Well Logging and Interpretation

Lecture 7 – Neutron Log

Neutron Log

- Neutron logs are porosity logs that measure the hydrogen concentration in a formation.
- In clean formation (i.e. shale free) where the porosity is filled with water or oil, the neutron log measures the liquid-filled porosity (Φ_N, NPHI, or PHIN).
- Neutrons are created from a chemical source in the neutron logging tool which continuously emit neutrons.
- Units: v/v decimal, fraction or %

Compensated Neutron Tool (CNL)

- Hydrogen in a porous formation is concentrated in the fluid-filled pores, energy loss is related to the formation's porosity.
- The most commonly used neutron log is the compensated neutron log which has neutron source and two detectors. It also directly displays value of porosity.
- Schlumberger and Halliburton have their own lithology correction charts.

Hydrocarbon and Shale Effect

- Whenever pores are filled with gas rather than oil or water, the reported neutron density porosity is less than the actual formation porosity. This is because there is a lower concentration of hydrogen in gas than oil or water.

- Whenever clays are part of the formation matrix, the reported neutron density porosity is greater than the actual formation porosity. This is because the hydrogen that is within the clay structure and in the water bound to the clay is sensed in addition to the hydrogen in the pore space.

Combination Neutron-Density Log

- The combination of the neutron and density measurements is the most widely used.
- It displays neutron porosity (NPHI) and density porosity (DPHI) in tracks 2 and 3.
- Both NPHI and DPHI are normally recorded in limestone porosity units. However, porosity referenced to sandstone and dolomite can also be recorded.

Neutron-Density Combination

- The technique of neutron-density porosity log works best with the following constrains:

1. Both the neutron and density curves are in porosity (decimal or percent) referenced to limestone units.

2. The formations are clean (no clays in the formations).

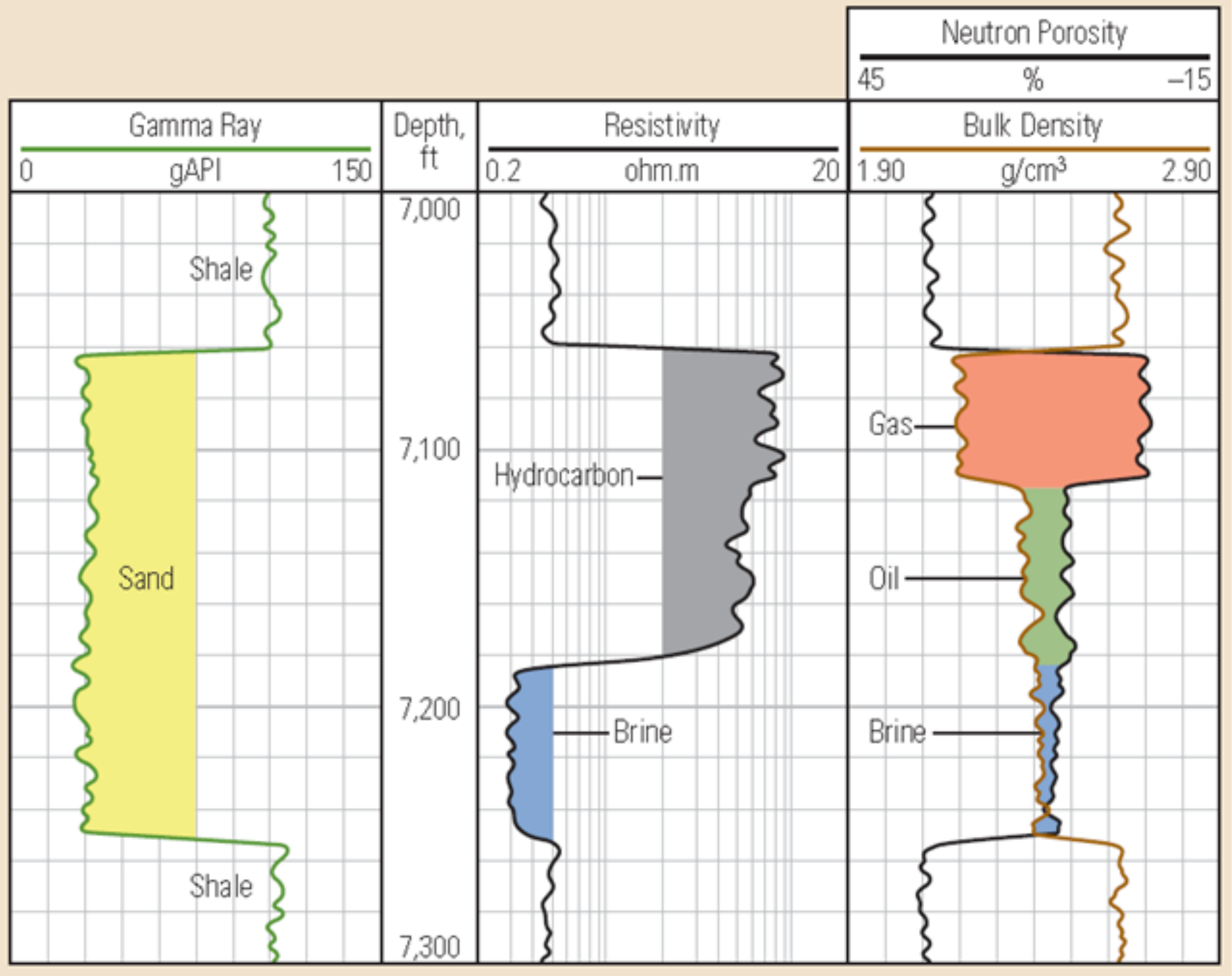
3. There is no gas in the formations, only water or oil.

