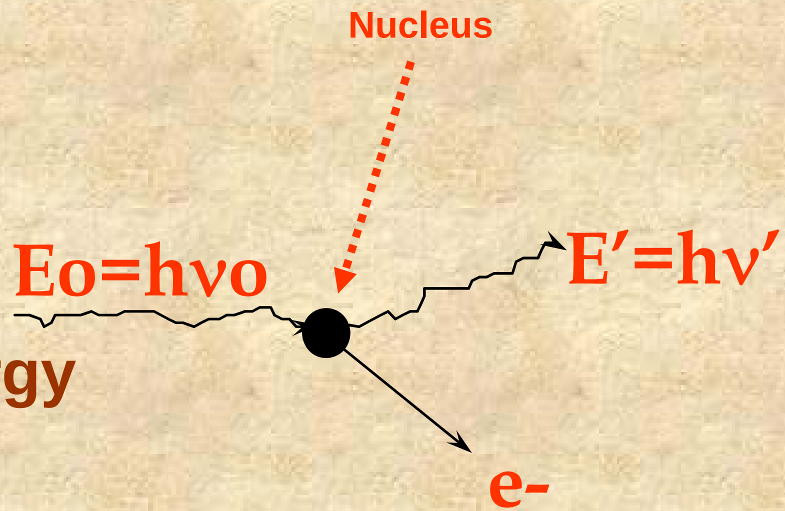
Not of significance to density tool operation since the source strength is 0.662 MeV and it requires 1.02 MeV for pair production (0.51 MeV is the energy equivalent of the mass of one electron)

GAMMA RAY SCATTERING

Compton Effect

Medium to High Energy GR's

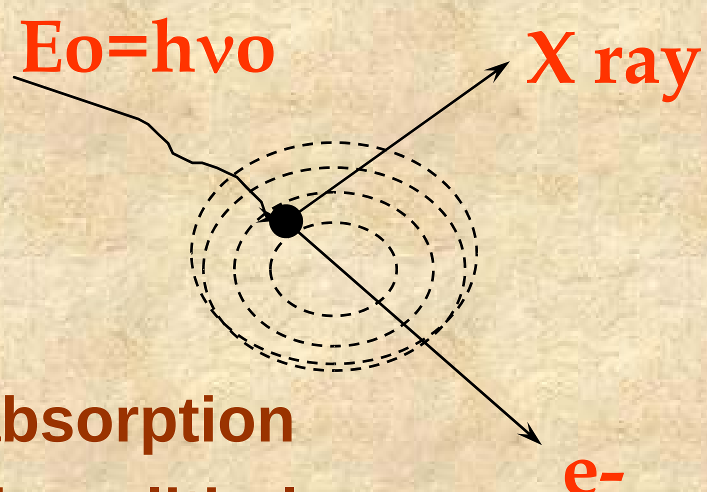
- scattered by electrons in formation
- each interaction loses energy
- more electrons => more scattering
- Related to elect. & rock den.



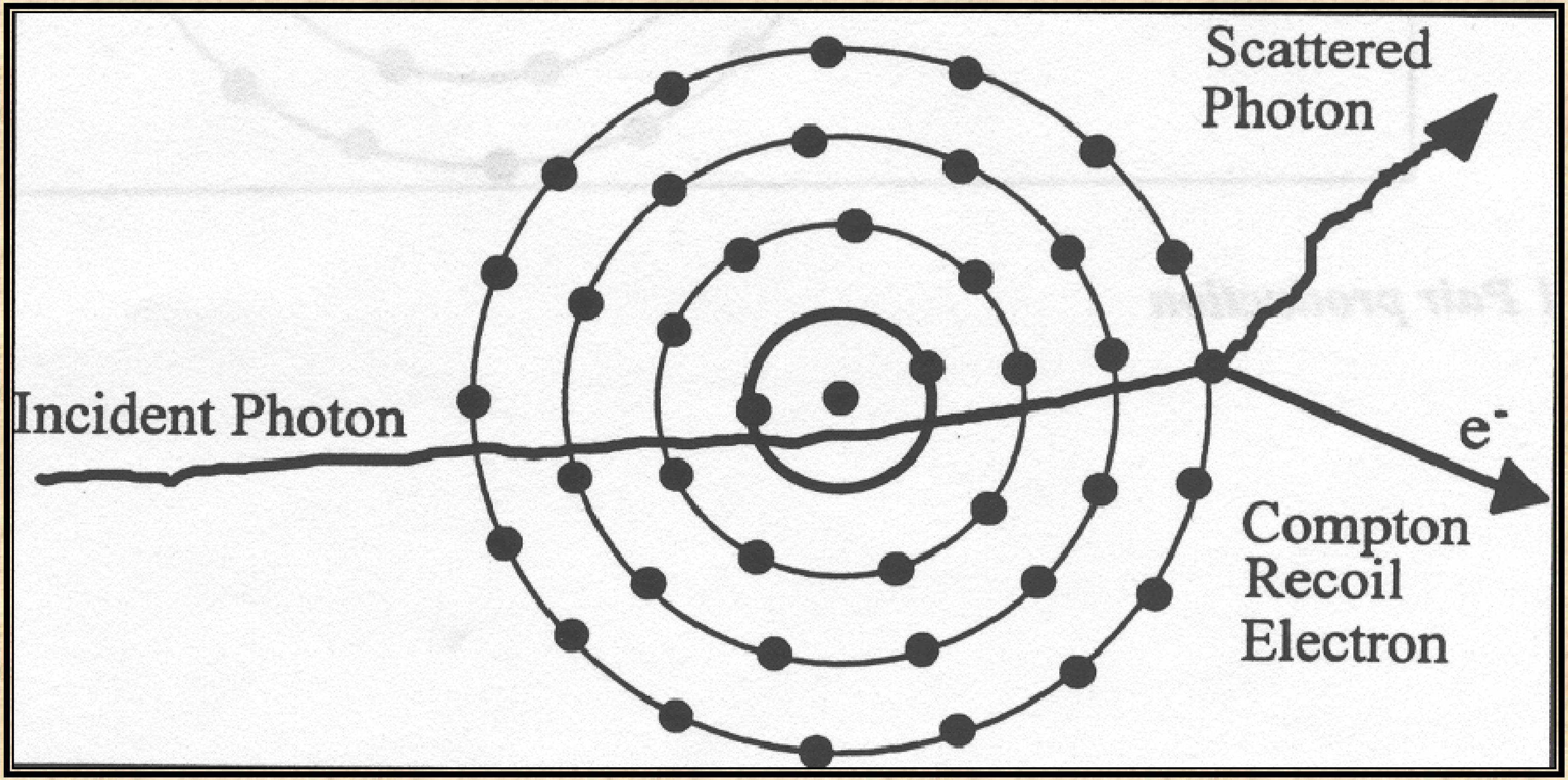
Photoelectric Effect

Low Energy GR's

- absorbed by atoms
- more electrons => more absorption
- Indicates the atomic number - lithology

