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 - 15

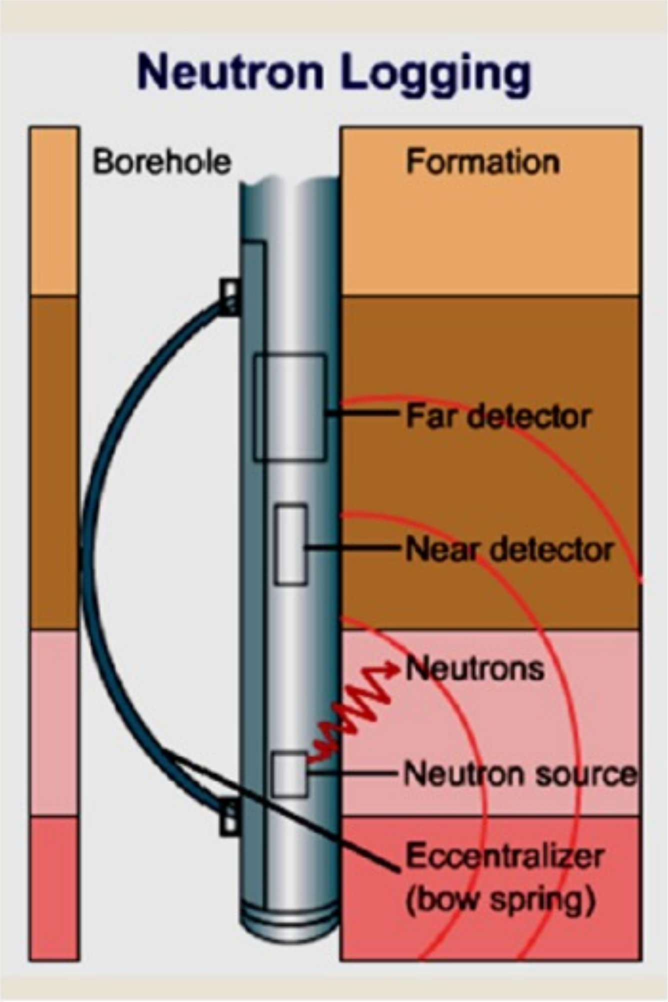
Partha Pratim Mandal
Assistant Professor
Department of Applied Geophysics
E: partham@iitism.ac.in / partha87presi@gmail.com

AGENDA

- Introduction
- Principles of neutron log measurement
- Tools
- Influencing factors
- Correction via nomogram

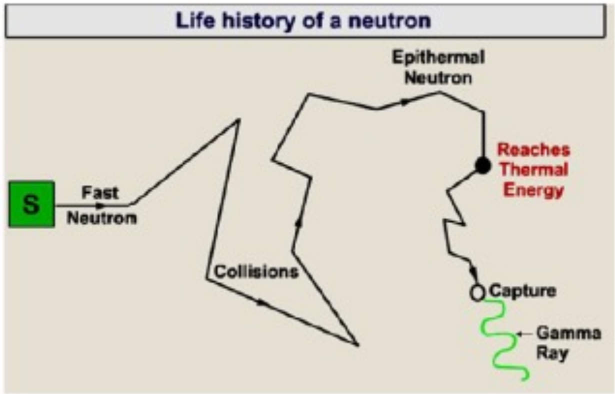
INTRODUCTION

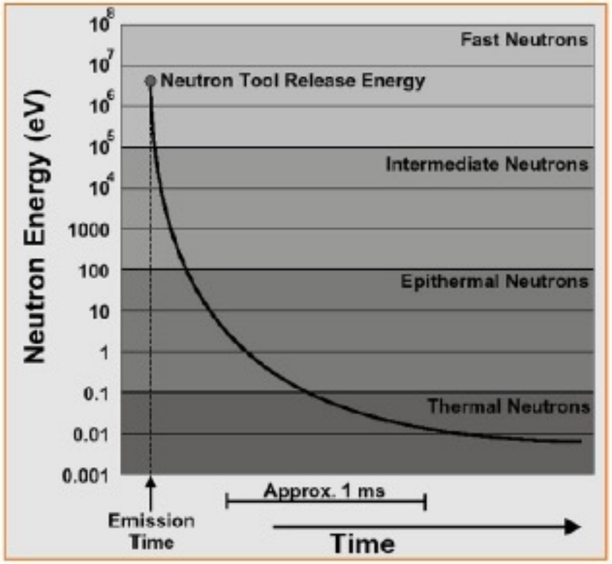
- From the Neutron tools, high energy neutrons are continuously emitted from a radioactive source
- Neutrons are natural particles, each having a mass almost identical to the mass of hydrogen atoms
- The emitted neutrons interact elastically and inelastically with atomic nuclei of the formation and the borehole surrounding the source.
- The life of neutrons can be divided into four phases: fast, slowing down, diffusion and capture
- They lose energy and slowed down when collided with nucleus of equal mass (hydrogen atoms)



PRINCIPLES

- The fast neutrons collide with the nuclei of atoms within the formation and looses some kinetic energy through stages called intermediate (102 to 105 eV), epithermal (0.1 to 100 eV), and finally thermal neutrons (<0.1 eV)
- In solid materials containing reasonable amounts of low atomic mass elements (e.g., H), this process can happen very quickly (of the order of microseconds)
- Thermal neutrons are named based on the level of kinetic energy which is similar to the average kinetic energy of the gas molecules in a room-temperature