Neutron-Density Combination (Gas Detection)

- Gas in the pores causes the density porosity to be too high (gas has a lower density than oil or water) and causes the neutron porosity to be too low (there is a lower concentration of hydrogen atoms in gas than oil or water).

- Next figure shows an example of a gas zone, where the neutron porosity is less than the density porosity, and two porosity curves cross each other (this is called cross-over).

- The larger the cross-over, the higher the gas saturation.


Neutron Porosity
45
%
–15
Gamma Ray
0
gAPI
150
Depth, ft
Resistivity
0.2
ohm.m
20
Bulk Density
1.90
g/cm³
2.90
7,000
7,100
7,200
7,300
Shale
Sand
Shale
Hydrocarbon
Brine
Gas
Oil
Brine

Porosity of Gas-Bearing Formation

- The porosity of a gas-bearing formation can be estimated by the following equation:

$$\emptyset_{NDgas} = \sqrt{\frac{{\emptyset_N}^2 + {\emptyset_D}^2}{2}} \approx \frac{1}{2} \times \emptyset_N + \frac{2}{3} \times \emptyset_D$$

- Where:

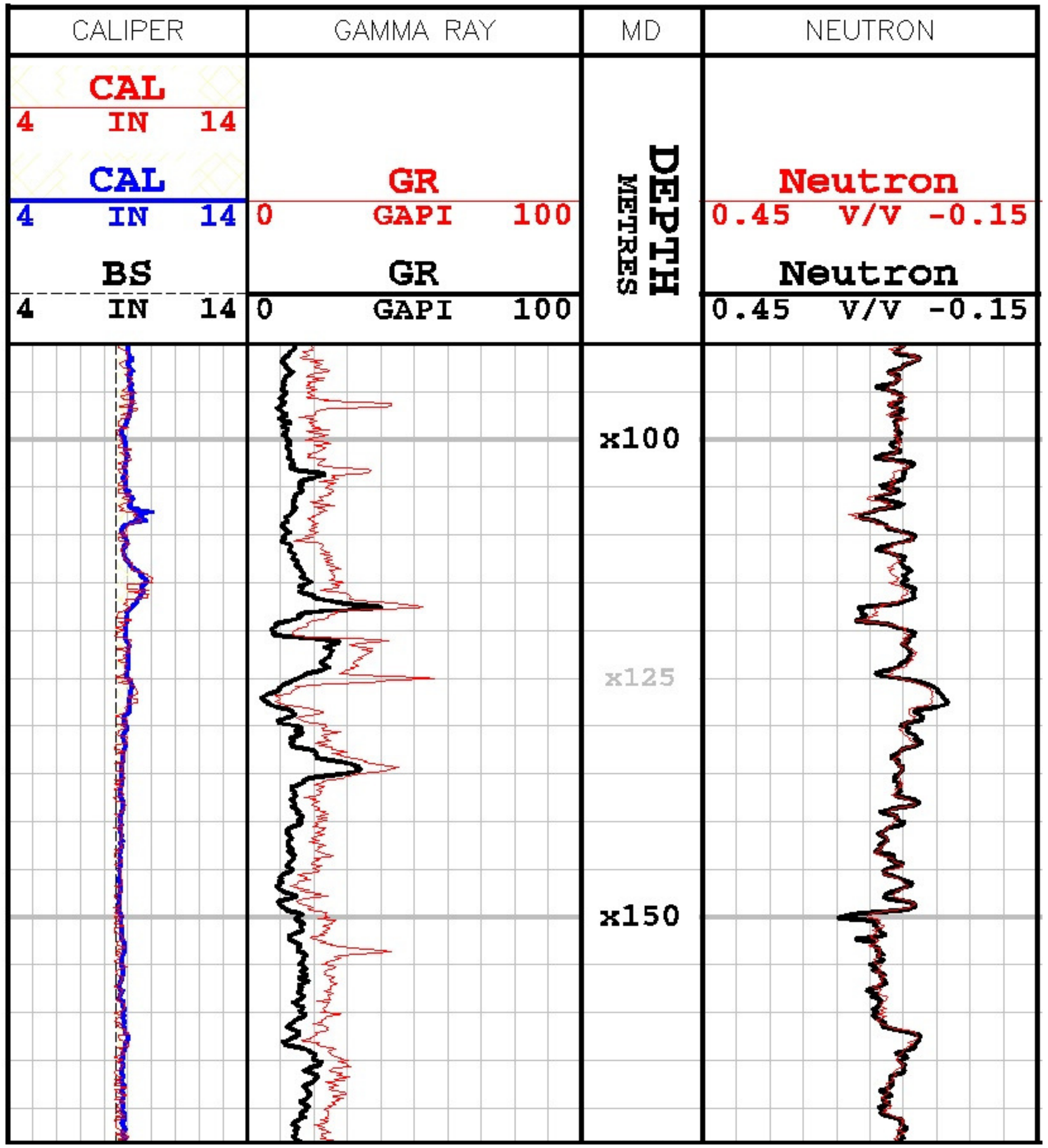
- Φ_{NDgas} is the porosity of the gas-bearing formation