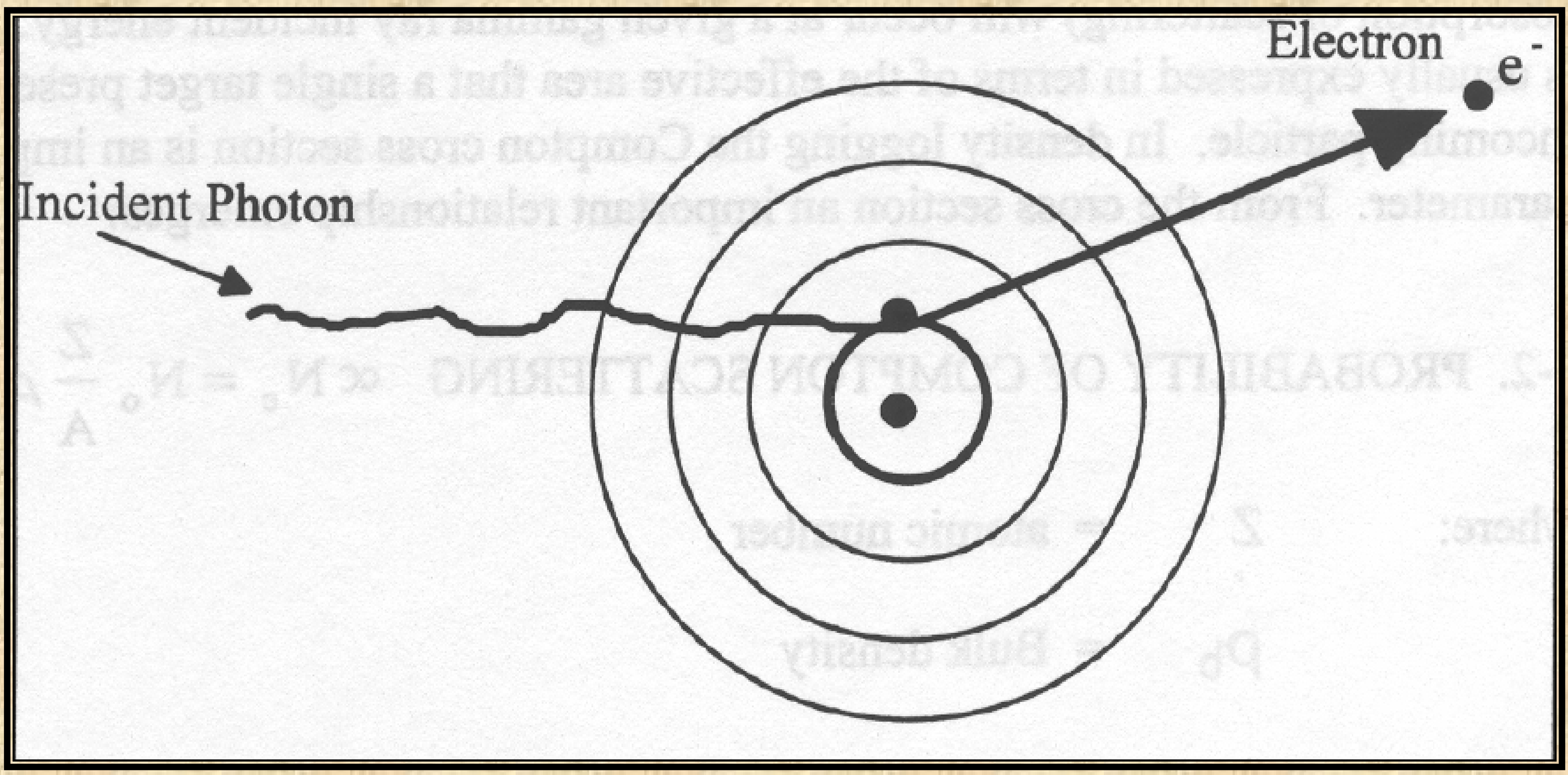


COMPTON SCATTERING



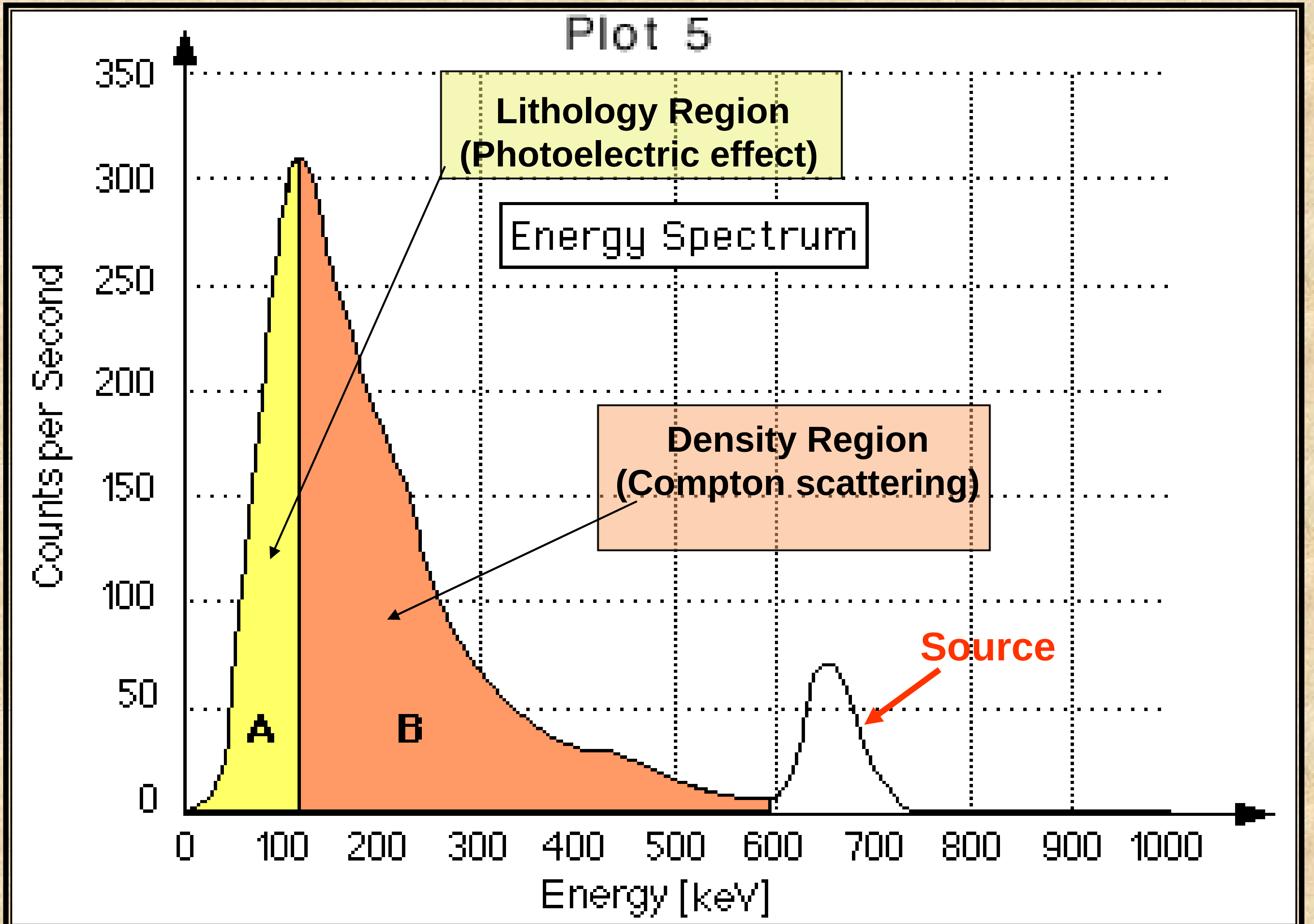
Measuring the number of gamma rays in the <u>Compton Scattering</u> energy range gives us the <u>bulk density</u>

PHOTOELECTRIC ABSORPTION

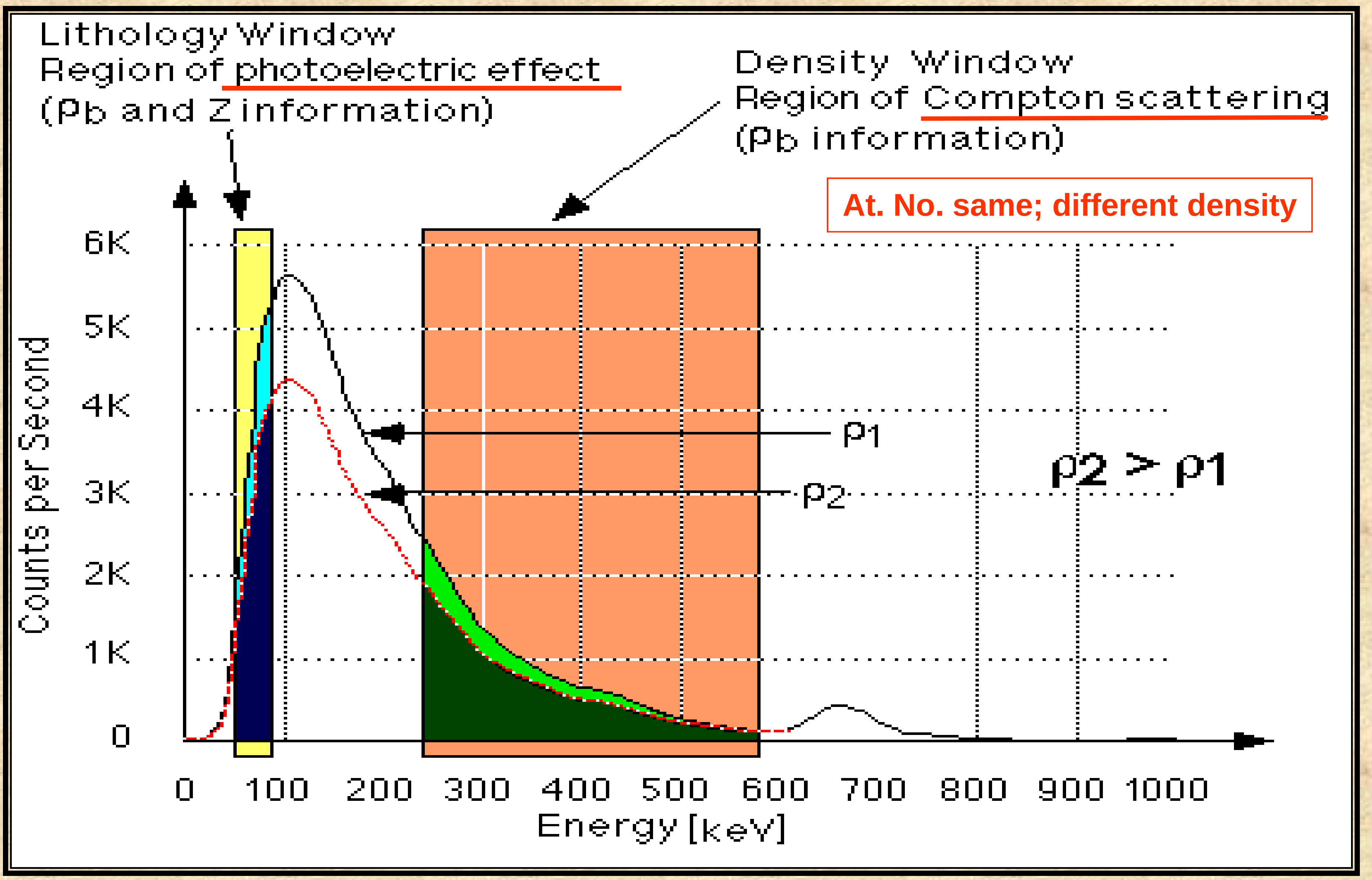


- The number of gamma rays capable of photoelectric absorption indicates the Atomic Number and hence the Pe
- This information indicates the lithology

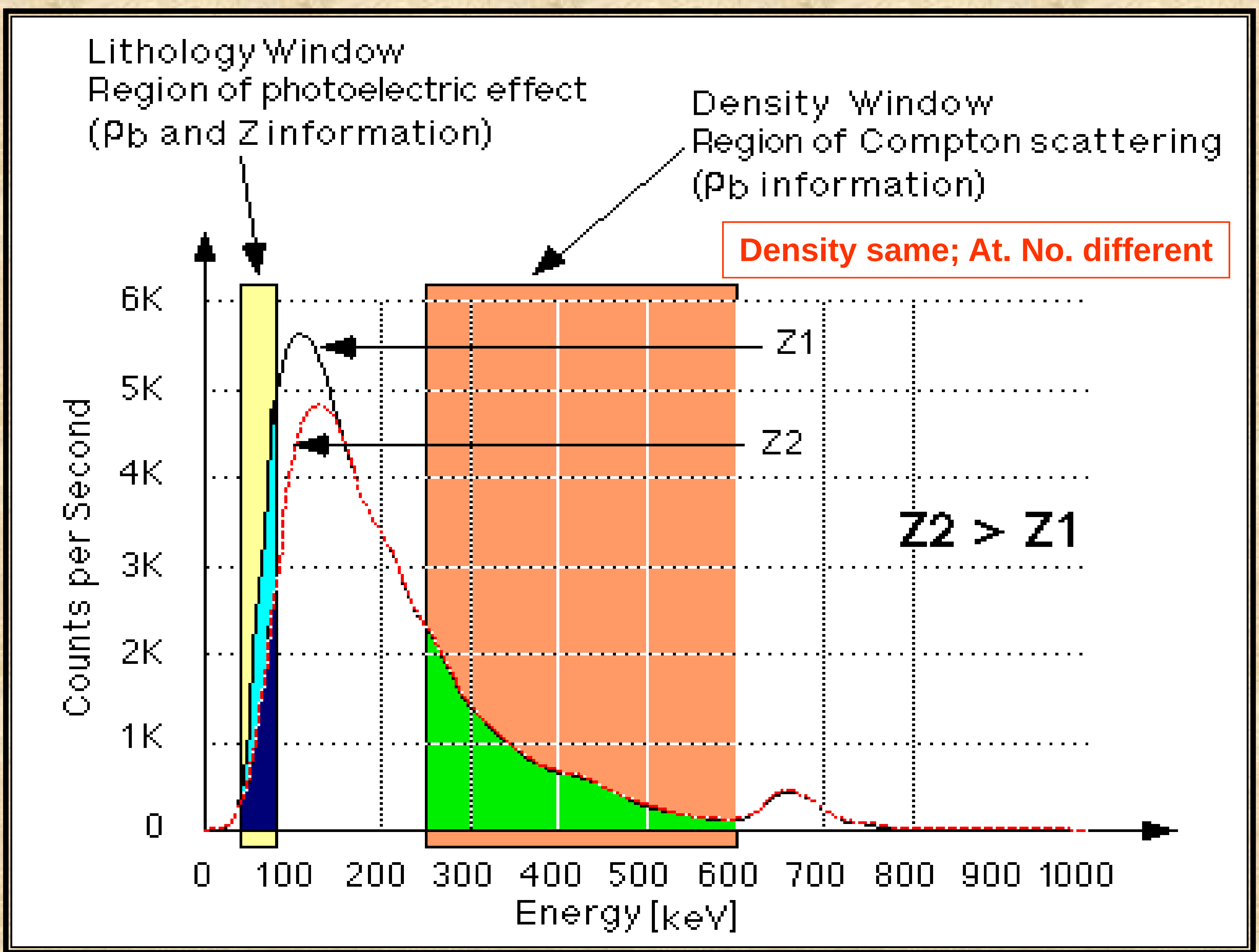
WHAT THE DETECTOR "SEES"



EFFECT OF FORMATION DENSITY ON DETECTOR COUNT RATES



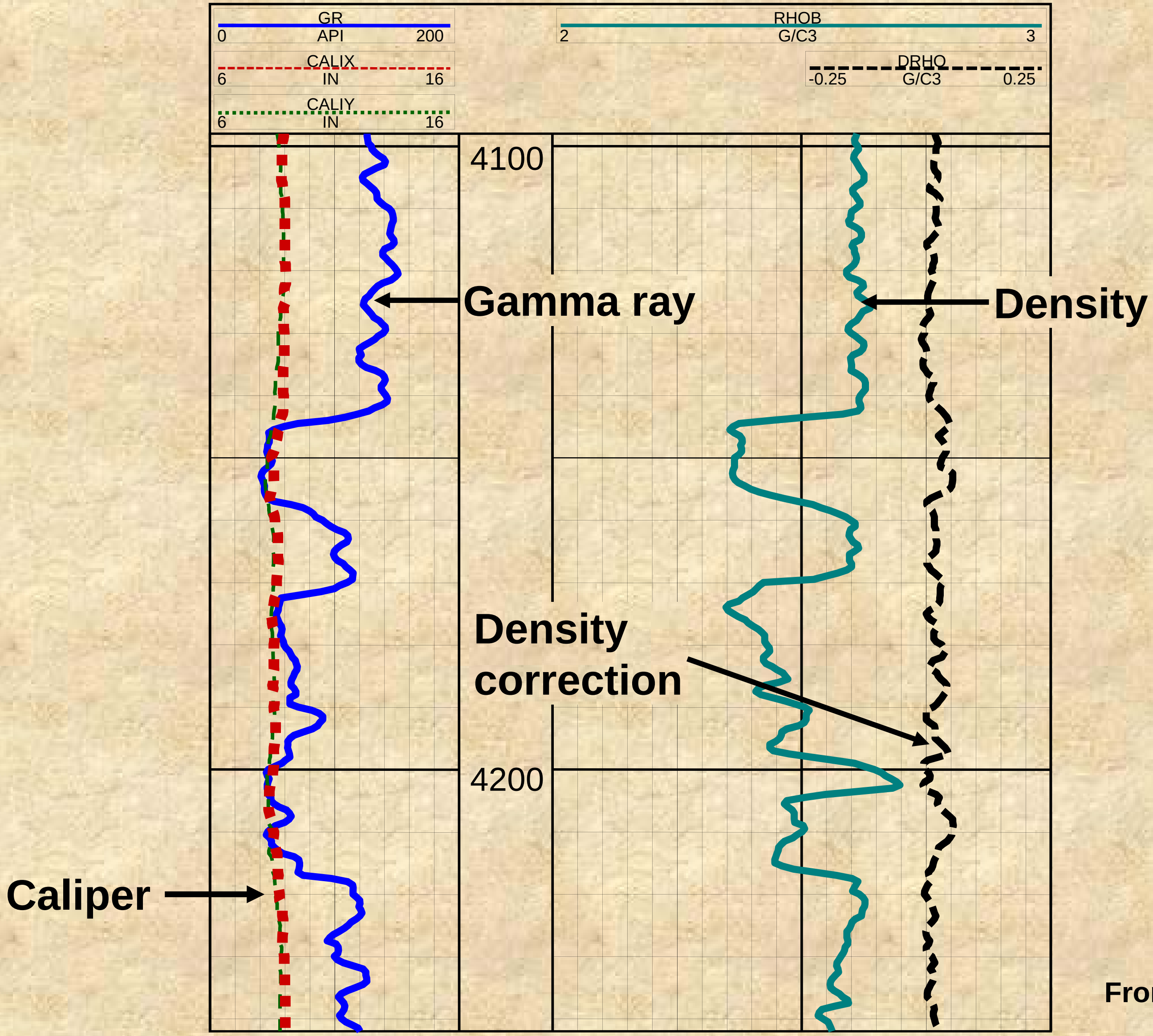
EFFECT OF FORMATION ATOMIC NUMBER ON DETECTOR COUNT RATES



DENSITY LOGS

- Bulk density, ρ_b, is dependent upon:
  - Lithology
  - Formation porosity
  - Density and saturation of fluids in pores