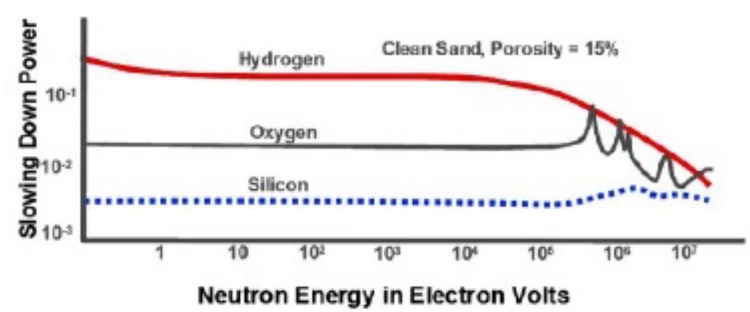
PRINCIPLES

- Neutron energy loss is most efficient when the masses of the neutron and the nucleus are the same, and becomes much less efficient when the nuclei of the formation material are more massive than the neutron
- Slowing down process depends upon mainly the number of hydrogen atoms present in the formation, which mostly is proportional to the amount of water or hydrocarbon contained in this formation, i.e., directly related to the porosity of the rock

Slowing down power of elements (from I. Kaplan)

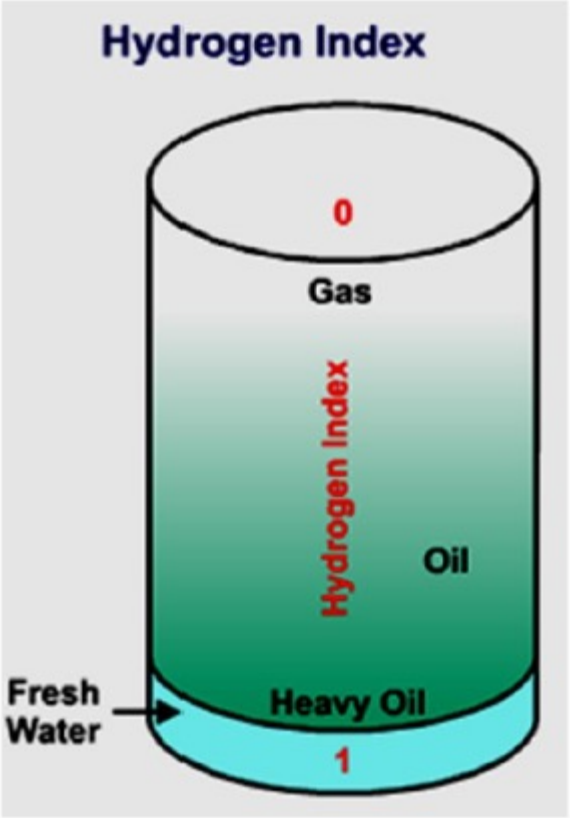
Element	Number of collisions needed to reduce the energy of neutrons from 2 MeV to 0.025 eV
Hydrogen	18
Carbon	114
Oxygen	150
Silicon	257
Chlorine	329
Calcium	368

* Nuclear Physics, Irving Kaplan.



HYDROGEN INDEX (HI)

- As hydrogen atom is influencing neutron energy levels, the tool measure hydrogen index of a formation
- HI is defined as the partial concentration of hydrogen per unit volume in a formation
- Due to abundance of hydrogen atoms in the pore filling fluids, HI can be a measure of formation porosity

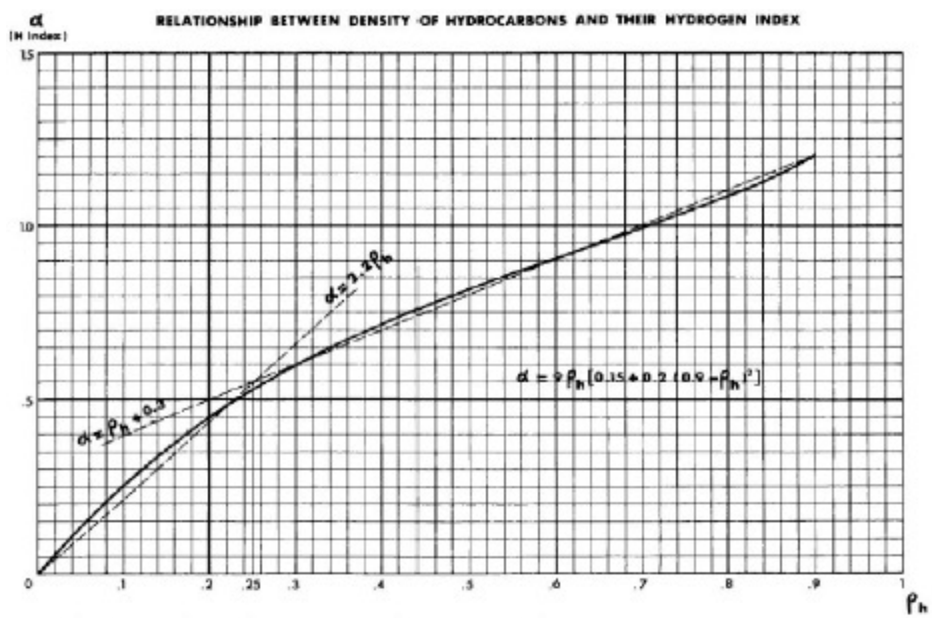


The HI of fresh water is 1 and it decreases significantly for gas.