- Φ_N is the neutron porosity

- Φ_D is the density porosity

Applications of Neutron Log

- Porosity (displayed directly on the log).
- Lithology identification (with Sonic and Density).
- Gas indication (with Density).
- Clay content, shaliness (with Density).
- Correlation, especially in cased holes.



Neutron Logging Tools

- Sidewall Neutron Porosity (SNP):

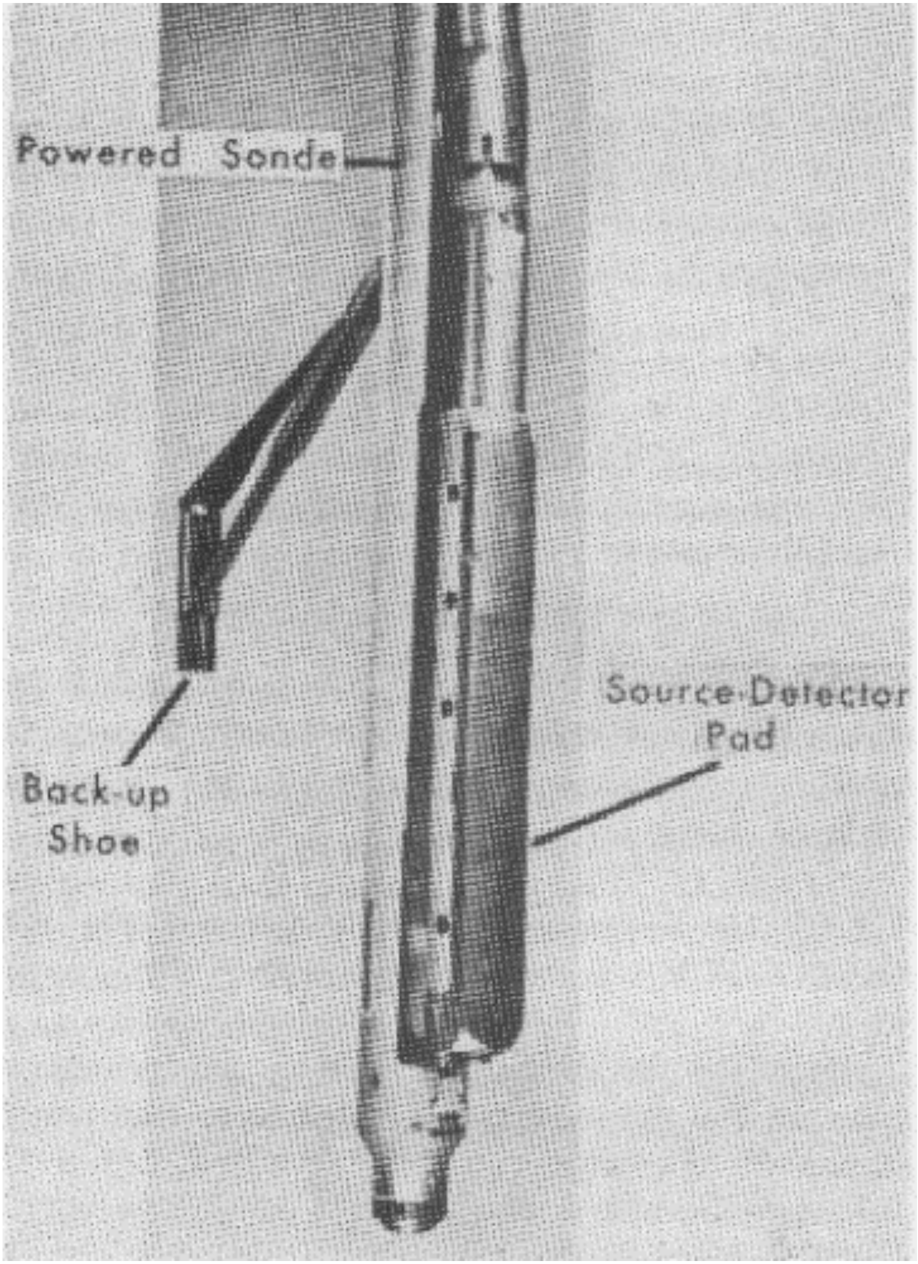
- Measures epithermal neutron porosity using pad

.type, single source – single detector tool

- However, it is sensitive to borehole conditions.