DENSITY LOG



From NExT, 1999

BULK DENSITY INTERPRETATION - 1

- **The bulk density (in g/cc) is the weighted sum of the matrix and fluid densities**

$$\rho_b = (1-\phi)\rho_{ma} + \phi\rho_{fl}$$

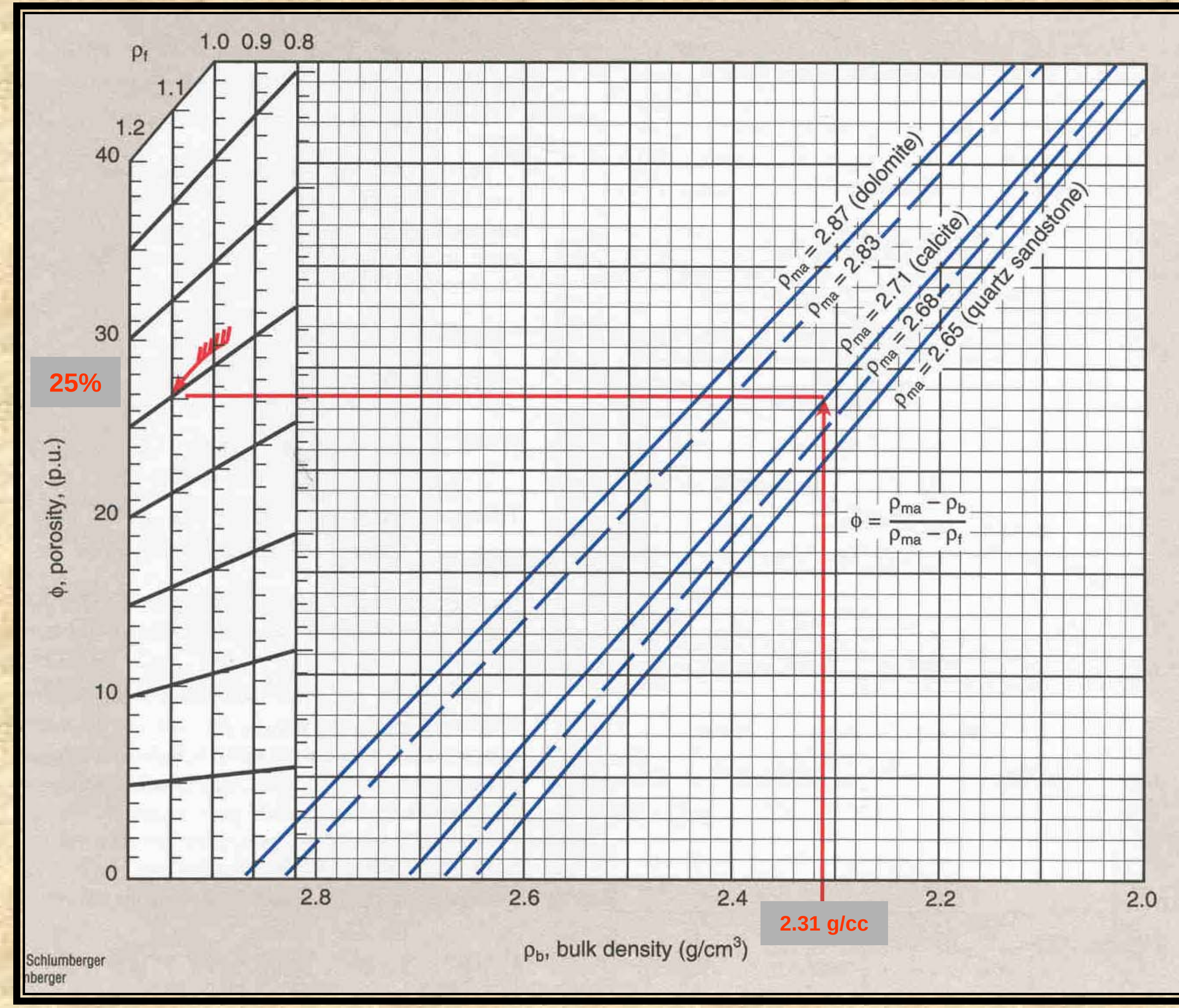
- **Typical values**
  - **<u>Matrix density</u> 2.65 SS; 2.71 LS; 2.87 Dol**
  - **<u>Fluid density</u>**
    - **0.9 – 1.0 OBM and fresh WBM**
    - **1.1 - 1.2 salty WBM**
- **<u>Density porosity</u> curve is derived from above equation**

BULK DENSITY INTERPRETATION - 2

- Rearranging the equation gives **POROSITY**

$$\phi_D = \frac{\rho_{ma} - \rho_b}{\rho_{ma} - \rho_{fl}}$$

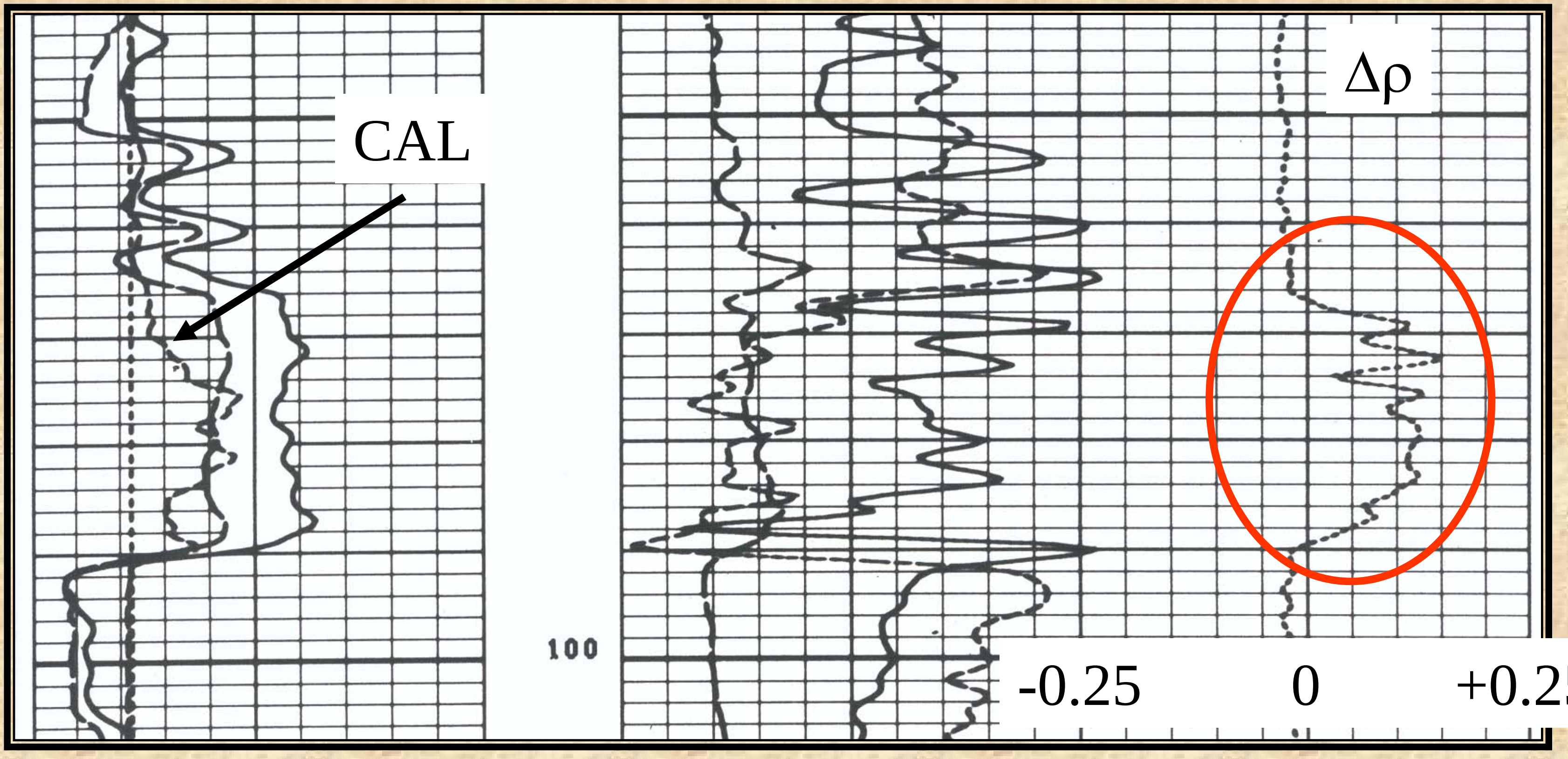
- Charts
  - POR-5 (S)
  - POR-10 (H)



BULK DENSITY INTERPRETATION - 3

- The density correction ($\Delta\rho$) curve is "measurement quality"
- Poor pad contact gives $\Delta\rho > 0.05$
- Often correlates with caliper

If correction > 0.20 g/cc
Bulk density curve is invalid



PHOTOELECTRIC INTERPRETATION - 1

- The **Pe** value (in barns/electron) is the weighted sum of the matrix and fluid capture cross sections

$$P_e = \frac{(1-\phi)\rho_{e_{ma}} P_{e_{ma}} + \phi \rho_{e_{fl}} P_{e_{fl}}}{(1-\phi)\rho_{e_{ma}} + \phi \rho_{e_{fl}}}$$

- <u>Typical Values</u>
  - Matrix Pe: <u>1.8 SS; 5.1 LS; 3.1 DOL</u>
  - Matrix $\rho_e Pe$: 4.8 SS; 13.8 LS; 9 DOL
  - Fluid $\rho_e Pe$:
    - 0.1 - 0.4 OBM and fresh WBM
    - 0.4 – 1.0 salty WBM