HYDROGEN INDEX (HI)

- HI values of water and some minerals

Material	Hydrogen Density (atm/cm^3 × 10^{23})	Hydrogen Index
Water (60°F, 14.7 psi)	0.669	1.000
Water (200°F, 2,000 psi)	0.667	1.000
Brine (200 kppm NaCl)	0.614	0.920
Methane (60°F, 14.7 psi)	0.001	0.002
Methane (200°F, 2,000 psi)	0.329	0.490
n-octane (60°F, 14.7 psi)	0.667	1.000
n-octane (200°F, 2,000 psi)	0.639	0.960
Gypsum	0.325	0.490
Anthracite	0.268	0.400
Kaolinite	0.250	0.370
Chlorite	0.213	0.320
Illite	0.059	0.090



Relationship between hydrocarbon density and hydrogen index . (from Gaymard and Poupon, 1968)

if $\rho_h \leq 0.25$, i.e. for gas:	$HI_g \approx 2.2\ \rho_g$
if $\rho_h \geq 0.25$, i.e. for oil:	$HI_O \approx \rho_o + 0.3$

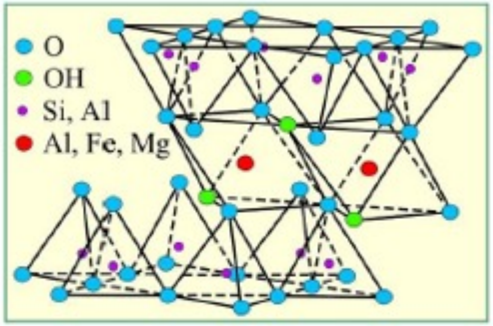
HI EFFECTS

- Chlorine effect:

Hydrogen and chlorine are only two atoms that contribute significantly to neutron absorption. There is no problem with the presence of hydrogen in the fluids as what we want to measure. However, in the presence of chloride ions, the tool will measure a lower flux of neutrons and hence overestimate the porosity. This is called the chlorine effect.

- Shale effect:

Clays have a significant amount of bound water and structural water. Therefore, apparent porosity read from the neutron tool in shale formations is always higher than it really is. This is called the shale effect



The clay minerals basic structural units consist of a silica tetrahedron and an alumina octahedron

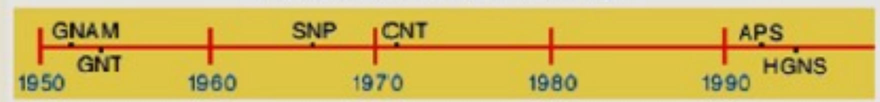
- Gas effect:

The presence of oil does not affect the tool response as it has approx. the same HI value as fresh water. But gas has less HI resulting from its low density, and its presence will give rise to underestimations in porosity

TOOLS

- The Gamma –ray detecting tools (not in use anymore)
- The epithermal Neutron detecting tools [the sidewall Neutron porosity tool (SNP)] – single detector
- The thermal neutron detecting tools, the compensated Neutron Tool (CNT or CNL) two-detector system
- HGNS – highly integrated Gamma ray Neutron tool

Neutron Tool History

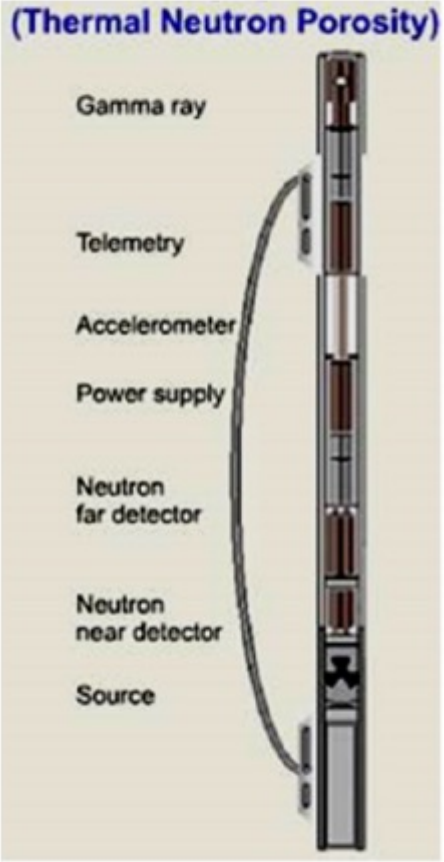


Neutron Porosity Tool Summary

	Basic Make-up	Advances and Response
GNAM	Ra-Be chemical source and one Geiger-Muller γ-ray detector	First neutron porosity tool
GNT	Pu-Be chemical source and one Geiger-Muller γ-ray detector	More reliable than GNT and 20" resolution
SNP	Pu-Be chemical source (later replaced by Am-Be) and one He^3 epithermal neutron detector	Epithermal pad tool with quantitative output and 15" resolution
CNT	Am-Be chemical source and two He^3 thermal neutron detectors	Combinable two-detector compensated thermal tool with environmental correction capabilities and 12" resolution (using enhanced resolution processing)
HGNS	Same as CNT	Popular CNT type measurement with Platform Express benefits
APS	Minitron source, one He^3 thermal neutron detector, and four He^3 epithermal neutron detectors	Superior epithermal measurement with porosity output, which is nearly free from matrix effects. Also a formation sigma measurement, and 4" resolution