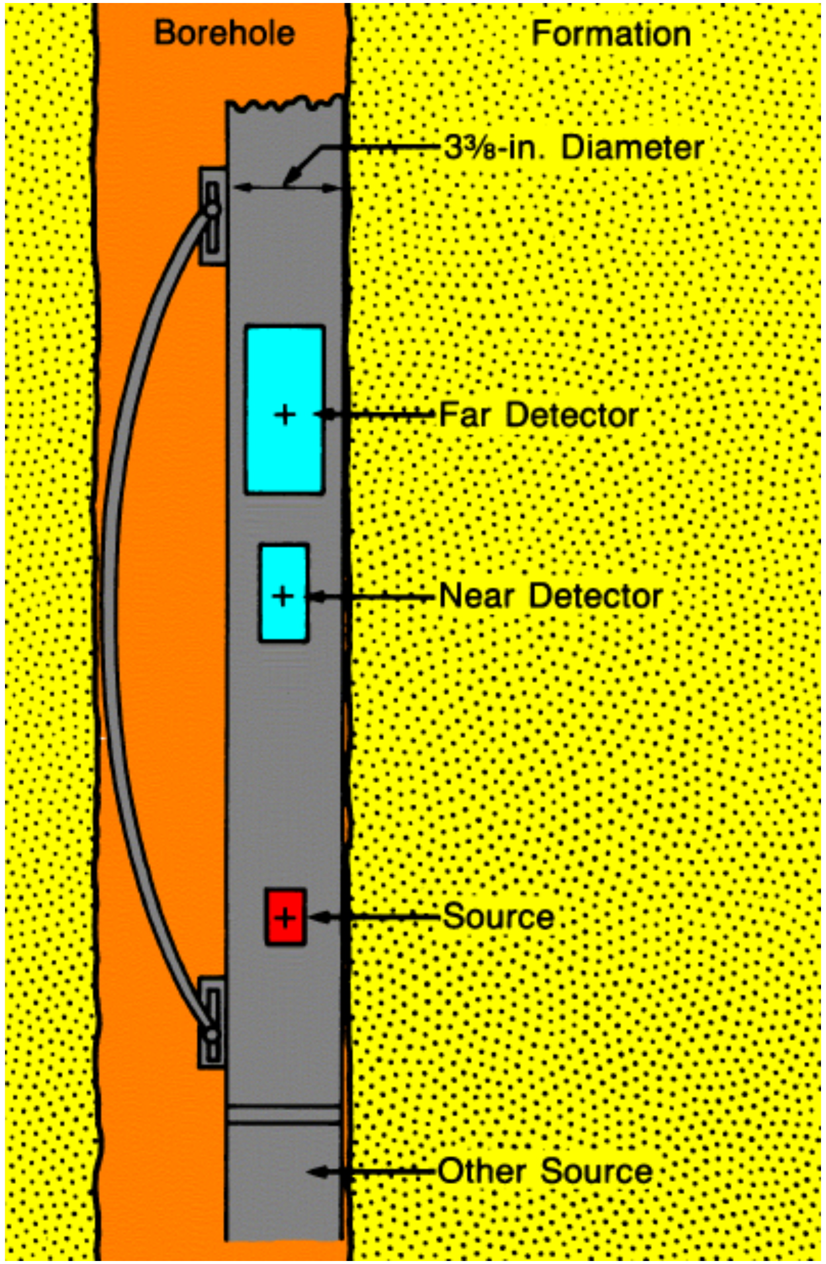
- Depth of investigation is 8 inches.

- Low vertical resolution (16 inches).



Neutron Logging Tools

- Compensated Neutron Logging (CNL):
- CNL uses single source and dual thermal neutron detector system that reduces borehole effect.
- It is less sensitive to borehole conditions.
- Depth of investigation is 12 inches.
- Vertical resolution is 10 inches.



Comparison between SNP and CNL

	SNP	CNL
Tool	Pad-type Single detector	Mandrel-type 2 detectors
Detects	Epithermal neutrons	Thermal Neutrons
DI	Shallow, 8”	Deeper, 12”
Borehole effect	Sensitive to mudcake and rugosity	Minimized by compensation
Depth resolution	16”	10”
Limitation	Open hole only	Open & cased hole
Porosity	Count rate $\propto \phi$	Ratio $\propto \phi$
Advantage	Insensitive to thermal neutron absorbers, e.g., Cl, Boron, Barite	Insensitive to borehole environment