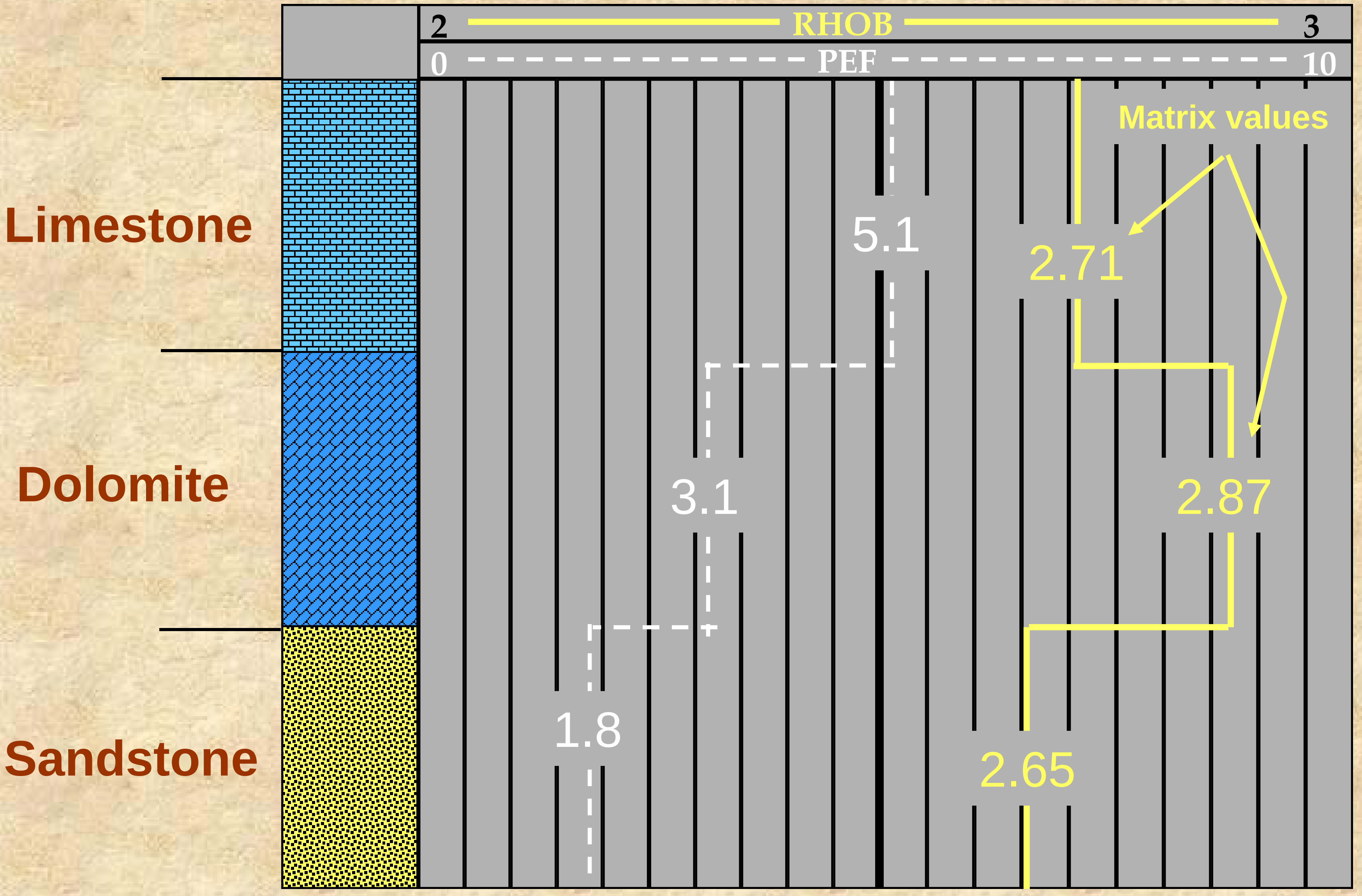
PHOTOELECTRIC INTERPRETATION - 2

- The logging curve is Pe
- The product $\rho_e Pe$ = U, capture cross-section/cc

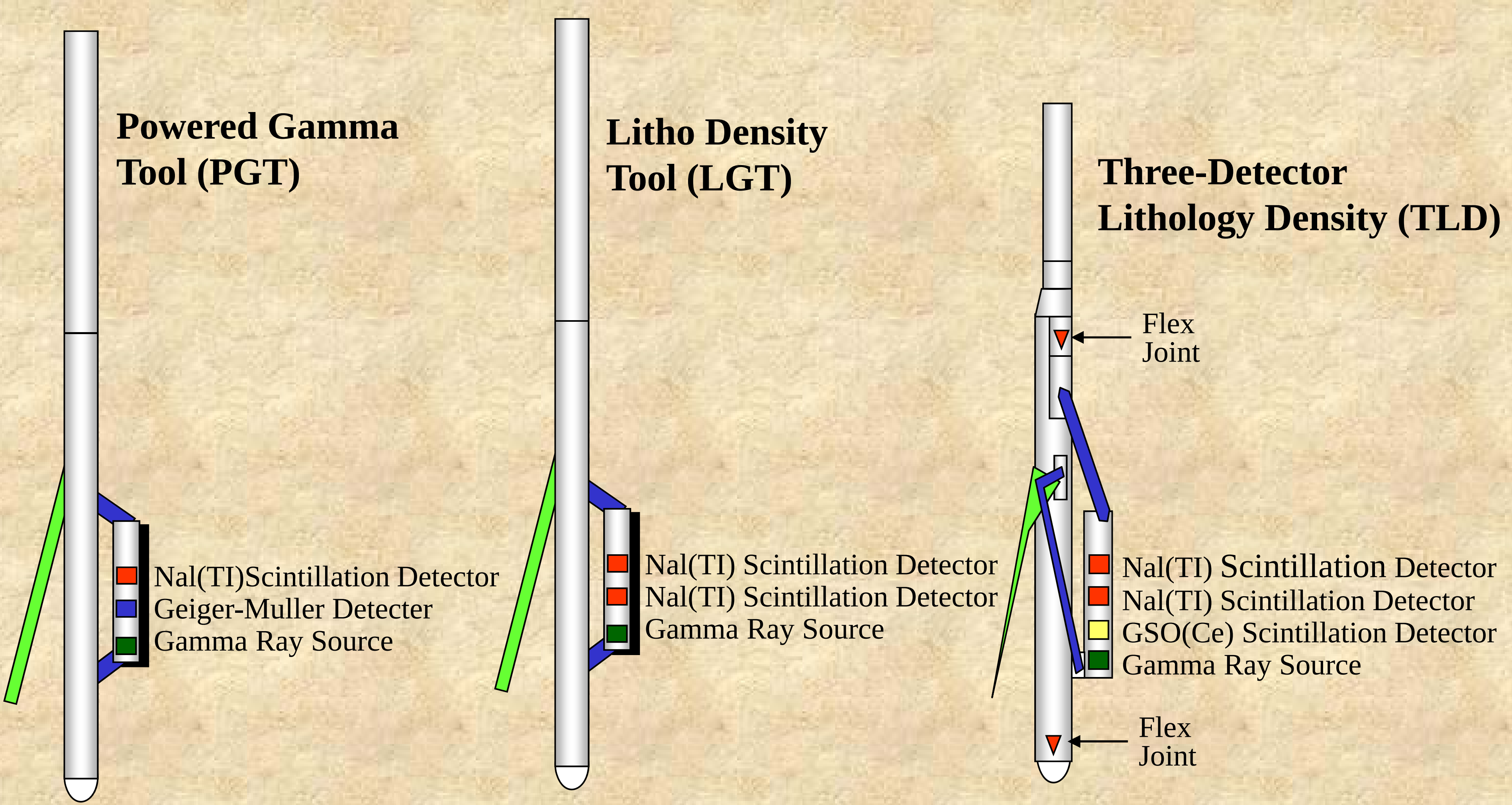
$$U = (1 - \phi)U_{ma} + \phi U_{fl}$$

- This looks like the density equation
- We don't solve for ϕ because $U_{fl} << U_{ma}$
- See Appendix 4 Charts for values of Pe

TYPICAL FORMATIONS



SCHLUMBERGER WIRELINE TOOL HISTORY

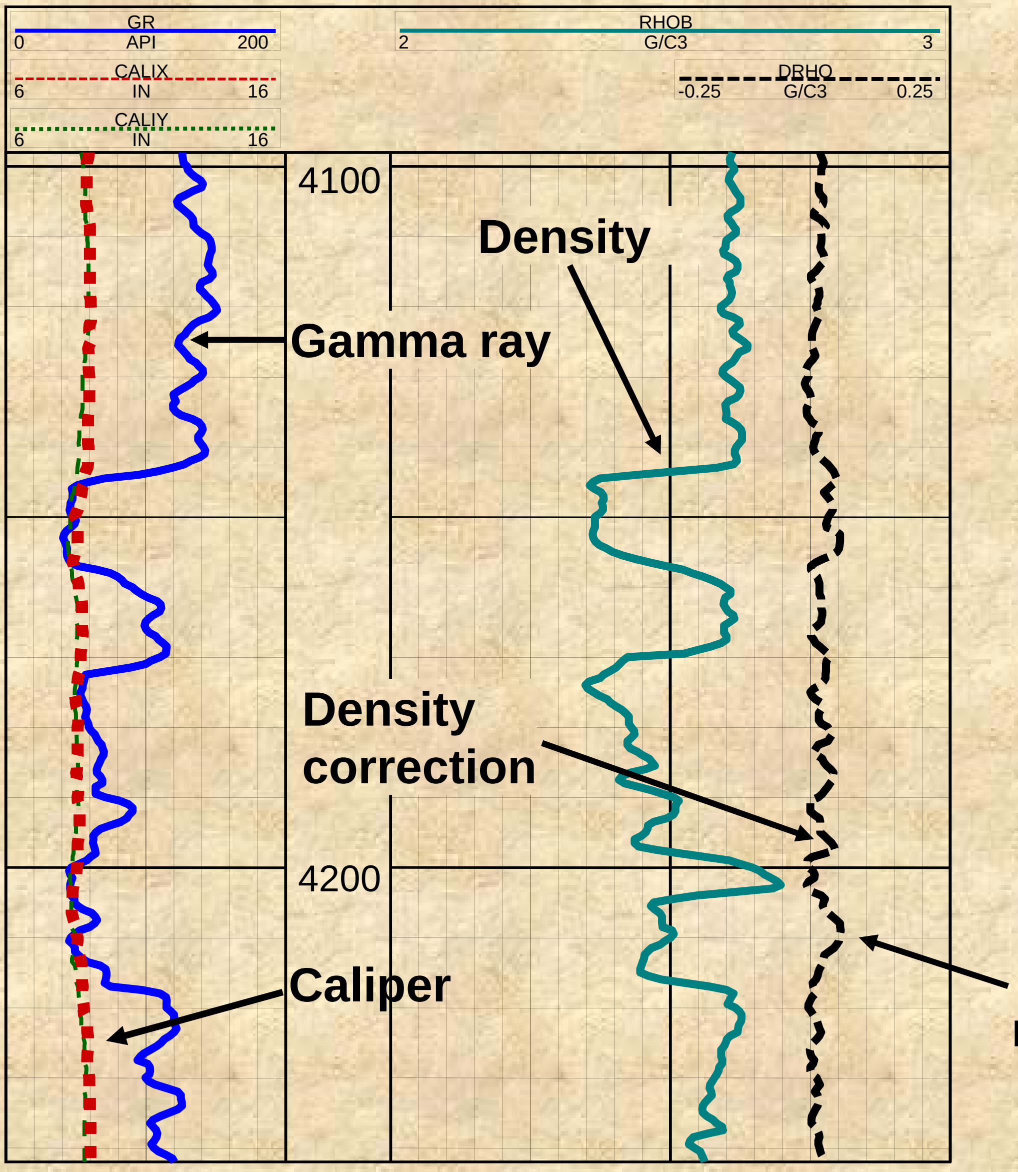


FACTORS AFFECTING DENSITY LOG RESPONSE

- **Shales and clays**
  - May cause porosity reading to be too high or too low
  - V_{sh} and ρ_{sh} can be obtained from log readings in shale zones
- **Hydrocarbons**
  - In oil zones, $\rho_{hc} = \rho_o$ which can be measured from fluid samples
  - In gas zones, $\rho_{hc} = \rho_g$ which can be measured or calculated using gas properties
  - Gas will cause anomalously low density and, thus, high density porosity

$$\phi_D = \frac{\rho_{ma} - \rho_b}{\rho_{ma} - \rho_{fl}}$$

DENSITY LOG COMMENTS



- **Very reliable tool**
- **Used to determine**
  - **bulk density**
  - **Porosity**
  - **lithology**
- **Shallow depth of investigation - 10 to 15 cm**