TOOL SKETCH

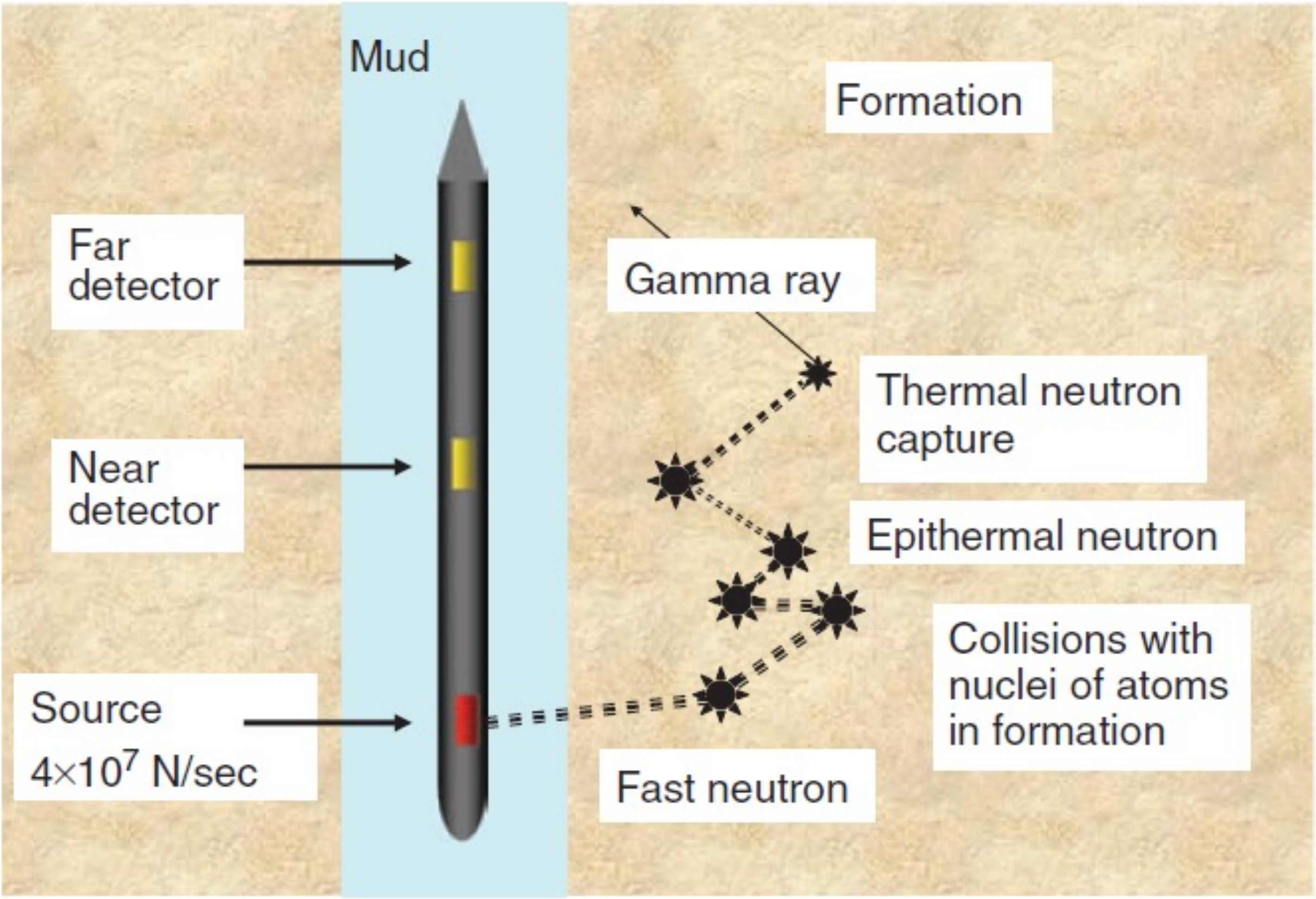
- Log : TNPH, NPHI or CNL
- Tools: CNT, TNPH
- Unit: Limestone PU
- Primary use: Porosity
- Sources consist of chemical sources such as plutonium-beryllium, or americium-beryllium which produce fast neutrons with energy peaks around 4 Mev [**Beryllium** with one of the α-emitters]
- The source and detector are placed on a skid, which is pressed against the borehole wall