Factors Affecting Neutron Logging

1. Hydrogen

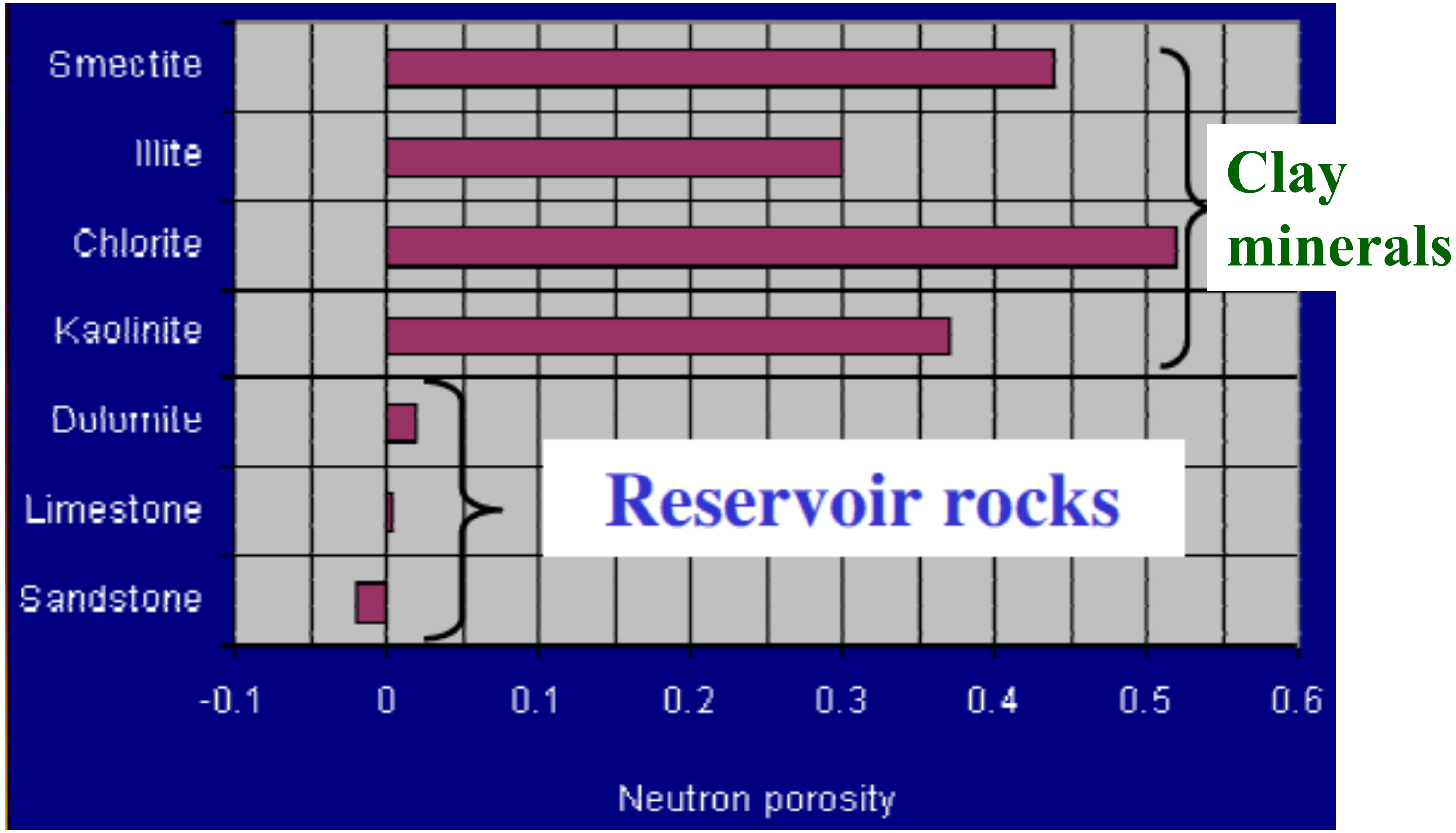
- Hydrogen content of minerals other than pore fluid substantially affect neutron porosity such as hydrous and clay minerals and minerals which contain hydroxyl ions (OH).

- Bound water of clay
- Hydroxyl ions (OH) in clays
- Bituminous shale (CH_{793}...)
- Water of crystallisation (Gypsum, Trona, Limonite)

Factors Affecting Neutron Logging

2. Clay minerals

- Bound water of clay
- Hydroxyl ions (OH) in clays
- Bituminous shale (CH_{793}…)



Factors Affecting Neutron Logging

3. Fluid salinity

- More saline water contains less hydrogen concentration.

