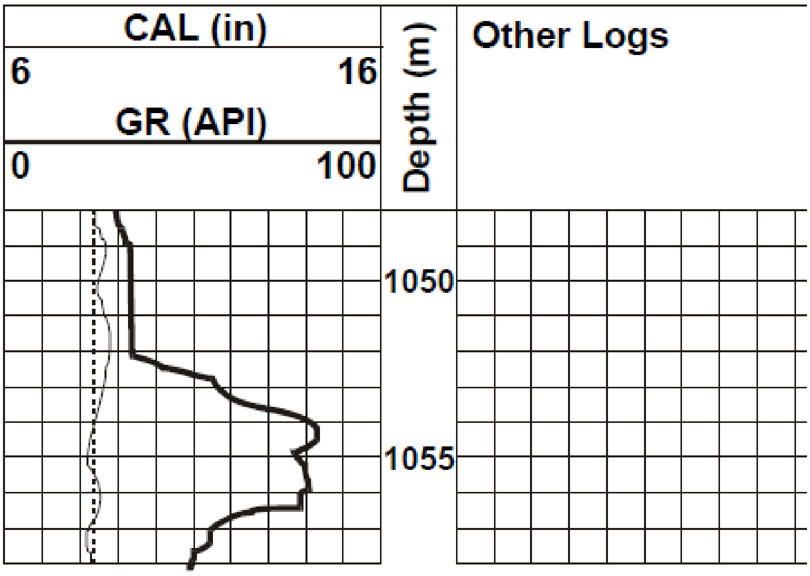
GAMMA RAY LOG

- The gamma ray (GR) log measures the natural radioactivity emanating from the formations.
- There are three naturally radioactive elements in nature:
  - ✓ **Uranium U** series – fixed by fine-grained organic material.
  - ✓ **Thorium Th** series – absorbed by clay minerals.
  - ✓ **Potassium** K^{40} – part of clay mineral composition.
- **Total gamma ray (GR) log** measures total (cumulative) response of U, Th, and K^{40}.
- In sedimentary formations the GR log normally reflects the shale content of the formations. This is because the radioactive elements tend to concentrate in clays and shales and these elements are more radioactive than sand or carbonate.
- Shale-free (clean) formation have low concentrations of radioactive elements therefore give low gamma ray readings.
- As shale/clay content increases, the gamma ray log response increases because of the concentration of the radioactive elements in shale/clay.
- Gamma Ray log unit recorded in API Units (American Petroleum Institute).
- The total gamma ray log is usually recorded in *track 1* with the *caliper* log, *bit size* and *SP* log.
- The API scale goes from 0 to 100 API, and 0 to 150 API used in log presentations.