DEPTH OF INVESTIGATION

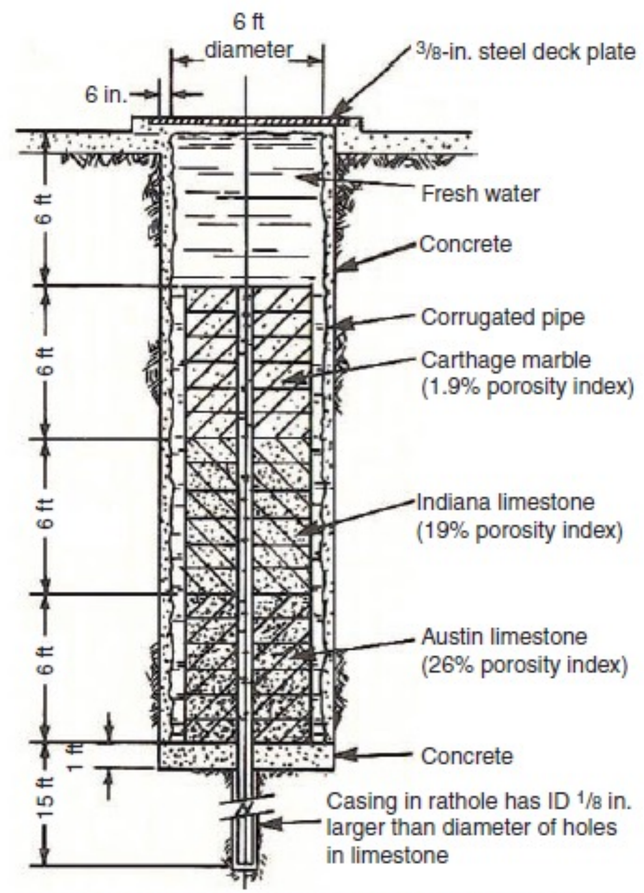
- The depth of investigation of the tool is generally shallow and in the region of 15-25 cm under normal logging conditions
- This will vary on different tools and as a function of the hydrogen index (and porosity). Maximum investigation is in low porosity rocks.
- In tight formations with a low hydrogen index, the tool may read up to 50-60 cm
- Vertical resolution depends upon logging speed 3 feet at 1800 ft/hr

GENERALIZED NEUTRON TOOL



CALIBRATION

- The calibration of the tool is done in a special calibration pit, Houston, Texas
- 1000 API units are defined as the difference between neutron tool readings (i) without a source (ii) with a source in the calibration pit
- The test pit contains three reference formation blocks under a 7’7/8” hole drilled with fresh water mud
- 1000 API standard corresponds to when the tool is opposite middle block contain 19% porosity Indian limestone, 26% porosity Austin limestone and 1.9% cartage marble blocks are used in conjunction with 100% porosity water-bath above and below
- Modern neutron logs are scaled directly in porosity/HI units through a software or a function-former



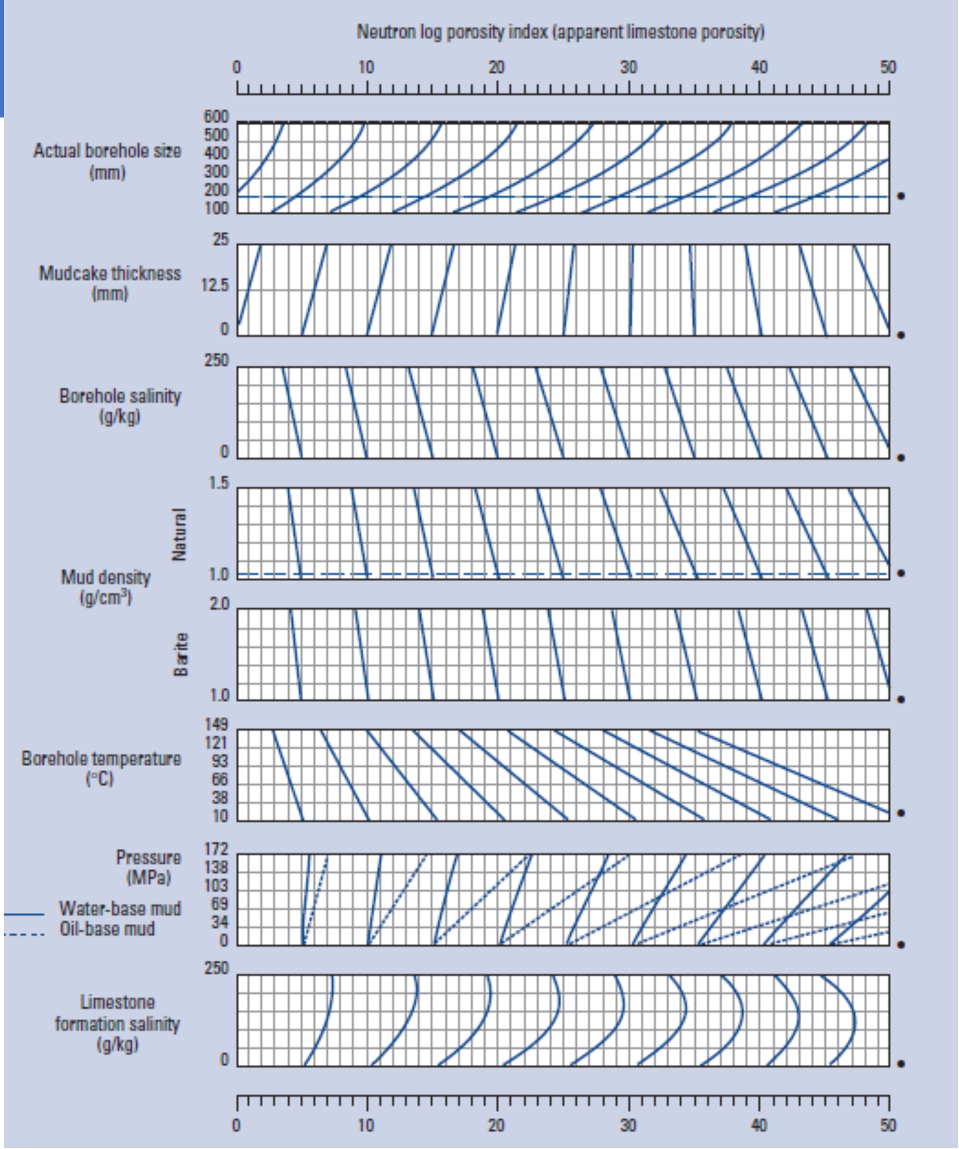
Carthage marble, Austin limestone, and Indiana limestone sections are each composed of 6 regular octagonal blocks, 5 ft across, 1 ft thick, with 7 7/8-in. (±1/16 in.) center bore hole.