From NExT, 1999

NEUTRON LOGS

NEUTRON LOGS

Uses of neutron logs

- Identify porous zones
- Determine porosity
- Identify gas in porous zones

Where neutron logs can be used

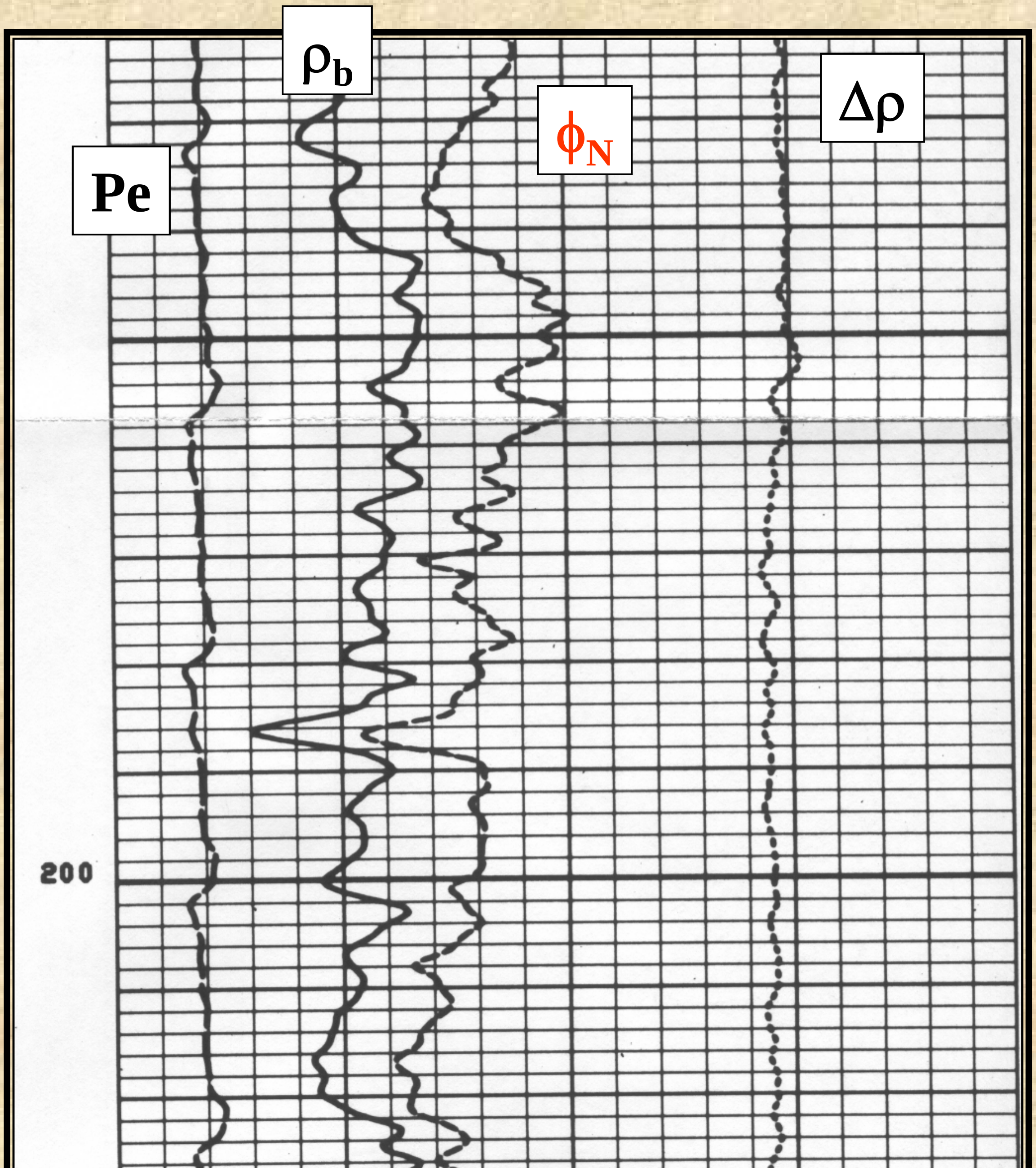
- Any borehole
    - Open or cased
    - Liquid- or air-filled

Depth of investigation

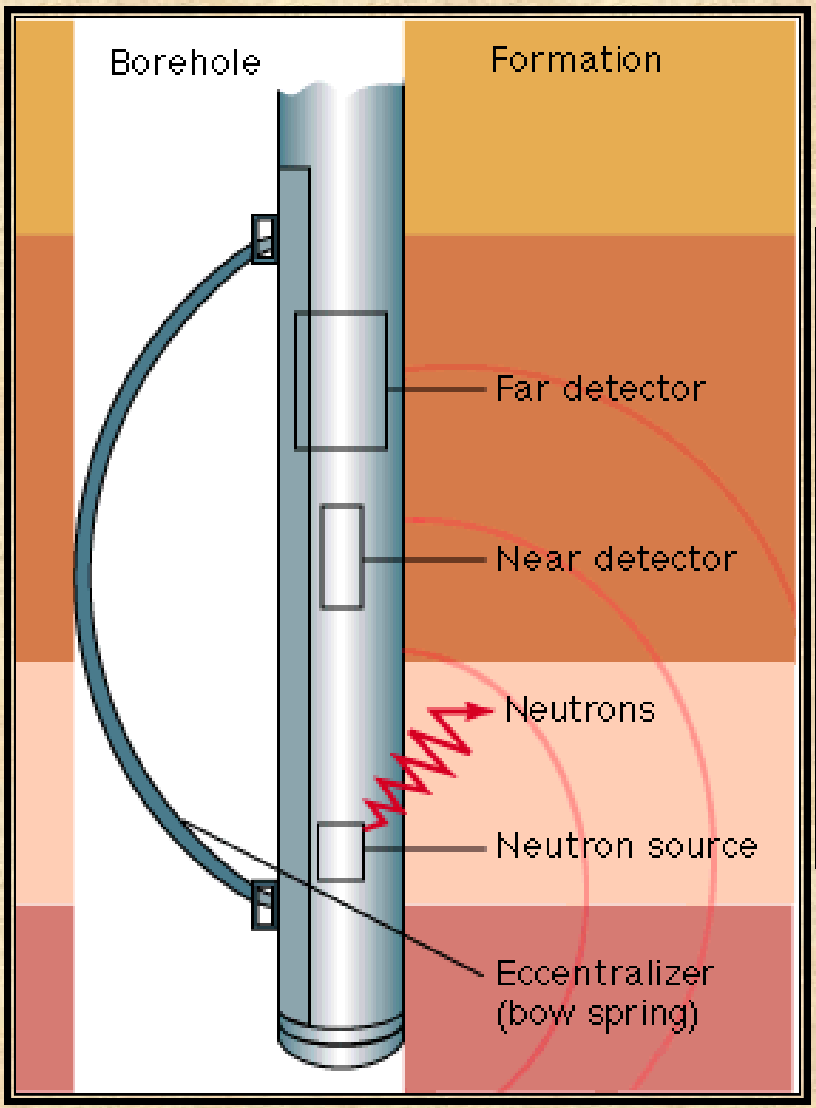
- 6-12 inches for CN

NEUTRON MEASUREMENT

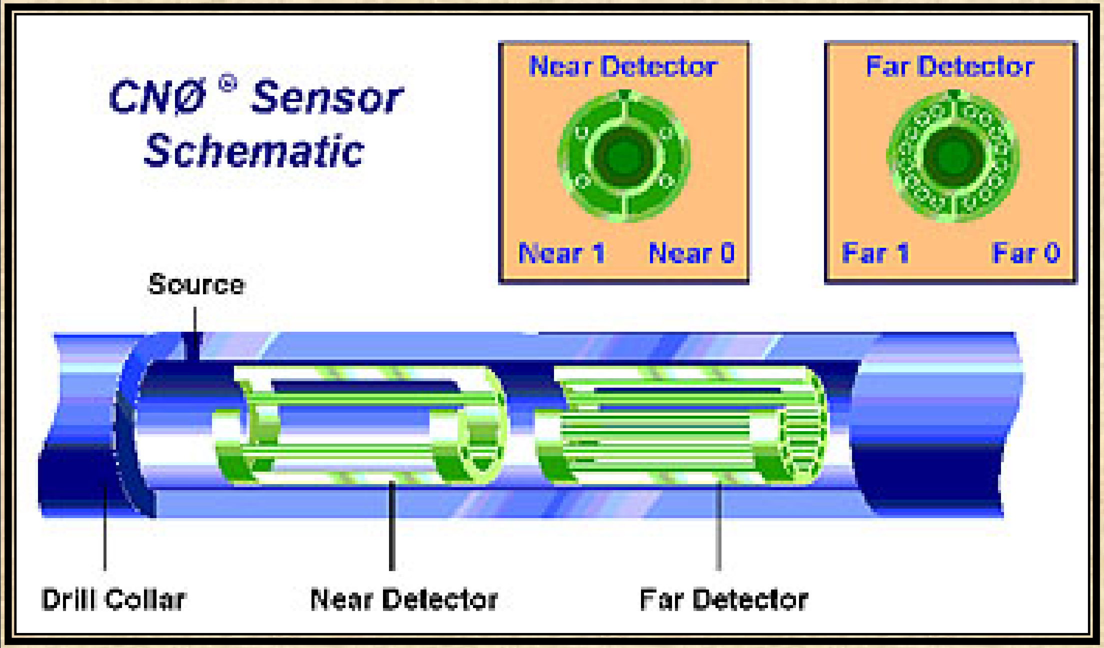
- **Uses**
  - **Lithology Porosity**
- **Curve ϕ_N**



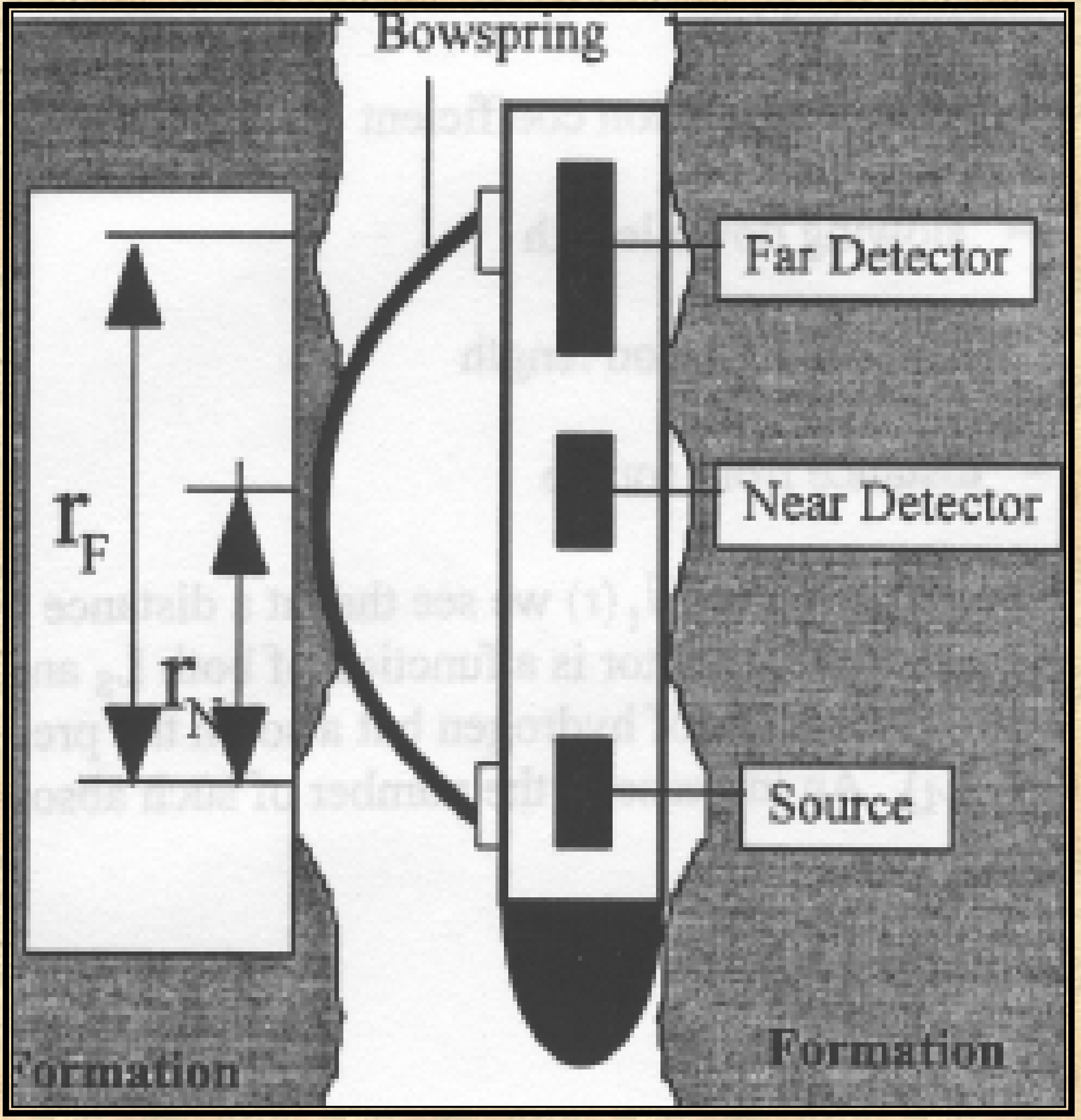
NEUTRON TOOL PRINCIPLE



- Source AmBe 15-20Cu 5MeV



- Detects neutrons from the source which have been scattered back by the formation