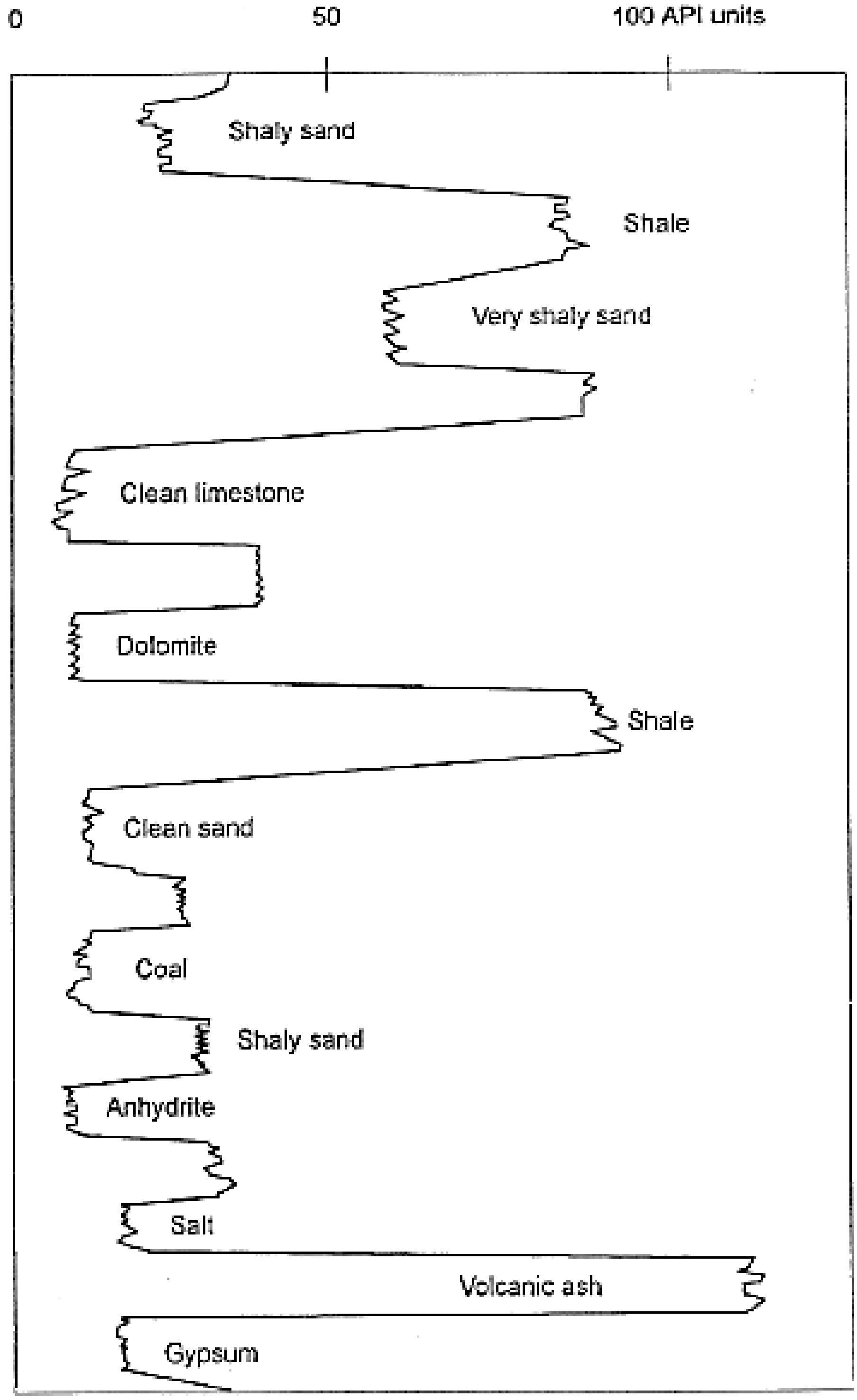


○ *GR response in Typical Formations*

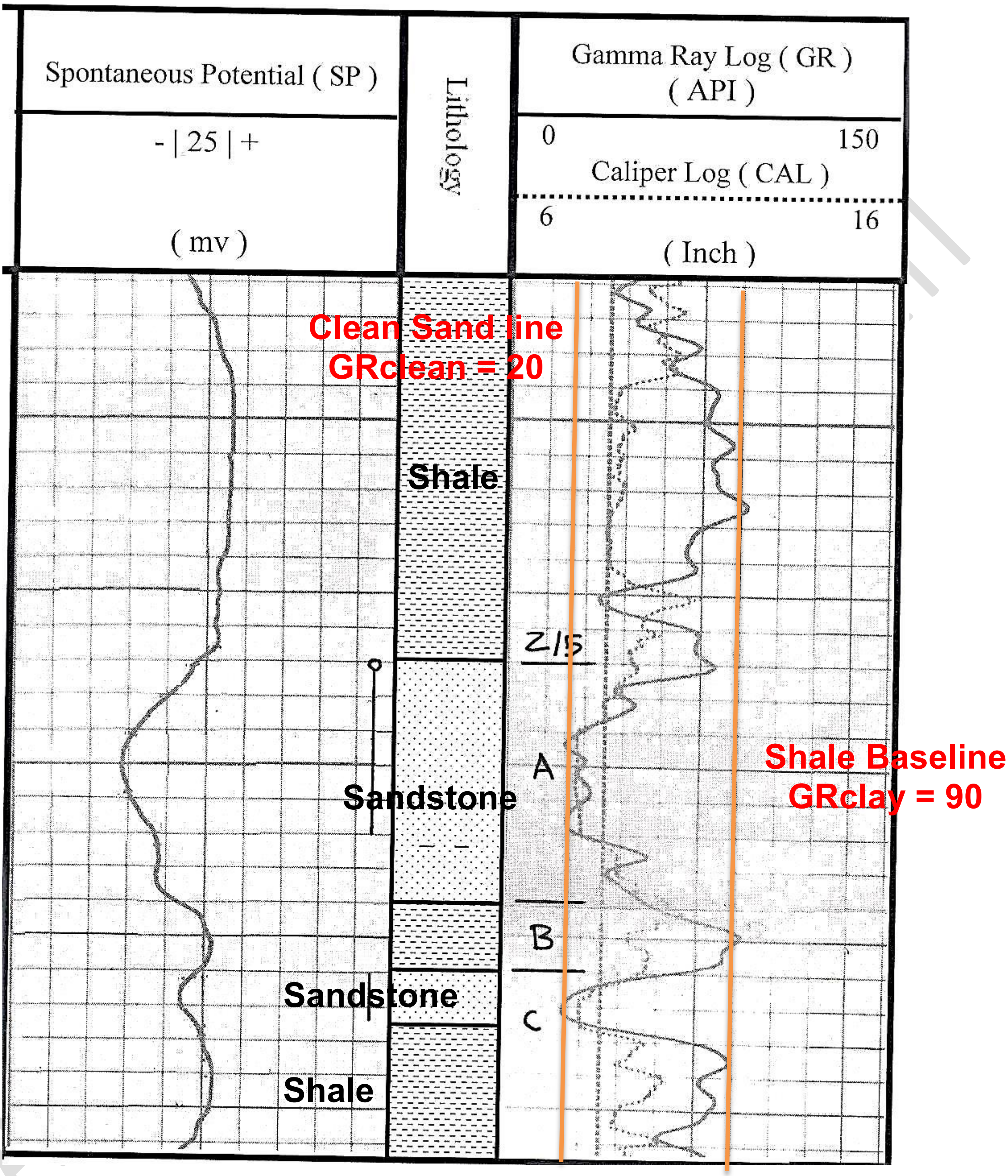
Lithology:	**API**
Limestone	5-10
Dolomite	10-20
Sandstone	10-60
Shale	80-140

Minerals:	**API**
Calcite	0 - 15
Dolomite	0 - 15
Quartz	0 - 15

Evaporates	**API**
Halite(NaCl)	Low
Anhydrite	Low
Coal	



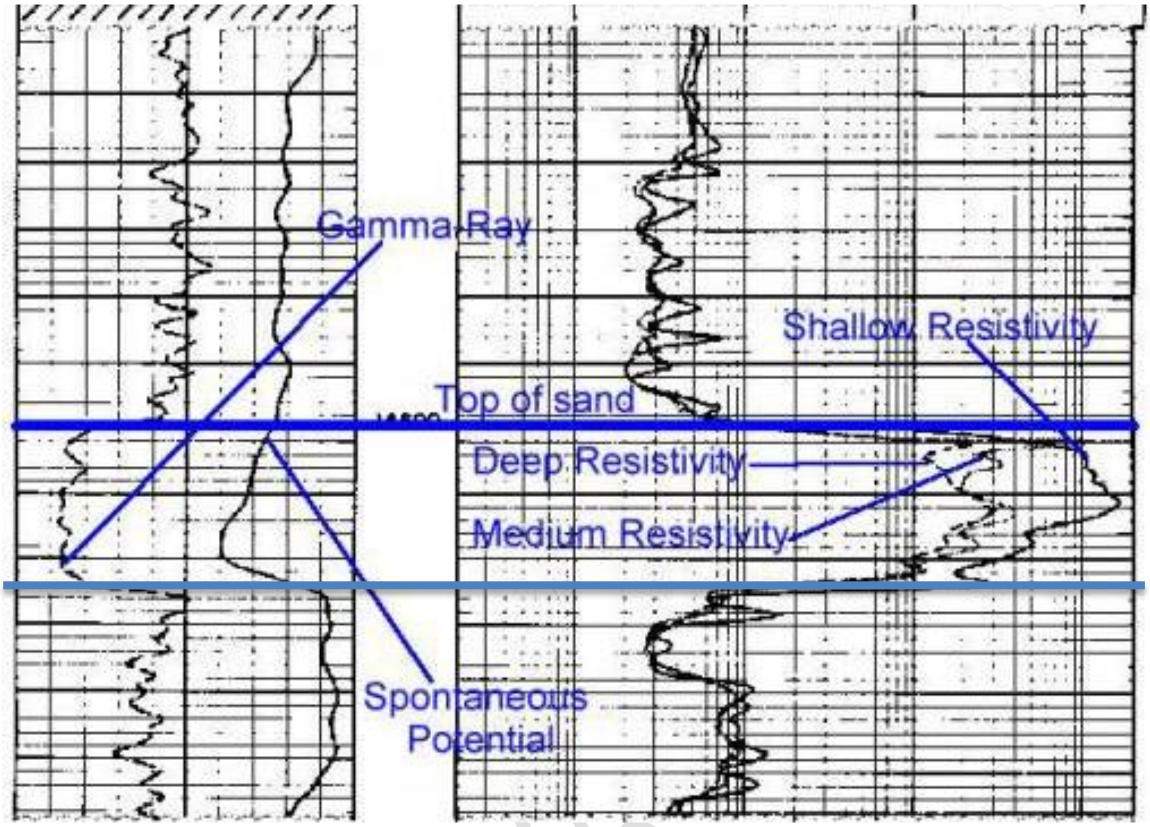
○ Example of GR Log



GR is high in shale/ clay formation, because shale/clay is more radioactive than sand or carbonate (high concentrations of radioactive elements in shale / clay)

GR is low in sand or carbonate formation because low concentrations of radioactive elements in sand or carbonate formation.