INFLUENCING FACTOR

- Borehole size
- Mud weight
- Borehole salinity (chloride)
- Porewater salinity
- Depth [temperature and pressure]

ENVIRONMENT CORRECTION

- Compensated neutron tool (CNT)
- Correction nomograph for open hole

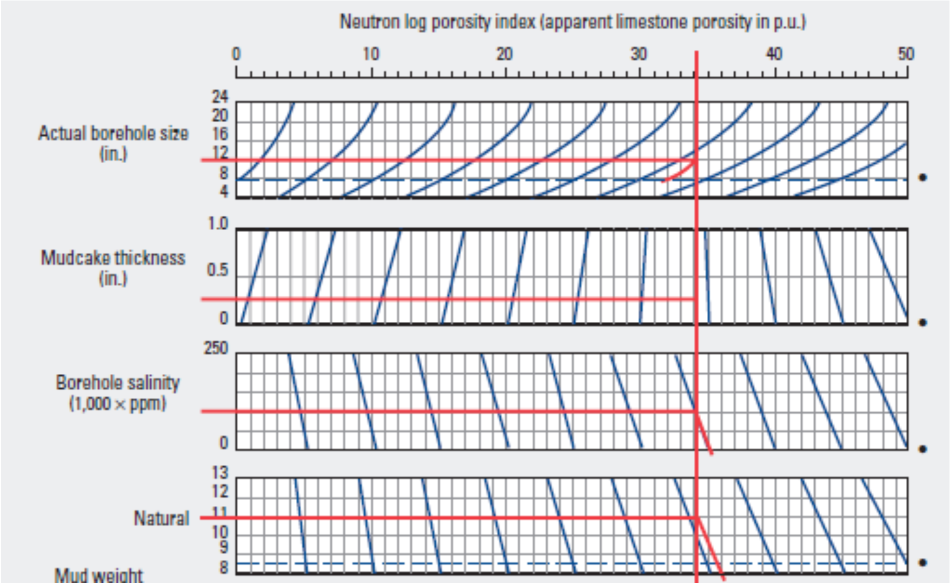


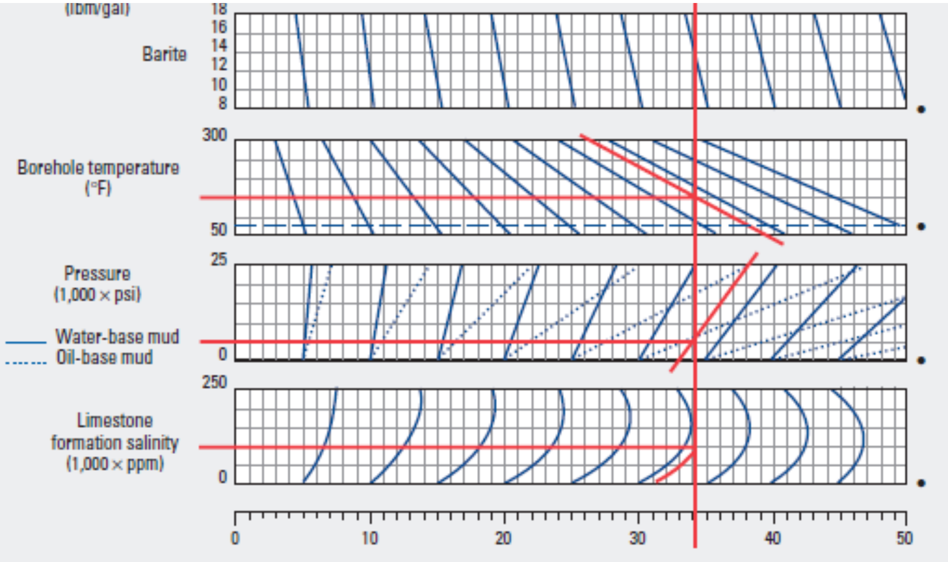
EXAMPLE - CORRECTION

CNT Neutron Porosity Correction Examples

		Correction		
		Example 1	**Example 2**	Δφ
Log porosity	32 p.u.			
Borehole size	12 in.	–2		
Mudcake thickness	¼ in.		0	
Borehole salinity	100,000 ppm		+1	
Mud weight	11 lbm/gal		+2	
Borehole temperature	150°F		+4	
Wellbore pressure	5,000 psi		–1	
Formation salinity	100,000 ppm		–3	
Standoff (from Chart Neu-3)	1 in.		–4	
Net environmental correction			–1	
Backed-out corrected porosity		34 p.u.		
Environmentally corrected porosity			33 p.u.	
Net correction				–3
Backed-out, environmentally corrected porosity				31 p.u.