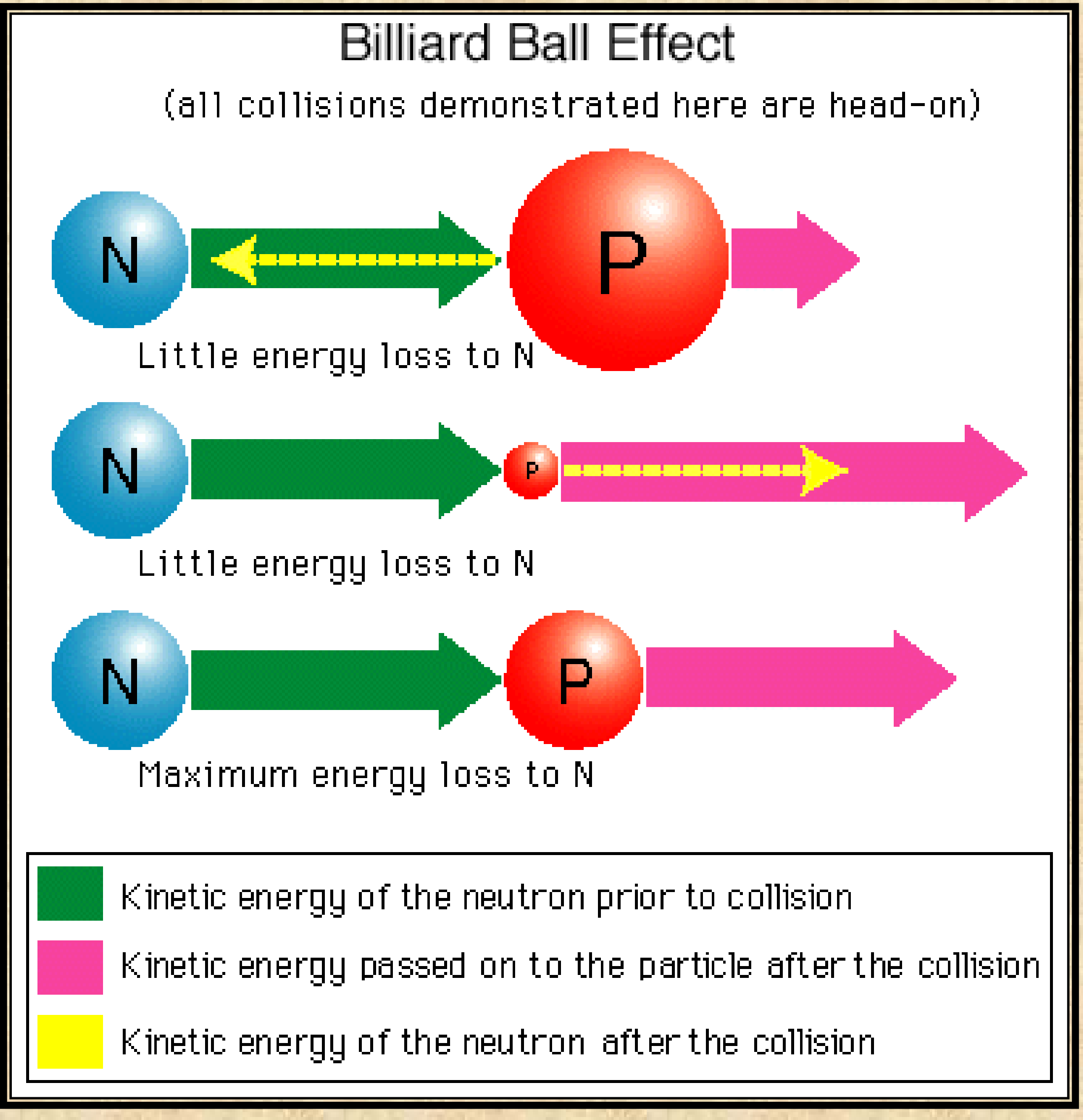


- The neutron tool employs a dual detector design to compensate for mudcake, lithology, etc.
- Still, corrections are required for the NPHI values
- NOTE : The tool is pressed against the borehole wall to minimize mud effects

LIFE OF A NEUTRON - 1

- Neutrons emitted from source
- Neutrons interact with Hydrogen in formation
- Neutrons lose energy
- Neutrons are absorbed or reflected back to detectors
  - High counts = Low porosity
  - Low counts = High porosity

LIFE OF A NEUTRON - 2

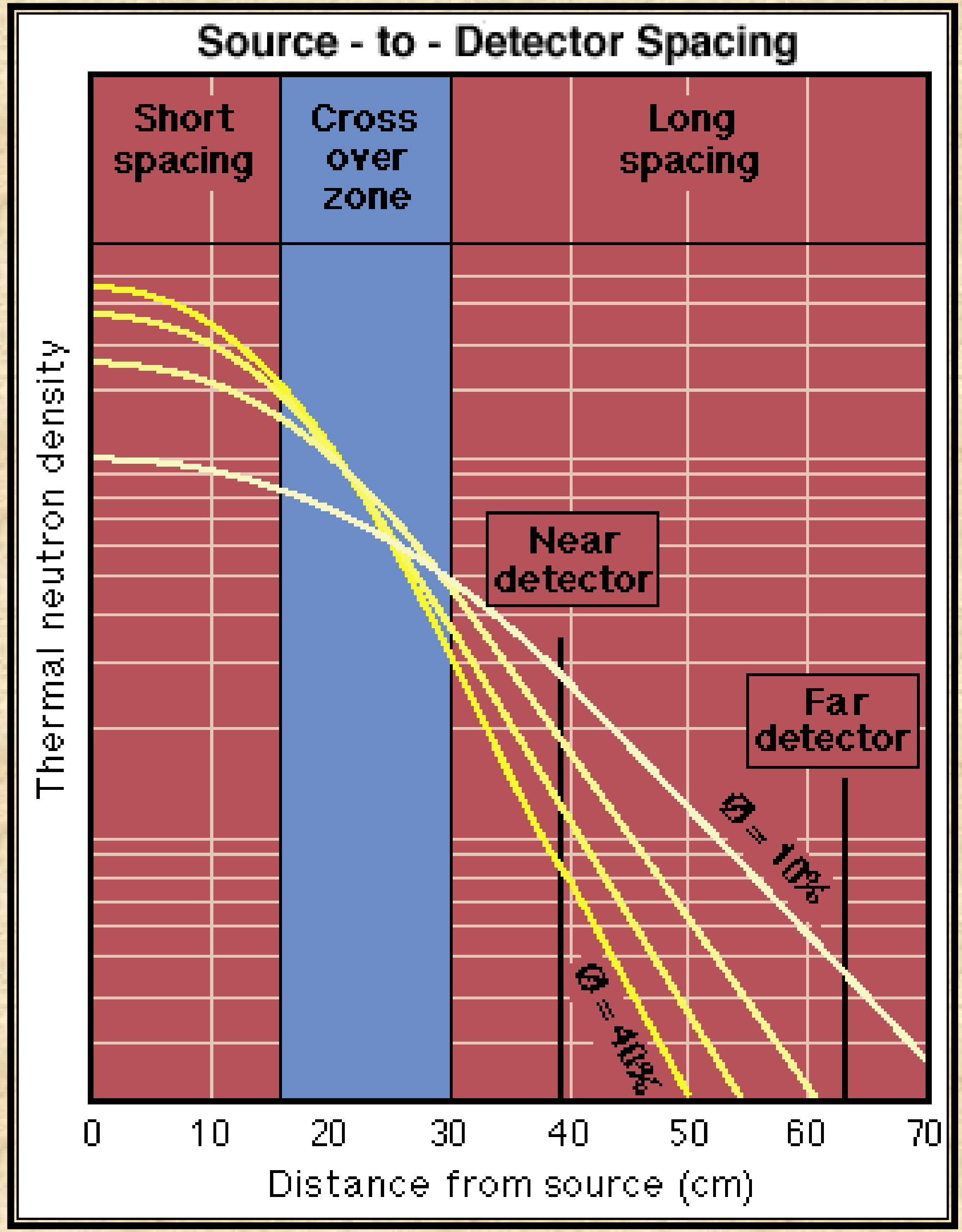


- Source AmBe 15-20Cu 5MeV neutrons
- Collisions cause neutrons to lose energy
- Energy loss due mainly to hydrogen
- Therefore tool measures amount of hydrogen in formation, ie., water, oil

Thermal Neutrons

- The neutron tool responds primarily to the presence of hydrogen
- The more hydrogen, more neutrons slowed to the thermal level and captured by the formation
- Other minerals also have a small effect on the neutron tool, which requires compensation

NEUTRON TOOL DESIGN



- Both detectors placed in long spacing zone
- Count rates at the detectors are inversely proportional to formation porosity and distance from source
- Near/Far Ratio proportional to porosity
- Ratio compensates for mudcake