○ GR Log Correlations with Other Logs



Identification hydrocarbon reservoir

Low GR

Low SP

high resistivity

large separation between shallow, medium, & deep resistivity

○ Uses of GR Log

1) Shale/ Clay Volume Calculations **(**Quantitative use**).**
2) Shale / Clay Zone Identification (Qualitative use).
3) Well to Well Correlation / Log tops, stratigraphic correlations.
4) Net thickness to gross thickness estimation (NET PAY).
5) Lithology indicator. (shaly sand evaluation – effective porosity)

1) Shale Volume(Content) Estimating

- The GR log measurement obtained from the formation is often used to calculate a shale/clay volume since naturally radioactive elements tend to have greater concentrations in shale/clay than in clean sandstones.

✓ **Clay** : Clay is very complex set of minerals. It is made up of very small individual grains which can only be seen by electron microscope.

✓ **Shale :** it is a mixture of clay and silt. Shale may have good porosity, but it's permeability is zero.

- The presence of shale in a reservoir can cause erroneous values for water saturation and porosity derived from logs. These erroneous values are not limited to sandstone but also occur in limestone and dolomites.
- Presence of shale in a formation lead to;
  - ✓ Porosity logs (sonic. density. and neutron) will record too high a porosity.
  - ✓ Resistivity log record too low resistivity.
- The most significant effect of shale in a formation is to reduce the resistivity contrast between hydrocarbon and water zone.
- Hilchie (1978) suggests that for shale to significantly affect log-derived water saturations (i.e. water saturation from Archie equation), shale content must be greater than 10 to 15 %.
- The first step in shaly sand analysis is to determine the volume of shale from a gamma ray log.
- After the volume of shale (V_h) is determined, it can then be used to correct the porosity log for shale effect.
- Remember that all shaly sandstone formulas reduce the water saturation value from the value that would be calculated if shale effect was ignored. However, this lowering of water saturation can be a problem in log evaluation, because. *if* an *engineer overestimates shale content,* a water-*bearing zone may calculate like a hydrocarbon zone.*

- Shale volume is the bulk volume of shale (exactly the volume of silt, dry clay, and bound water) to the rock bulk volume.
- Calculation of the ***gamma ray index*** is the first step needed to determine the volume of shale from a gamma ray log.
- The ***gamma ray index IGR*** is calculated from the gamma ray log data using the relationship;

$$I_{GR} = \frac{GR_{log} - GR_{min}}{GR_{max} - GR_{min}} \qquad (1)$$

where:

IGR = the gamma ray index

$GR_{\log}$ = the gamma ray reading at the depth of interest

$GR_{\min}$ = the minimum gamma ray reading. (Usually the mean minimum through a clean sandstone formation.)

$GR_{\max}$ = the maximum gamma ray reading. (Usually the mean maximum through a shale or clay formation).

The relationship between gamma ray magnitude and shale content may be linear or non-linear.

1. Linear Gamma Ray - clay volume relationship:

$$V_{sh} = I_{GR} = \frac{GR_{log} - GR_{min}}{GR_{max} - GR_{min}} \qquad (2)$$

2. Non-linear Gamma Ray - clay volume relationships:

(a) Larionov [for *older rocks* /**cretaceous**(consolidated) rocks] use;

$$V_{sh} = 0.33(2^{2xI_{GR}} - 1) \qquad (3)$$

(b) Larionov **[for tertiary** (unconsolidated) rocks] use;

$$V_{sh} = 0.083(2^{3.7x\, I_{GR}} - 1) \qquad (4)$$

All the above relationships are empirical. If there is no enough information known, the linear relationship is probably the best choice, although it is the most pessimistic. All the non-linear relationships predict less clay volume than the linear response, in varying amounts depending on the GR reading and the clean and shale values.

Example: Example of gamma ray log with density and neutron logs. This example illustrates the curves and scales of a gama ray log, and is also used to pick values to estimate the value of (Vsh) from (IGR).

In **track-1**, the gamma ray log is the only one represented on this track. Note that the GR scale increases from left-to-right, and ranges from (0-150 API).

At the depth of (13570 ft), pick the gamma ray reading of the formation. It is (28 API) gamma ray units (the scale measures in increments of (15 API) units; slightly less than two units from (0 API)).

Next, pick the minimum gamma ray reading from the log which is (GR_{min}, clean =15 API gamma ray unit) at the depth of (13590 ft). and the maximum gamma ray reading from the log is (GR_{max}, shale = 128 API gamma ray units) at the depth of (13720 ft).

Given Data:

From the figure: GR_{log}=28

GR_{min}, clean = 15

GR_{max}, shale = 128

Calculate the shale volume?

Solution:

$$I_{GR} = \frac{GR_{log} - GR_{min}}{GR_{max} - GR_{min}} = \frac{28 - 15}{128 - 15} = 0.115$$