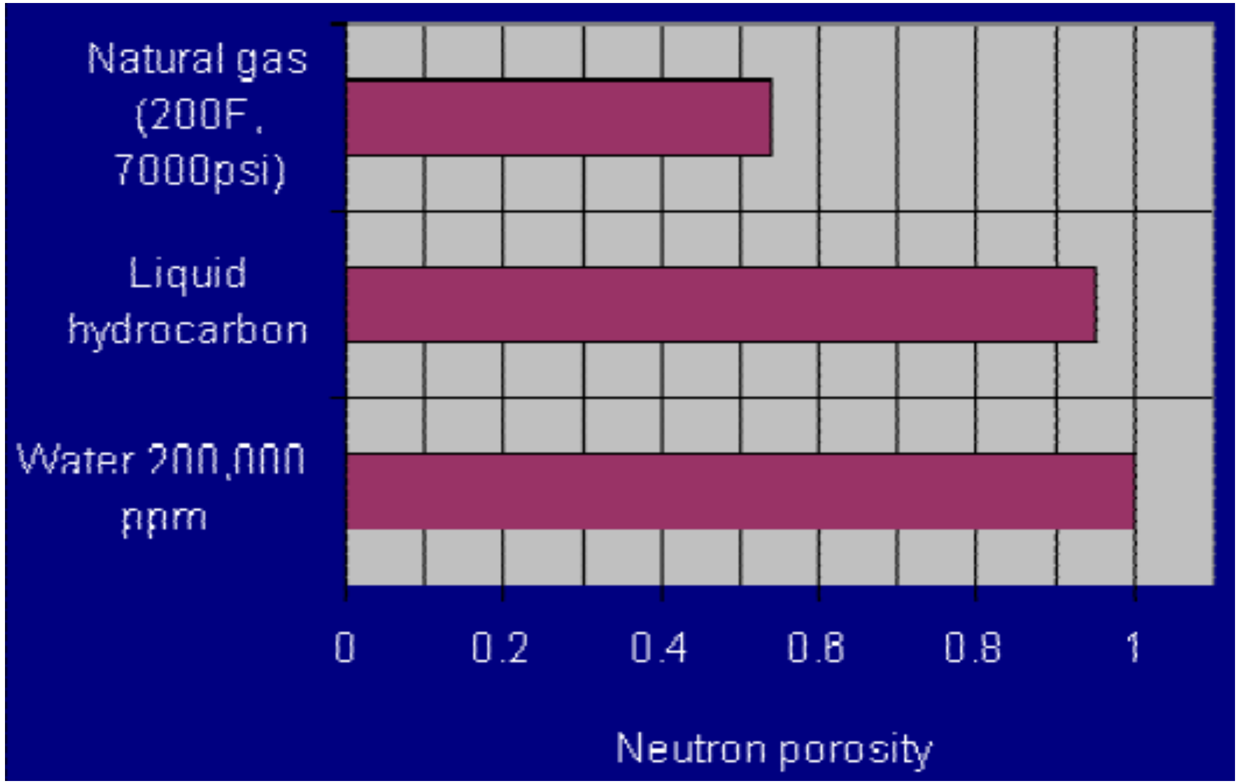
Pure water	Salt water 200,000 ppm
1.0	0.9

Factors affecting tools

Factors Affecting Neutron Logging

4. Hydrocarbons

- Medium to heavy oils have hydrogen index close to 1.
- Light oil and gas can reduce neutron porosity because of low concentration of hydrogen, specially in gases.



Factors Affecting Neutron Logging

5. Pressure and temperature

- Pressure tends to increase the hydrogen index specially of light oil and gas. However, temperature tends to decrease hydrogen index of the formation.

	14.7 psi 60 F	7000 psi 200 F
Salt water 200,000 ppm	0.92	0.90
N-octane	1.0	0.96
Natural gas	0.0017	0.54

Hydrogen index of liquid and gas as a function of pressure and temperature.