ENVIRONMENT CORRECTION



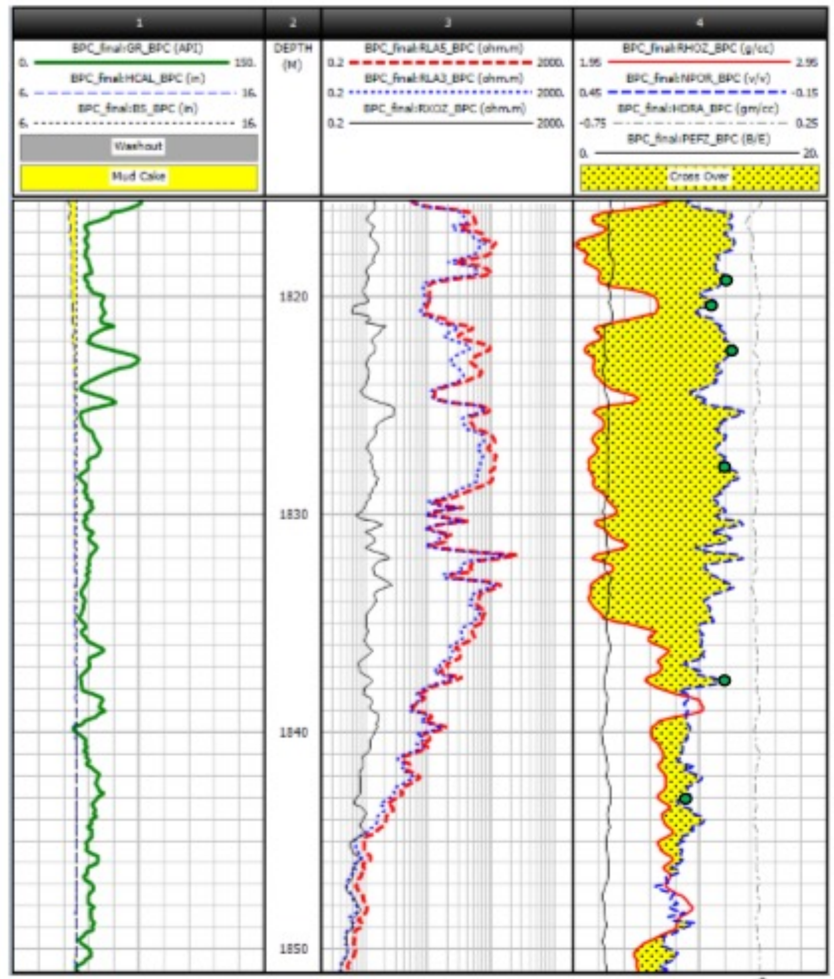


APPLICATION

- Porosity calculation
- Identification of lithology
- Detection of gas zones in combination with density log
- Correction nomograph for open hole

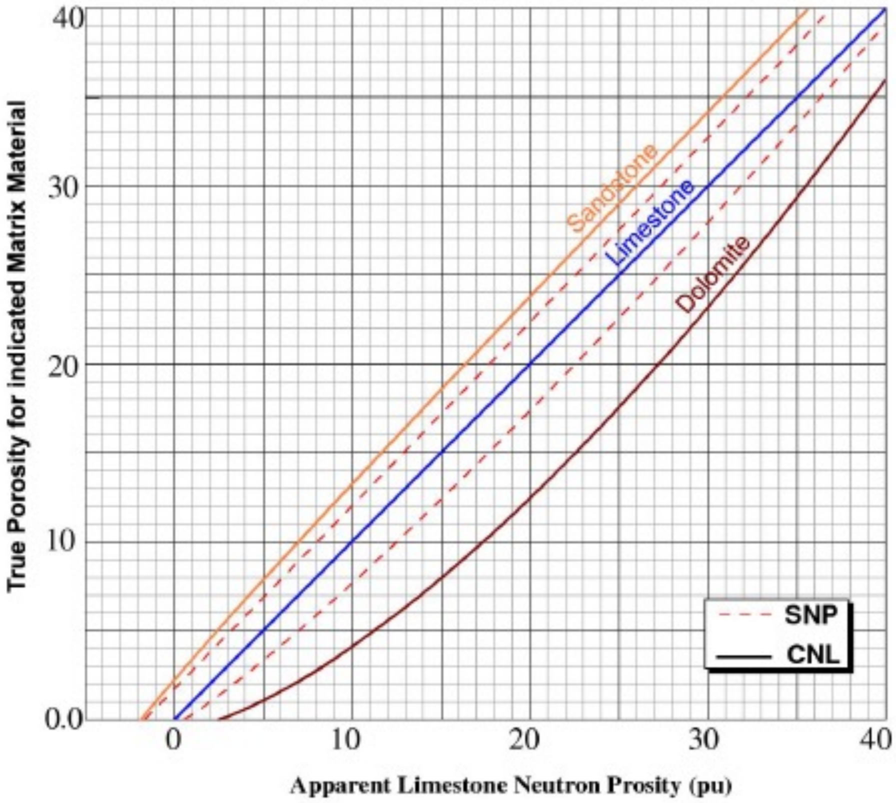
LOG DISPLAY

- The neutron log is plotted on a linear scale of limestone porosity units which range from 0.45 to -0.15 from left to write
- Displayed in combination with density log



POROSITY

- Since tool is limestone calibrated, it is required to empirical approach to derive porosity in other lithologies