Linear

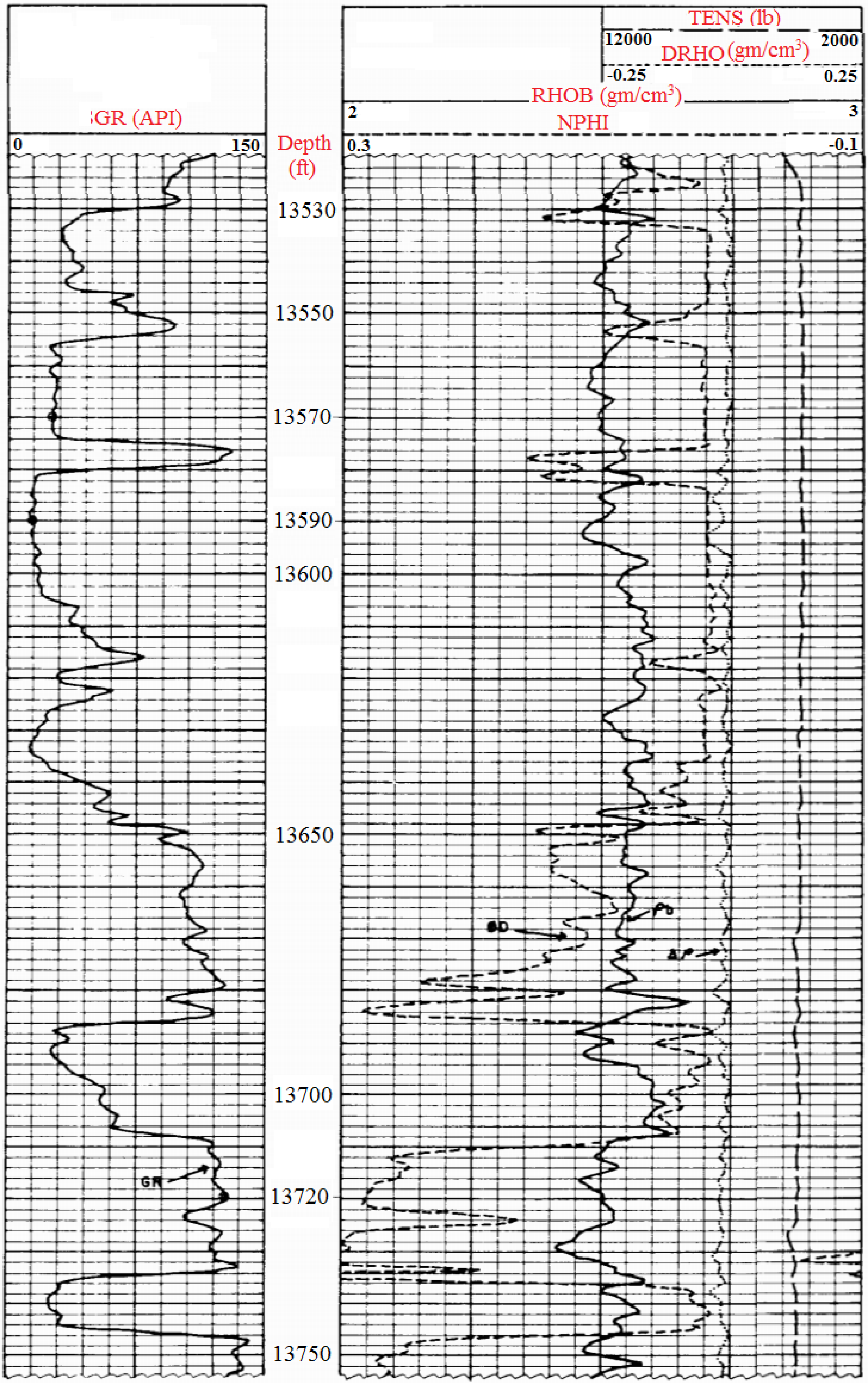
$$V_{sh} = I_{GR} = 0.115 \; or \; 11.5\%$$

Non-Linear (*older rocks***)**

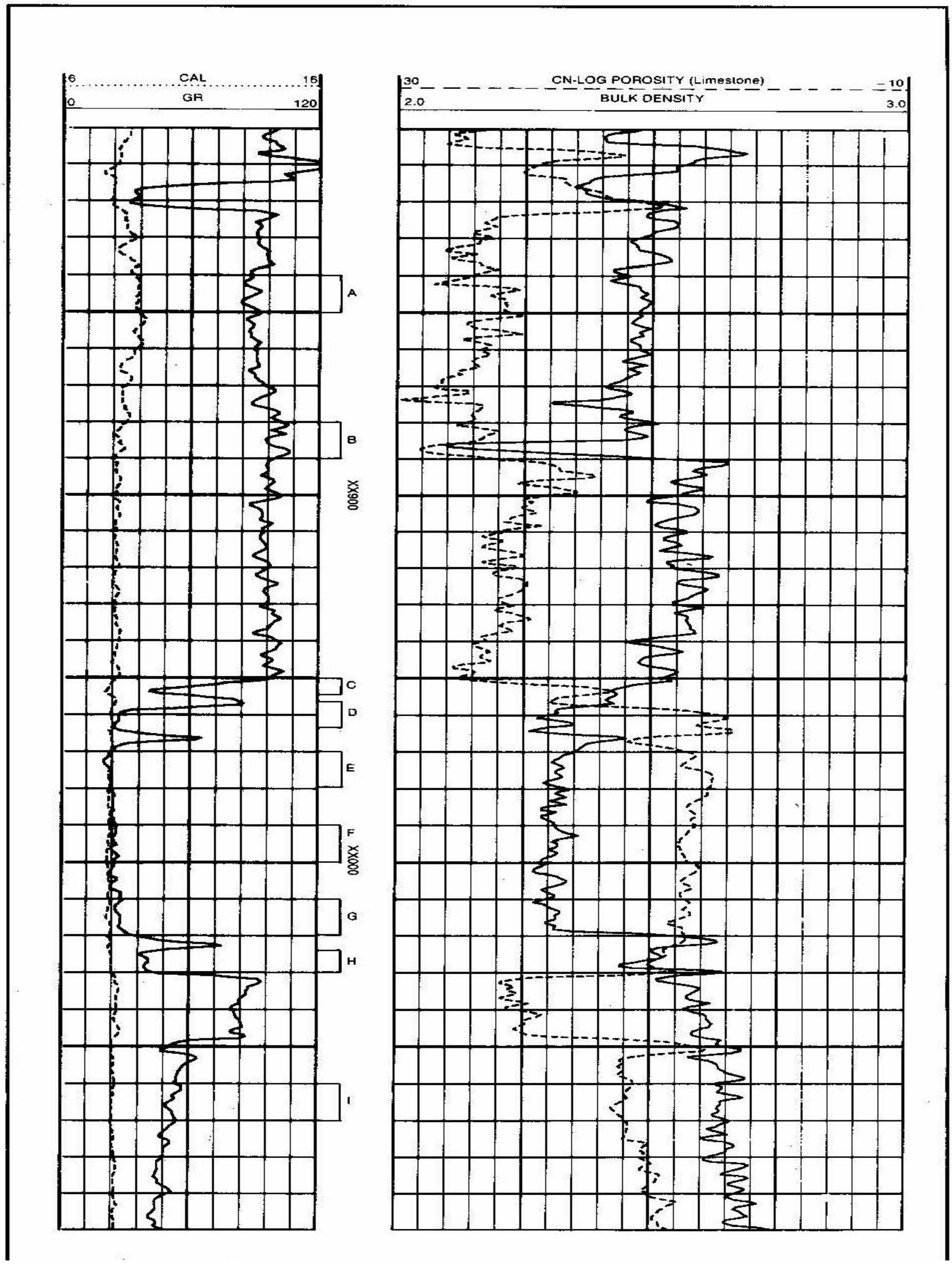
$$V_{sh} = 0.33(2^{2xI_{GR}} - 1) = 0.33(2^{2*0.115} - 1) = 0.057 \; or \; 5.7\%$$

Non-Linear (tertiary rocks**)**

$$V_{sh} = 0.083(2^{3.7x\, I_{GR}} - 1) = 0.083(2^{3.7*0.115} - 1)$$
$$= 0.0284 \; or \; 2.84\%$$