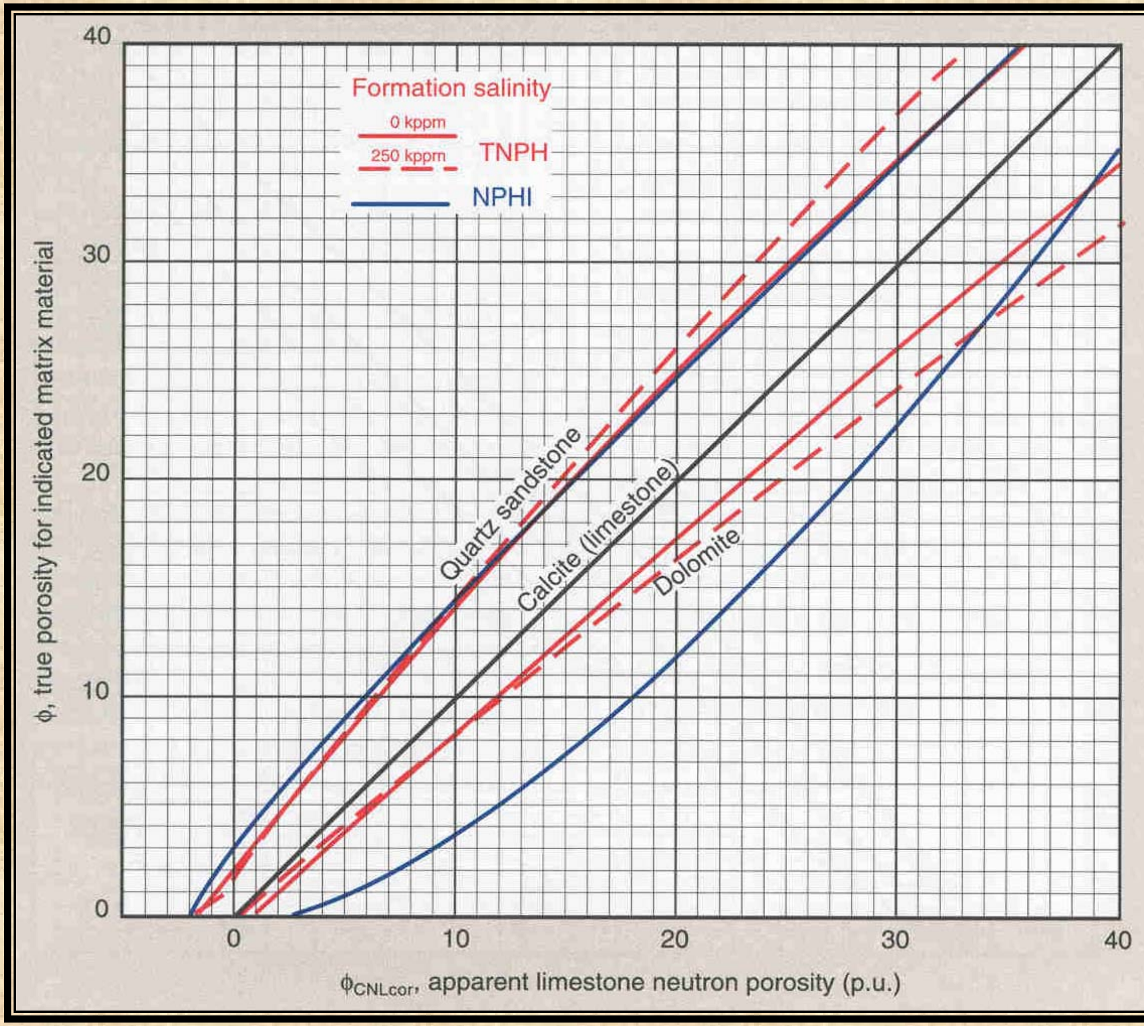
ENVIRONMENTAL EFFECTS ON NPHI

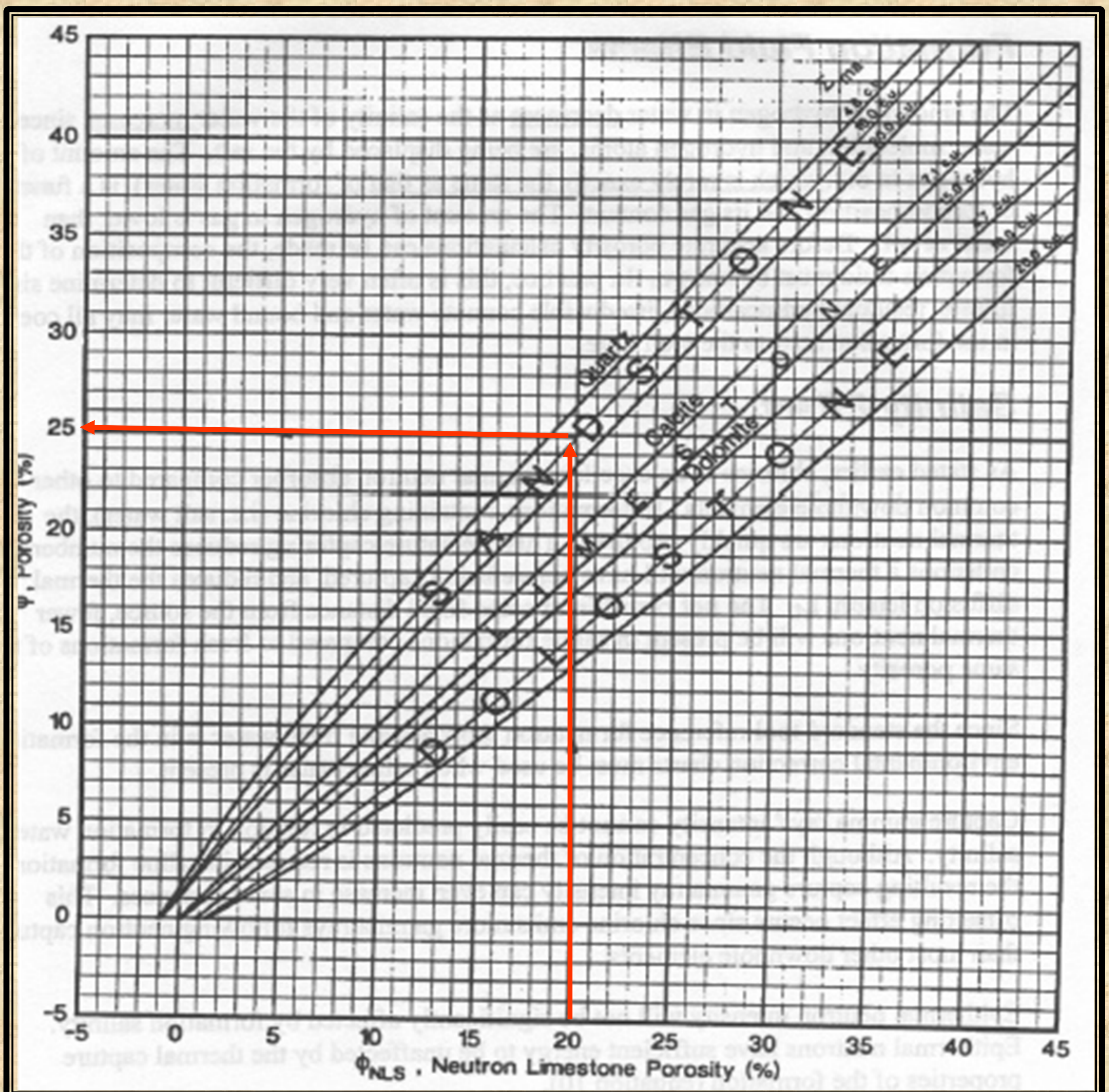
Lithology Effects

- The tool responds mostly to the presence of hydrogen, but different minerals will slow neutrons to different degrees
- Therefore, the Neutron tool reads different values for NPHI in different formations of the same porosity
- This must be taken into account for the NPHI curve

NEUTRON LOG INTERPRETATION - 1

- Ratio converted to apparent porosity, ϕ_N
- Many environmental effects
- Assumes
  - Matrix
    - Usually LS
    - Sometimes SS
  - Water-filled
- Charts POR-12--16
  - Chart varies with tool





Question:

On a limestone scale, the NPHI is 20%. However the formation is a sandstone. What is the true porosity?

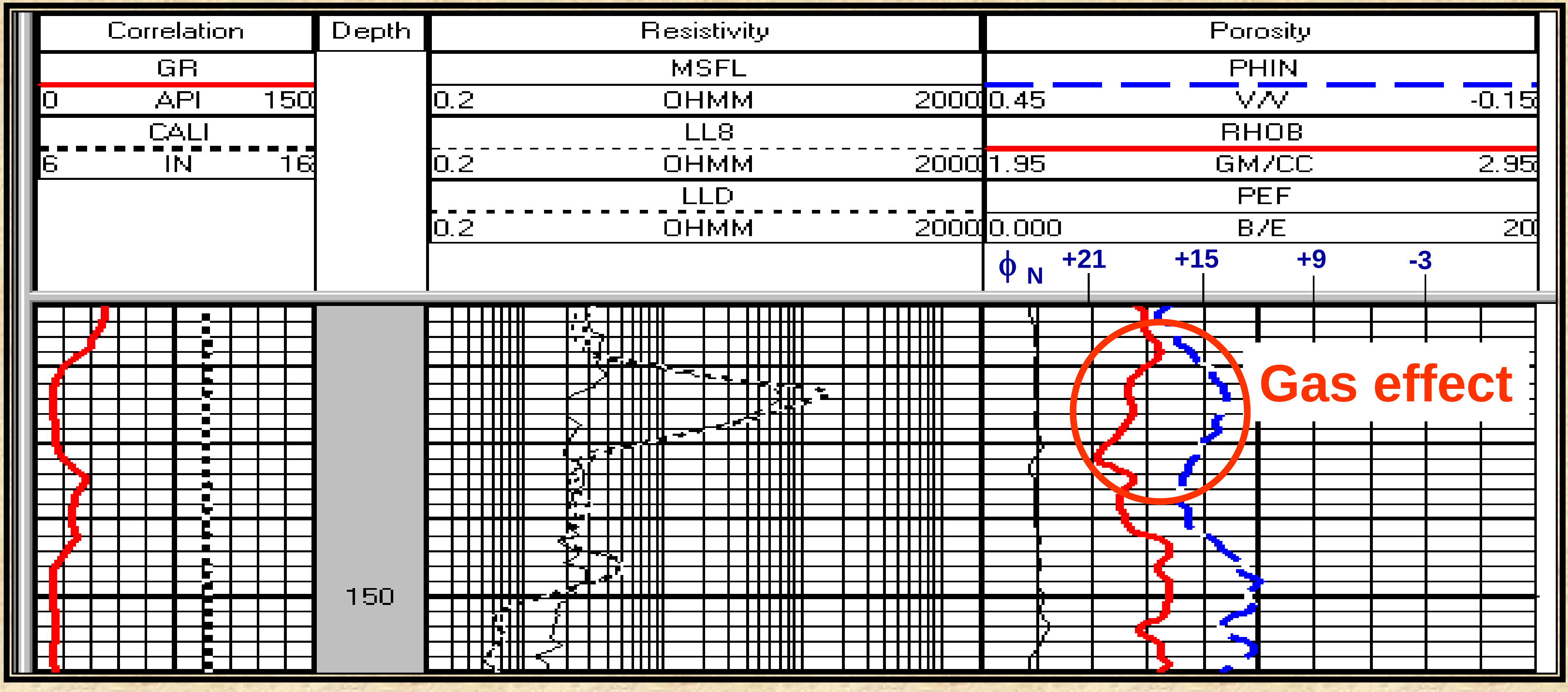
Answer : 25%.

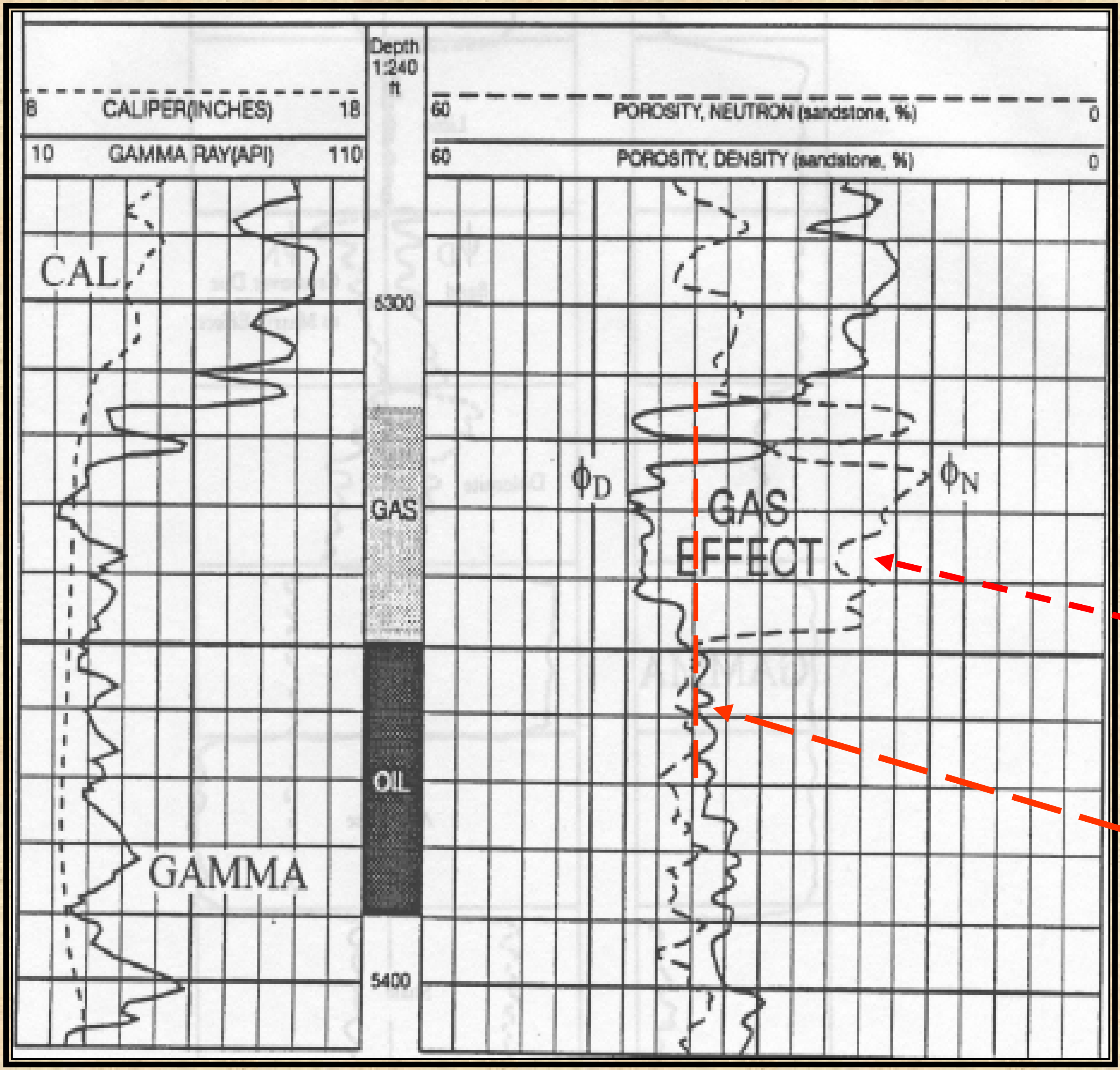
GAS EFFECTS ON NPHI

- Gas has a lower hydrogen concentration than oil or water due to it's lower density
- A neutron tool interprets gas to be water occupying a smaller volume; a smaller volume means a smaller porosity
- Hence in gas zones, the neutron tool reads anomalously low porosity

NEUTRON LOG INTERPRETATION - 2

- Reads deeper than density
  - More affected by virgin zone fluid
- Gas effect
  - Gas lowers H concentration, lowers apparent porosity





GAS EFFECT

Notice the NPHI reading is less in a gas zone than in an oil zone in the same lithology