MATRIX CORRECTION

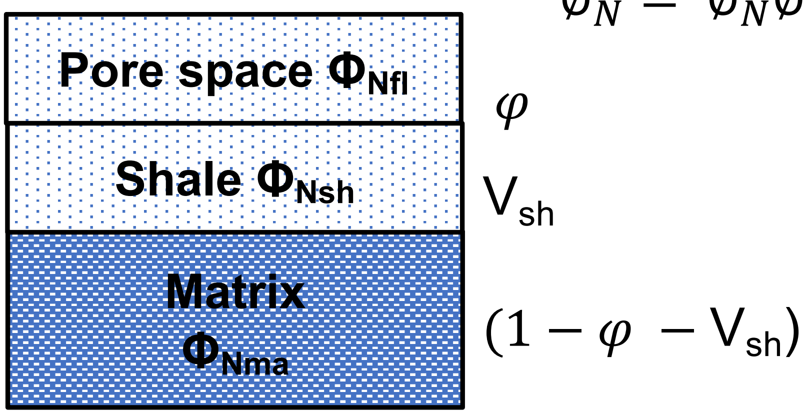
$$\emptyset_{Ncorr} = \emptyset_N + \emptyset_{Mcorr}$$

Matrix	**ϕ_{Mcorr} (pu %)**
Limestone	0.0
Sandstone	+4
Dolomite	- 2 to - 8

VOLUME OF SHALE CORRECTION

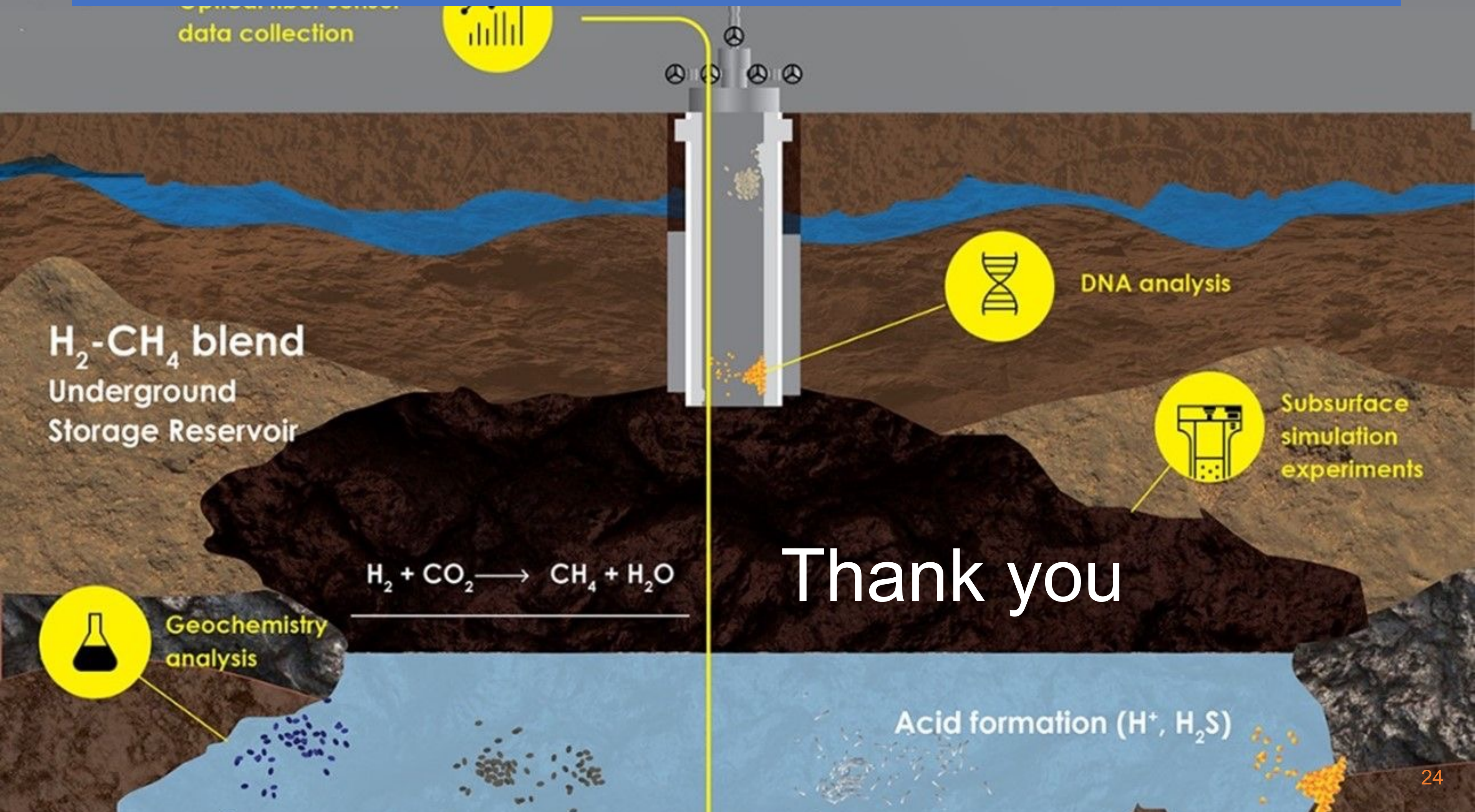
- Neutron log is affected by presence of shale content, leading to over estimation of the porosity

$$\emptyset_N = \emptyset_N \emptyset_{Nfl} + V_{sh}\emptyset_{Nsh} + (1 - \emptyset - V_{sh})\emptyset_{Nma}$$



$$\emptyset = \emptyset_N - V_{sh}\emptyset_{Nsh}$$

END OF LECTURE



Thank you