Neutron-Density cross plot

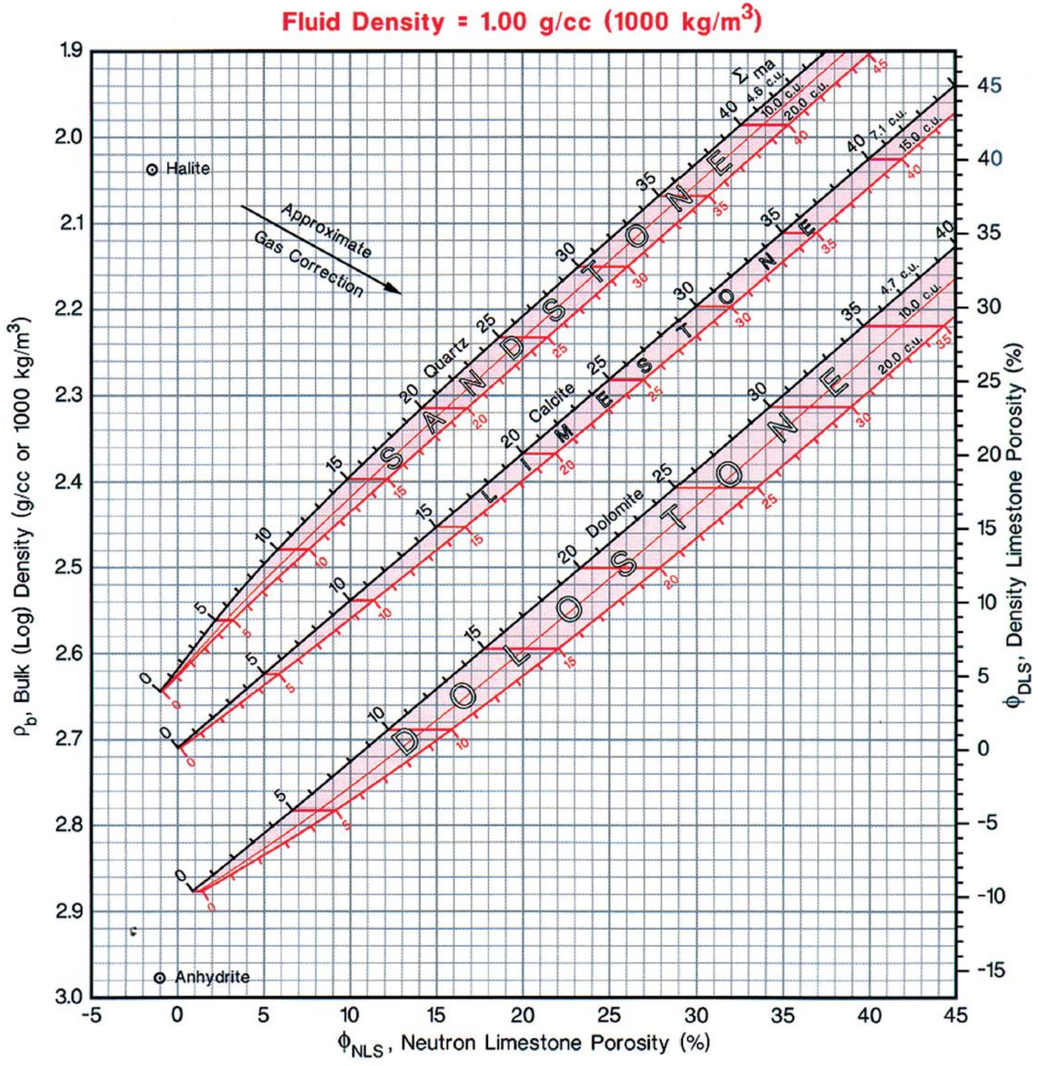
- **Advantage:**

– Given two possible lithology pair solutions, the porosity remains relatively invariant between the solutions.

– The combination of neutron and density is the most common of all porosity tool pairs.

- **Disadvantage:**

– In rough holes or in heavy drilling muds, the density data might be invalid.



Sonic-Density cross plot

- **Advantage:**

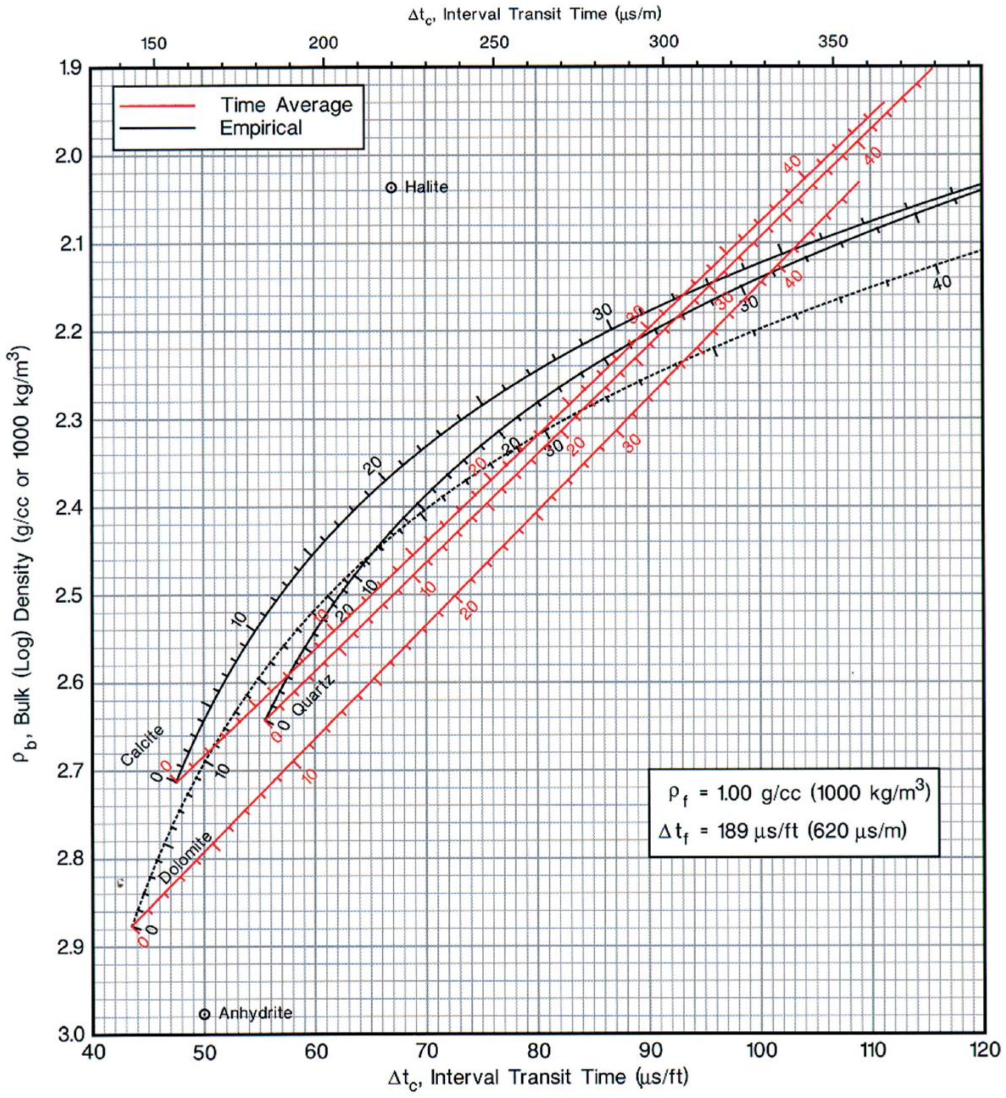
– Potential reservoirs plot along the closely spaced lithology lines, while shales tend to fall toward the lower right of the plot.