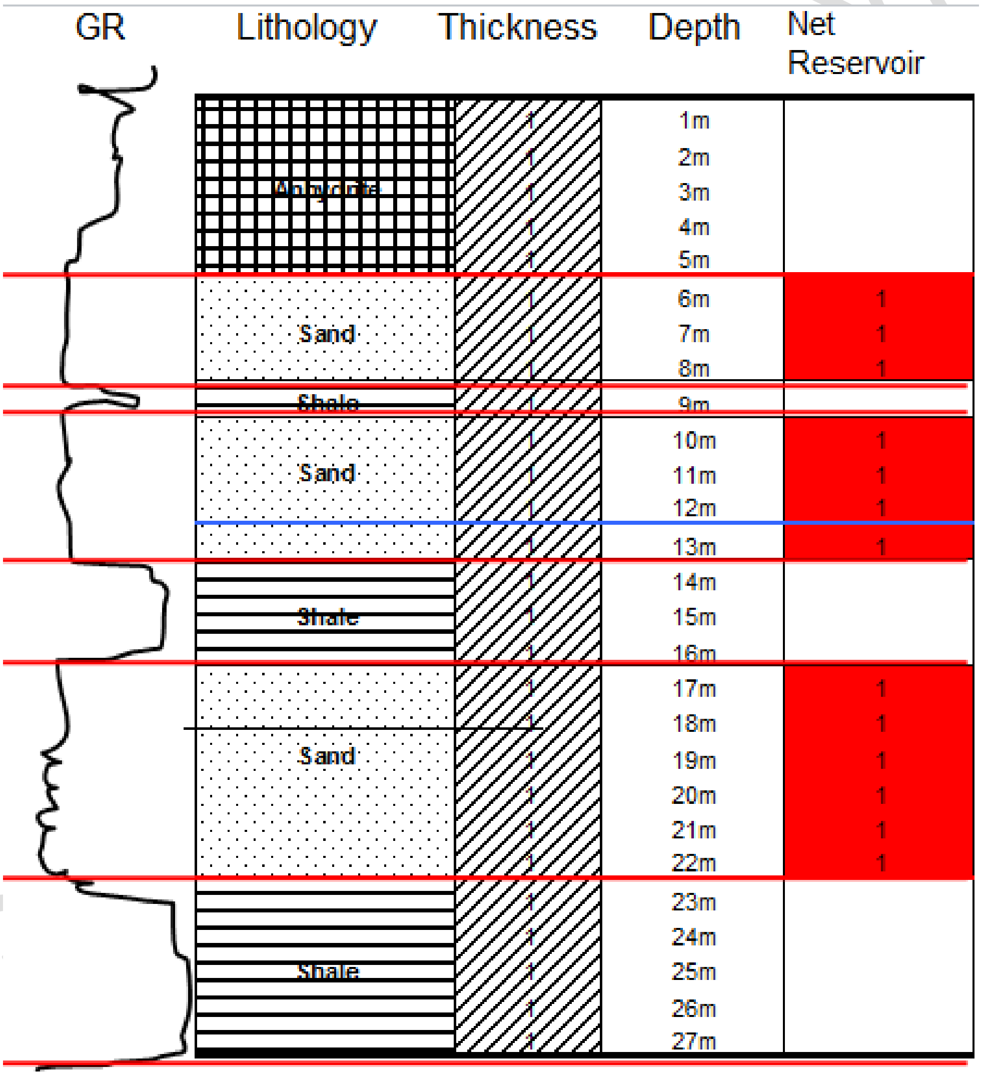

GR (API)
0
150
Depth
(ft)
13530
13550
13570
13590
13600
13650
13700
13720
13750
GR
TENS (lb)
12000
2000
DRHO (gm/cm^3)
-0.25
0.25
RHOB (gm/cm^3)
2
3
NPHI
0.3
-0.1
ΦD
ρb
Δρ

H.W; A Tertiary sand and shale sequence is represented by the interval shown on the accompanying log. Determine **Vsh** for the indicated zones.



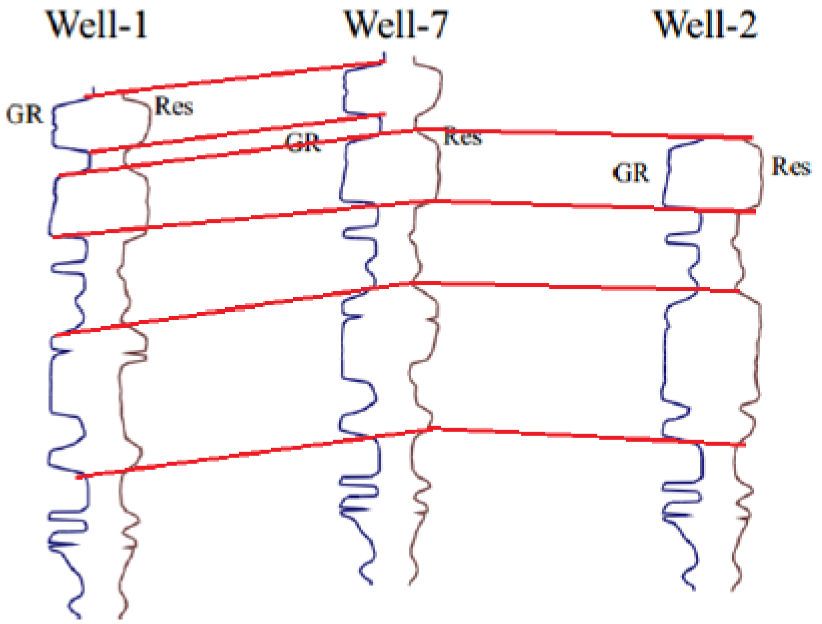
2) Net-To-Gross Calculation

- The ***net pay thickness*** is the clean, permeable, hydrocarbon-containing zones, from which hydrocarbons can be produced at economic rates.
- The **gross thickness,** is the total thickness of the reservoir interval, that contains *produced* and *non-produced hydrocarbon* zones.
- The ***net to gross ratio*** is thickness of net pay divided by the gross thickness, and is often <u>used to represent the quality of a reservoir zone</u>.



3) Well to Well Correlation

Total gamma ray log is used for correlation between wells were being logged for determining the lateral extension of subsurface geologic cross sections. Because there is a similarity between log readings.



Because of drilling operations is too expensive, so that relatively fewer wells will be drilled, and hence the maximum data must be squeezed out of each well regardless almost of the cost. If there are no hydrocarbon shows, the well data will still be very useful for correlation with other wells that do show hydrocarbons, will help to constrain the extent of neighboring reservoirs, as well as adding to the information about the general geological structure of the area.

○ GR Log Corrections For Borehole Effects

- Borehole conditions that affects GR log are;

1) Borehole size.
2) Mud weight (mud density).
3) Tool Eccentricity.