In a gas zone, NPHI reads too low and DPHI reads too high

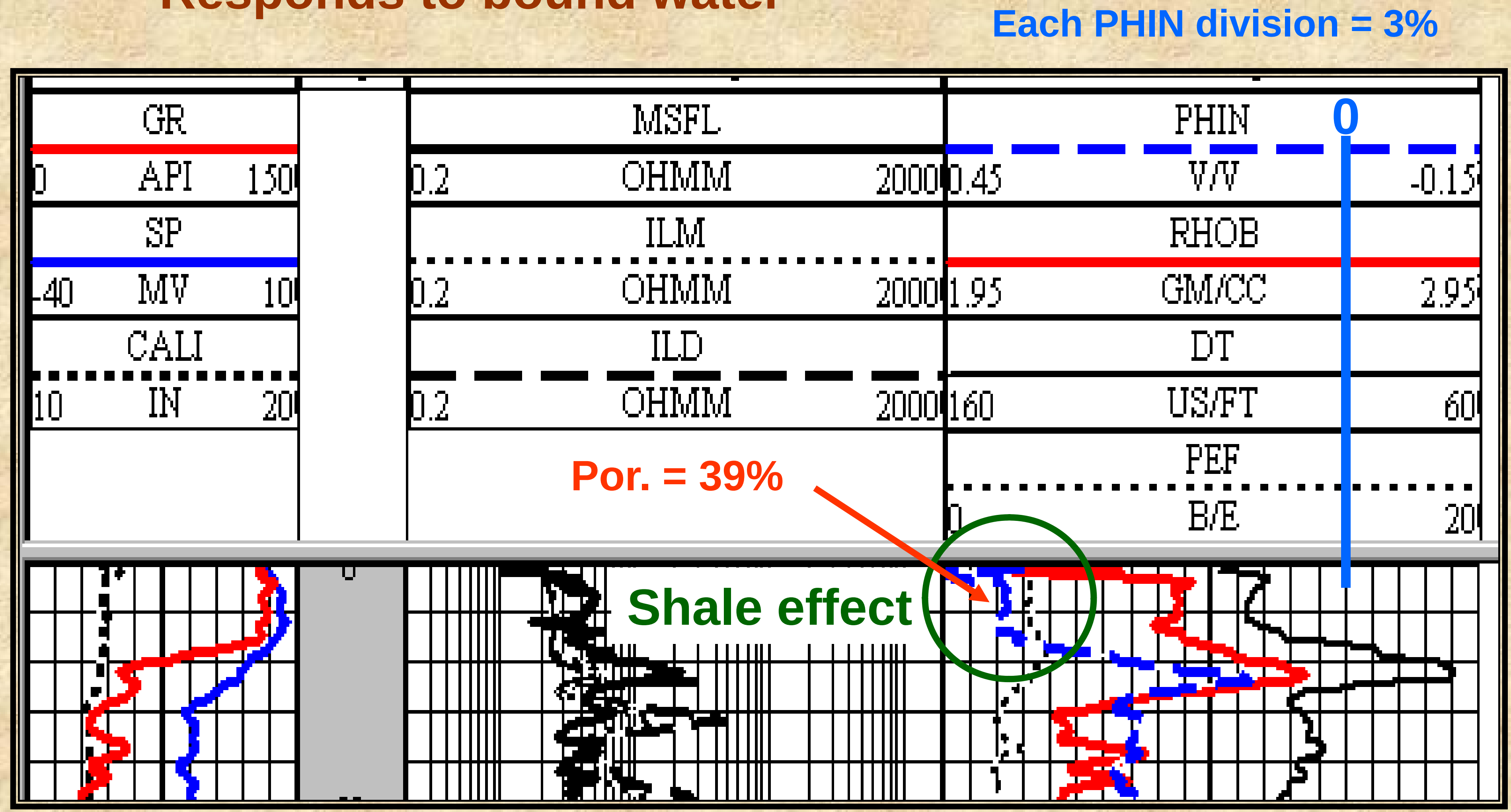
The 2 curves track closely in oil-saturated zone

SHALE EFFECTS ON NPHI

- Shaliness affects neutron porosity
- Shale has bound water in lattice structure
- This water is immobile and does not represent EFFECTIVE porosity
- However, the neutron tool responds to the presence of hydrogen in the bound water of shales, and the neutron tool reads anomalously high NPHI

NEUTRON LOG INTERPRETATION - 3

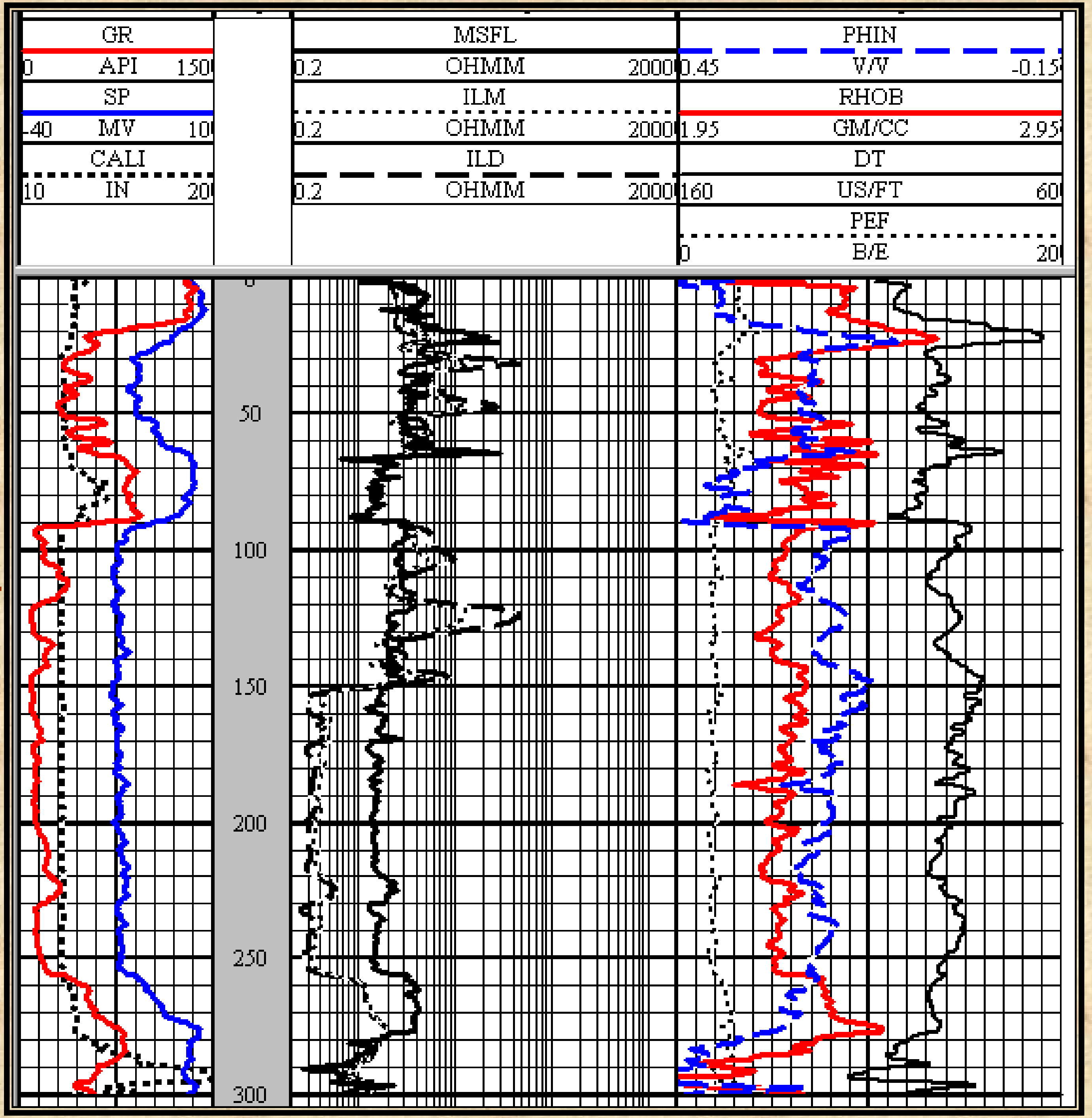
- **Shale effect**
  - **Responds to bound water**



NEUTRON SHALE EFFECT

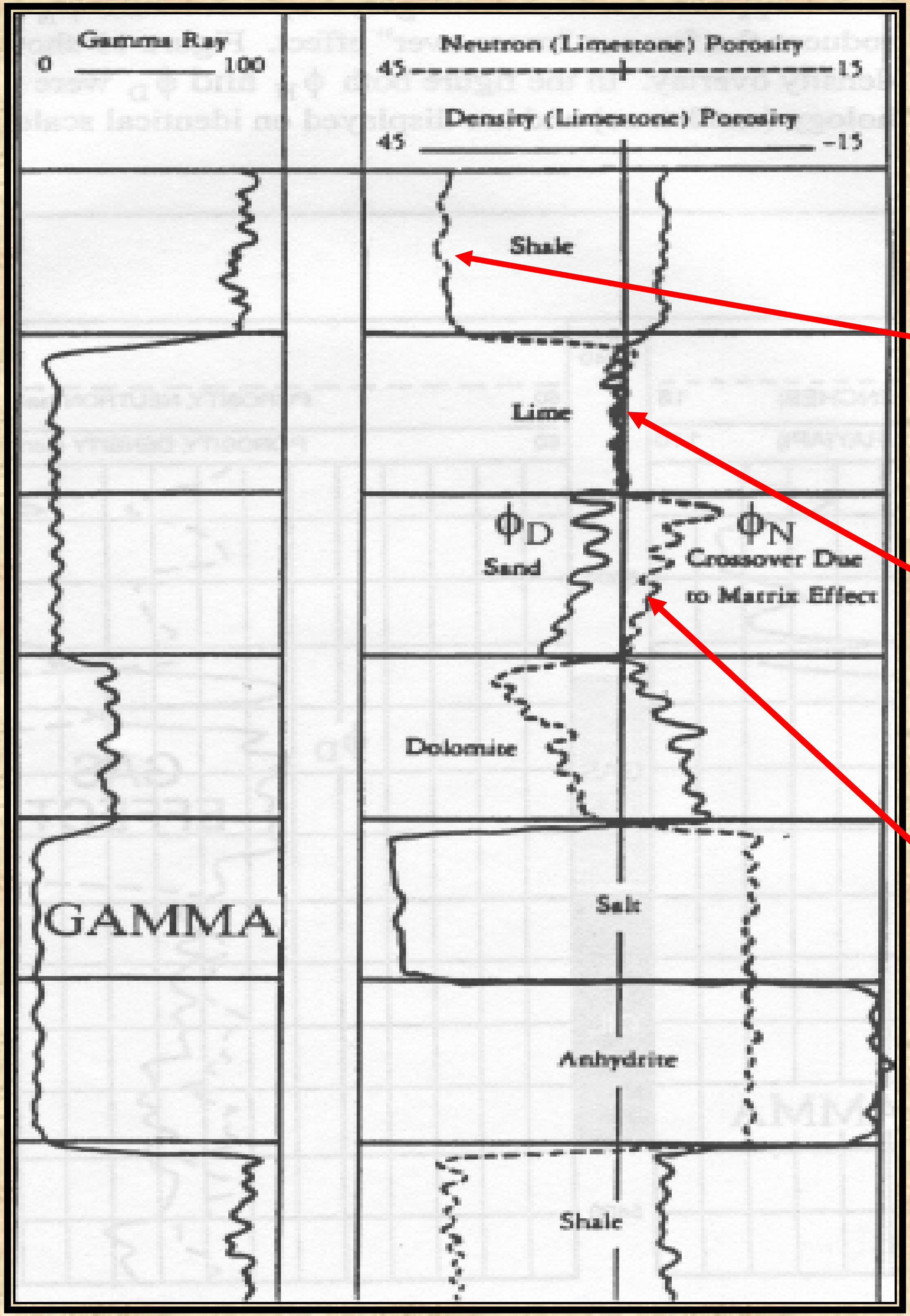
PEF

- Sand – Clean ~ 1.8
- Sand – Dirty ~ 2.7
- Average Shale ~3.4



NPHI SCALES

- **NPHI is usually plotted on a limestone scale or a sandstone scale**
- **If on a <u>limestone scale</u>, in a 100% water bearing limestone, the neutron reads the correct porosity; in a 100% sandstone, the porosity is wrong and must be corrected for lithology**
- **If on a <u>sandstone scale</u>, in a 100% water bearing sandstone, the neutron tool is reads the correct porosity; in a limestone, readings must be corrected for the lithology**



SHALE EFFECT

High NPHI across shales

On a limestone scale, it reads actual porosity in limes

In sands, it reads a different porosity from the actual

NEUTRON LOGS

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- Determine porosity
- Identify gas in porous zones

Where neutron logs can be used

- Any borehole
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Depth of investigation

- 6-12 inches for CN

SUMMARY

- Nuclear porosity tools
  - Source
  - Detectors
- Density
  - Bulk density
  - Photoelectric effect
  - Quality curve
  - Flushed zone measurements
- Neutron
  - Apparent porosity
  - May respond to virgin zone