– Quite useful for determining some evaporate minerals.

- **Disadvantage:**

– The choice of the lithology pair has a significant effect on the estimation of the porosity.

– The lithology lines are closely spaced, so any uncertainty in the measurements produces large changes in lithology and porosity estimates.



Sonic-Neutron cross plot

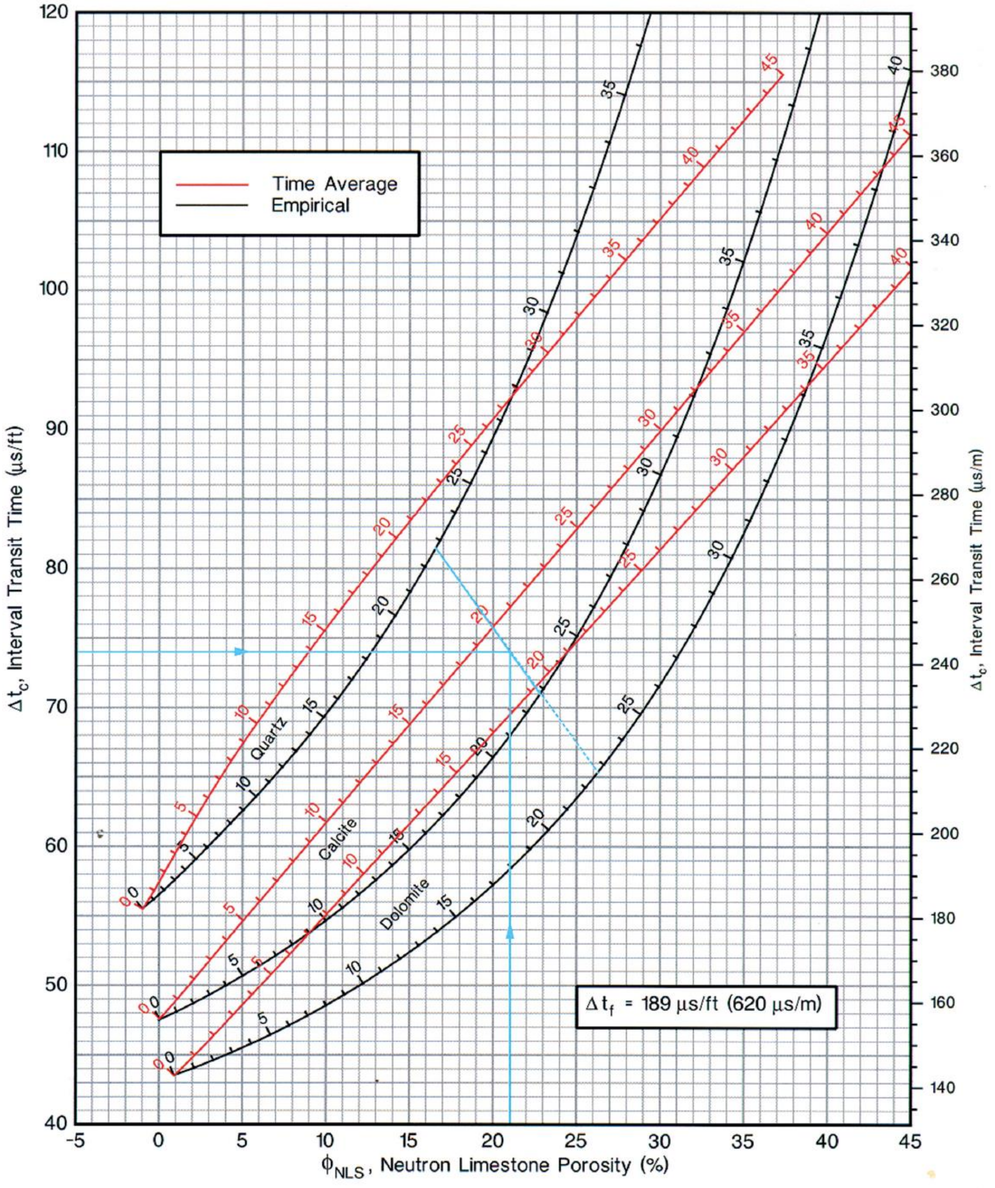
- Advantage:

– Given two possible lithology pair solutions, the porosity remains relatively invariant between the solutions.

–The sonic is less sensitive to rough holes than the density.

- Disadvantage:

– The combination of sonic and neutron data is not common.



Density-Photoelectric cross plot

- Advantage:

– Both measurements are made with the same logging tool; both will be available in newer wells.

- Disadvantage:

– The choice of the lithology pair has a significant effect on the estimation of the porosity.

– In rough holes or in heavy drilling mud the data may be invalid.

– The Pe will not be present in wells logged before 1978.