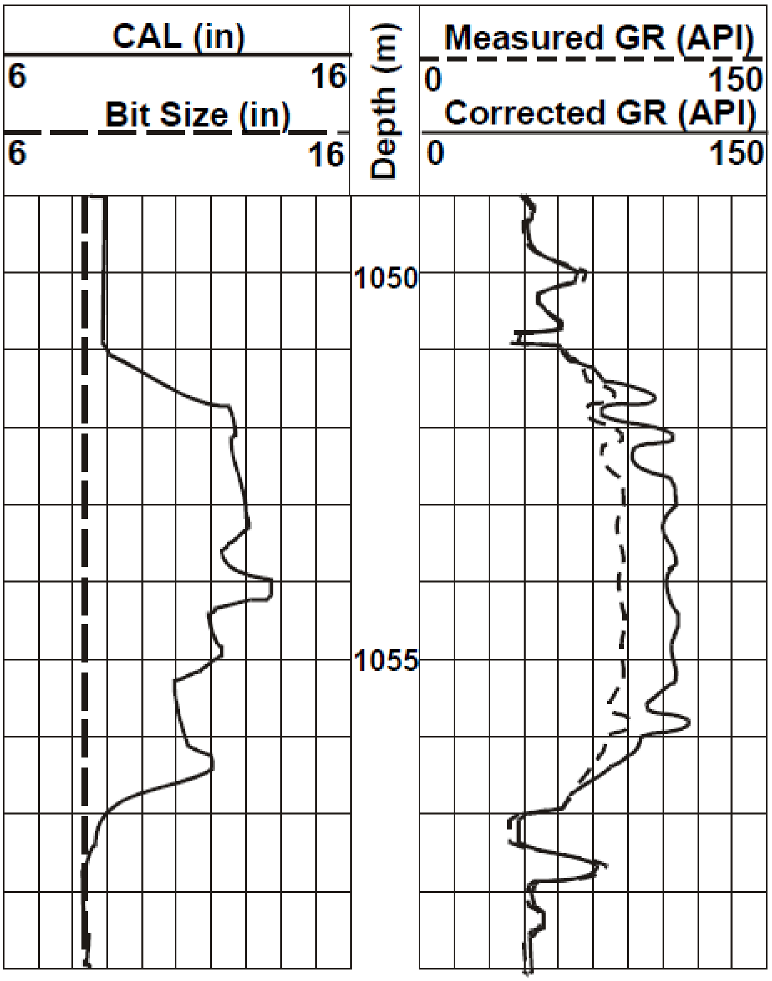
✓ Large holes **(caving)**, and **heavy muds** *reduce* the gamma ray log response.

✓ In caved intervals there is more drilling mud between the formation and the gamma ray detector which is reduce the gamma rays response, hence, the log is underestimated, as shown in Fig. below.

✓ The denser mud, increase the gamma rays scattering in the mud.

✓ Air drilling increases the log response.

✓ KCl mud increase GR log response, because of potassium containing.



Use **chart GR-1** to correct the GR log for mud density and hole size.

H.W: From the following given data, find the corrected GR.;

1. GR = 36 API units (gAPI), dh = 12 in., mud weight = 12 lb/gal, tool OD = $3\frac{3}{8}$ in., and the tool is centered. (**ANS; 58 API**)
2. Borehole diameter = 6.0 in., tool OD = $3\frac{3}{8}$ in., the tool is centered, mud weight = 12 lbm/gal, measured, GR = 36 gAPI. (**ANS; 45.4 API**)

- **Log Correction Steps Without Using Charts**

$$N'_{GR} = N_{GR} \times A \times 10^{x}$$

$$N'_{GR} = \text{Corrected Gamma Ray Response (API Units)}$$

$$N_{GR} = \text{Measured Gamma Ray Response (API Units)}$$

Where :

$$A = \begin{cases} 1 \text{ for } 3\frac{5}{8} \text{ in. diameter instrument} \\ 1.05 \text{ for } 3\frac{7}{8} \text{ in. diameter instrument} \\ 0.95 \text{ for 2 in. diameter instrument} \\ 0.92 \text{ for } 1\frac{11}{16} \text{ in. diameter instrument} \end{cases}$$

$$x = \left(\frac{d_{bh} - d_{inst}}{k}\right)\left[0.047(\rho_m - 8) + 0.38\right] - 0.1548$$

$$d_{bh} = \text{Borehole diameter (inches)}$$

$$d_{inst} = \text{Instrument diameter (inches)}$$

$$\rho_m = \text{Muddensity (lb/gal)}$$

$$k = \begin{cases} 16, \text{ instrument centered} \\ 20, \text{ instrument uncentered} \end{cases}$$

H.W: From given data correct the GR log, then estimate the shale volume.

Depth	=	4300 ft	GR_{log}	=	36 API
Caliper Log	=	8.799 inch	Mud Density	=	9.878 lb/gal
GR_{min}	=	6 API	GR_{max}	=	62 API
$d_{instument}$	=	3.625 inch	Instrument Uncentered		

Gamma Ray—Wireline

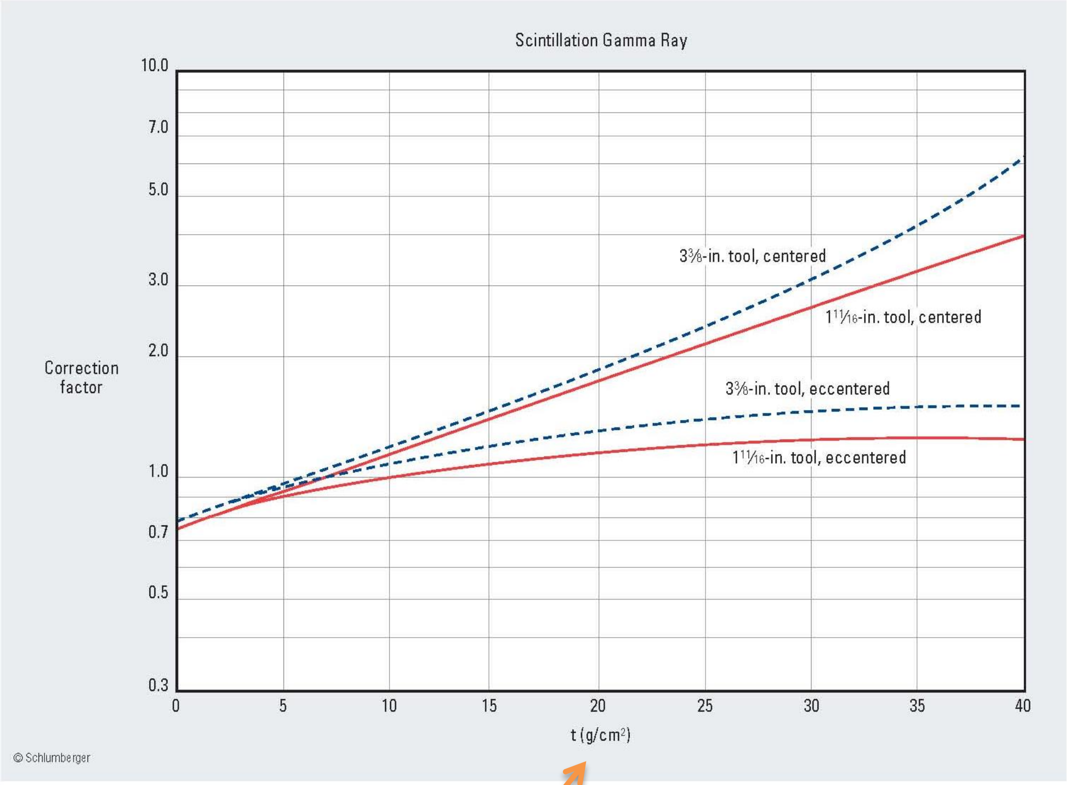
Schlumberger

Scintillation Gamma Ray—3⅜- and 1¹¹⁄₁₆-in. Tools

Gamma Ray Correction for Hole Size and Barite Mud Weight

GR–1
(former GR-1)

GR



$$t=\frac{W_{mud}}{8.345}\left(\frac{2.54\left(d_h\right)}{2}-\frac{2.54\left(d_{sonde}\right)}{2}\right), \quad g/cm^2$$

Covert to gm/cm^3

Covert to cm

Example: Given: GR = 36 API units (gAPI), dh = 12 in. mud weight =12 lbm/gal, tool OD = 3 ⅜ in., and the tool is centered. Find: Corrected GR value.
Sol:

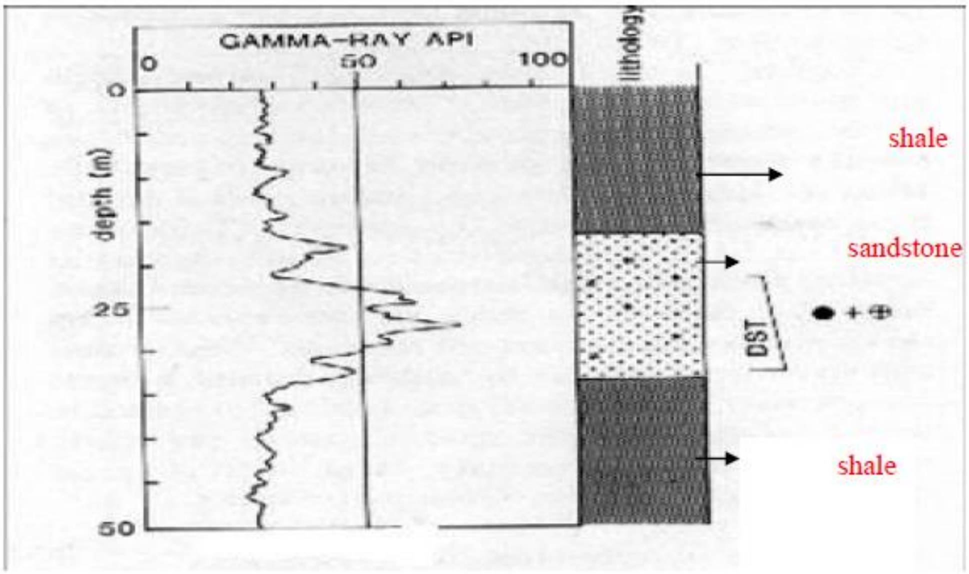
$$t=\frac{12}{8.345}\left(\frac{2.54\left(12\right)}{2}-\frac{2.54\left(3.375\right)}{2}\right)=15.8\ g/cm^2.$$

Enter the chart at 15.8 on the x-axis and move upward to intersect the 3⅜ in. centered curve. The corresponding correction factor is 1.6.

Grcorr = 1.6 × 36 gAPI = 58 gAPI

○ Spectral Gamma Ray (SGR) Log

- The total gamma ray log in clean sands can sometimes produce high gamma ray readings which would confuse them with shales.
- Such sandstones include radioactive contaminant such as feldspars, micas , volcanic ash, granite wash **or** the formation waters contain dissolved radioactive salts.

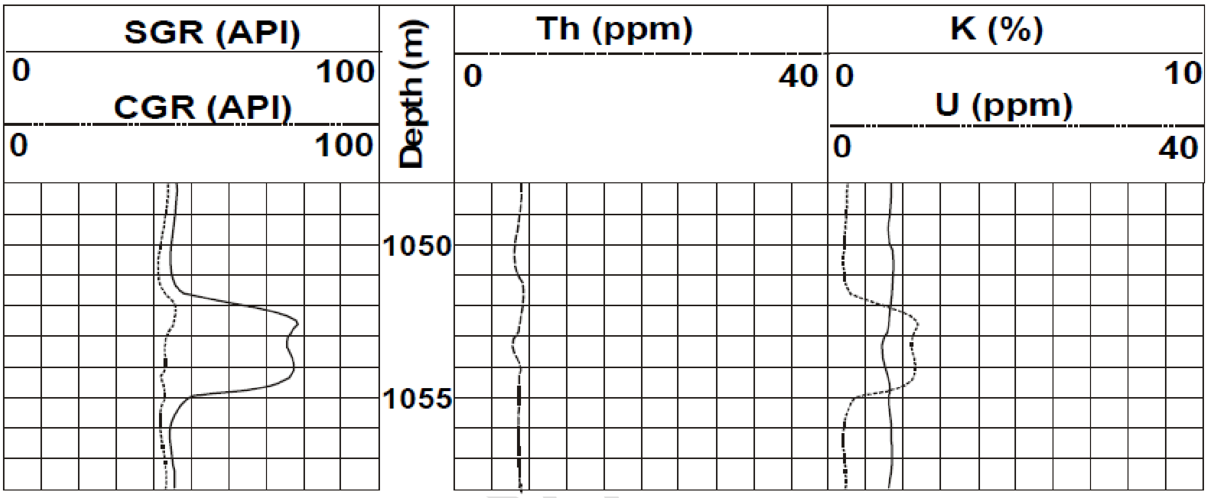


- The extra information supplied by the *spectral gamma ray* tool can, in most cases, help recognize these situations, and give us information about the composition and possible lithology of the formation.
- The ***spectral gamma ray* SGR log** measures the natural gamma radiation emanating from the formations separated into different types of radio-isotopic sources : (1) thorium, (2) potassium, and (3) uranium.
- The format for reporting the spectral gamma ray data is more complex than for the total gamma ray log because it contains much more detailed information.
  - **Track 1** is used to record;

✓ The spectral gamma ray log (*SGR*), which is a sum of all the radiation contributions.

✓ the computed gamma ray log (*CGR*), which is the sum of the **potassium and thorium** responses, leaving out the contribution from uranium.

- **Tracks 2 and 3** are used to record the calculated abundances associated with the radiation from the individual contributions from each of K^{40}, U^{238}, and Th^{232}.
- It should be noted that potassium is reported as a percentage, while U^{238} and Th^{232} are reported in parts per million (ppm).
- The spectral gamma ray log (*SGR*) is also called *Natural Gamma Ray Spectrometry Tool* (NGS).



○ Uses of the Spectral Gamma Ray Log

Uses	Knowing
Lithology identification	Radioactive content for the minerals
Identification of organic material and source rocks.	Uranium content of organic material
Fracture identification.	Uranium contribution to radioactivity
Correction of the GR for clay content evaluation.	
Identification of clay minerals .	Th, U, K content of individual clay mineral.
Study of depositional environments.	Th/K content of shale depositional environments
Volume of shale determination.	Th (max.) and Th(min) for pure shale

○ SGR Log Interpretation

- The three radioactive elements measured by the SGR log occur in different parts of the reservoir. If we know the lithology, we can obtain further information.

A) In Carbonates:

U - indicates phosphates, organic matter.
Th - indicates clay content.
K - indicates clay content, radioactive evaporates.

B) In Sandstones:

Th - indicates clay content, heavy minerals.
K - indicates micas, micaceous clays and feldspars.

C) In Shales:

U - in shale, suggest a source rock.
Th - indicates the amount of detrital material or degree of shaliness.
K - indicates clay type and mica.

- We can calculate the **shale volume** from the individual readings of the spectral gamma ray log (K, Th, and U), and from the computed gamma ray log (*CGR*).

$$V_{sh}\big|_{CGR} = \frac{CGR - CGR_{\min}}{CGR_{\max} - CGR_{\min}} \quad \ldots\ldots\ldots\ldots(5)$$

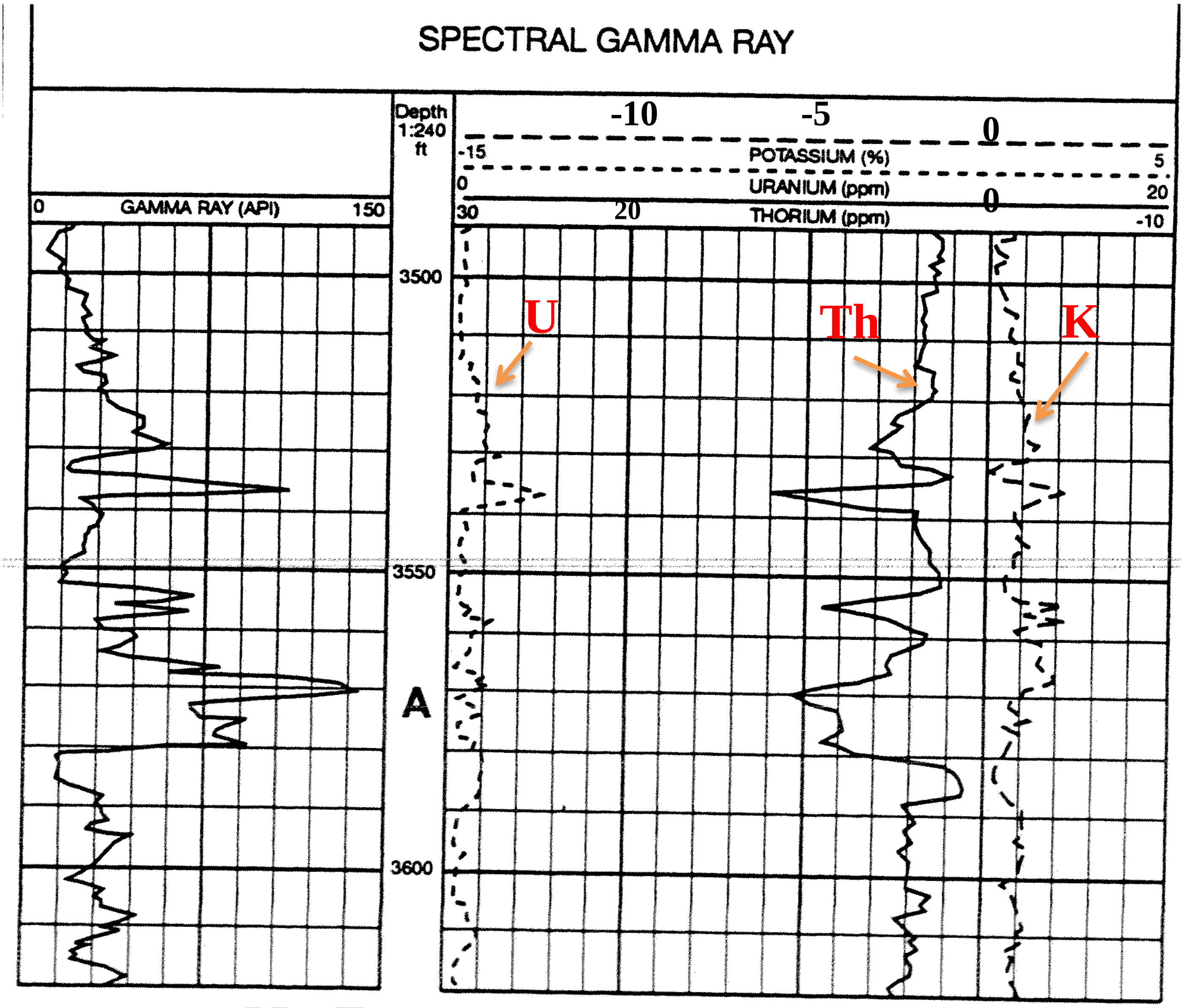
$$V_{sh}\big|_{K} = \frac{K - K_{\min}}{K_{\max} - K_{\min}} \quad \ldots\ldots\ldots\ldots(6)$$

$$V_{sh}\big|_{Th} = \frac{Th - Th_{\min}}{Th_{\max} - Th_{\min}} \quad \ldots\ldots\ldots\ldots(7)$$

$$V_{sh}\big|_{U} = \frac{U - U_{\min}}{U_{\max} - U_{\min}} \quad \ldots\ldots\ldots\ldots(8)$$

Note
Equation (5) is better shale indicators than Eq. (1), since the random contribution of U is eliminated. Equation (8), is almost never used.

○ Spectral Gamma Logs: Example



	Min	Max
GR	15	139
Th	1.2	11.5
K	0.22	1.9
U	0.21	2.5

- In clay-bearing carbonate rocks high total gamma readings are not related only to the clay fraction, but are also due to the presence of uranium series minerals of organic origin.
- High total gamma ray readings are therefore not a reliable indicator of the shaliness of a carbonate.
- If the spectral gamma ray log indicates the presence of K and Th together with the U, it may be said that the K and Th contributions are associated with the clay content of the shaly carbonate, while the U is associated with some organic source.
- Thus, when calculating the shaliness of a carbonate, it is better to use the *CGR* (Eq. 5).
- Table below show interpretation of spectral gamma ray data in carbonates.

K	**Th**	**U**	**Explanation**
Low	Low	Low	Pure carbonate, no organic matter
Low	Low	High	Pure carbonate, organic matter
High	High	Low	Shaly carbonate, no organic matter
High	High	High	Shaly carbonate, organic matter
Low	High	Low	Not a carbonate, or shaly carbonate rare low K high Th clay minerals
Low	High	High	Not a carbonate, or shaly carbonate rare low K high Th clay minerals