Tishk International University
Engineering Faculty
Petroleum and Mining Department

Well Logging I

Lecture 3: Gamma Ray Logging

3rd Grade - Fall Semester 2021-2022

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- Radioactivity Theory
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- Depth of Investigation
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Spectral Gamma Ray Log

- Spectral Gamma Ray Log (NGS)
- The main purposes of Spectral GR Log
- Log Presentation
- Occurrence of Radioactive Elements

Gamma Ray Logs

Radioactivity Theory:

Radioactivity is a fundamental property of all matter.

The atoms of all elements have a ***nucleus*** which contains ***protons*****(+v),*****neutrons*** *and* ***electrons*** **(-v).**

The number of its **P**rotons = ***atomic number*****(Z)**.

Protons **+N**eutrons is **=**the ***atomic mass number*** **(A**).

No of **e**= **p ,** and their charge is balance.

The number of **p** and **e** for a given element is characteristic of that element, the number of neutrons is not.

An element may have several ***isotopes*** which are atoms with different numbers of **neutrons** in their nucleus.

Thus, any given atom of an element will have a fixed ***atomic number*** **Z**,

The atomic ***mass number*** **A** depends upon which isotope it is.

Gamma Ray Logs

Most natural materials are a mixture of different isotopes.

Each isotope of each element is given a code $_{Z}\mathbf{X}^{A}$, where **X** is the elemental code.

For example, carbon has an atomic number Z=6, but 7 isotopes containing between 4 and 10 neutrons.

These are $_{6}\mathbf{C}^{10}$, $_{6}\mathbf{C}^{11}$,$_{6}\mathbf{C}^{12}$,$_{6}\mathbf{C}^{13}$,$_{6}\mathbf{C}^{14}$, $_{6}\mathbf{C}^{15}$, **and** $_{6}\mathbf{C}^{16}$. Carbon-12($_{6}\mathbf{C}^{12}$),is the most common isotope, and it is stable.

Most of the other isotopes are not stable energetically, and decay to more stable elements by various processes whereby they lose energy by expelling particles or photons.

Carbon-14 ($_{6}\mathbf{C}^{14}$), is one of these, and its decay process can be used to date archaeological remains

There are four main methods whereby an unstable isotope can gain stability by losing energy: These are: Emission of **α**, **β+, β-,**and **γ**

Gamma Ray Logs

Emission of a gamma rays (**γ**) which are high energy photons (electro-magnetic waves) and have no mass and carry no charge.

Most isotopes found naturally in rocks are either stable, or present in insignificant amounts, or generate insignificant amounts of radiation.

But There are, a few which are **significant**, These are:

The potassium isotope ${}_{19}K^{40}$(0.0199) per/stables (${}_{19}K^{39}$and ${}_{19}K^{41}$).

The Thorium series isotopes. (${}_{90}Th^{232}$All 100%)

The Uranium-Radium series isotopes. (${}_{92}U^{238}$99.27%, ${}_{92}U^{235}$0.72%, ${}_{92}U^{234}$0.0057%)

The three gamma ray sources also produce different intensities of radiation per gram per second.

- The **U-Ra** series produces 26000photons per gram per second,
- The **Th** series produces 12000photons/g/s,
- and **19K40**produces 3photons/g/s.

One might think that the potassium would be insignificant. However, the potassium is much more abundant than the isotopes in the other two series, which makes its contribution to the overall radioactivity of a formation significant. Potassium is common in most clays and some evaporites

Gamma Ray Logs

Gamma radiation from common minerals and lithologies (after Pirson, 1963).

Mineral or Lithology	Composition	Gamma Radiation (API Units)
Pure Mineral		
Calcite	$CaCO_3$	0
Dolomite	$CaMg(CO_3)_2$	0
Quartz	SiO_2	0
Lithology		
Limestone	-	5-10
Dolomite	-	10-20
Sandstone	-	10-30
Shale	-	80-140
Evaporites		
Halite	$NaCl$	0
Anhydrite	$CaSO_4$	0
Gypsum	$CaSO_4(H_2O)_2$	0
Sylvite	KCl	500
Carnalite	$KCl\ MgCl_2(H_2O)_6$	220
Langbeinite	$K_2SO_4(MgSO_4)_2$	290
Polyhalite	$K_2SO_4MgSO_4(CaSO_4)_2(H_2O)_2$	200
Kainite	$MgSO_4KCl(H_2O)_3$	245
Others		
Sulphur	S	0
Lignite	$CH_{0.849}N_{0.015}O_{0.221}$	0
Anthracite	$CH_{0.358}N_{0.009}O_{0.022}$	0
Micas	-	200-350

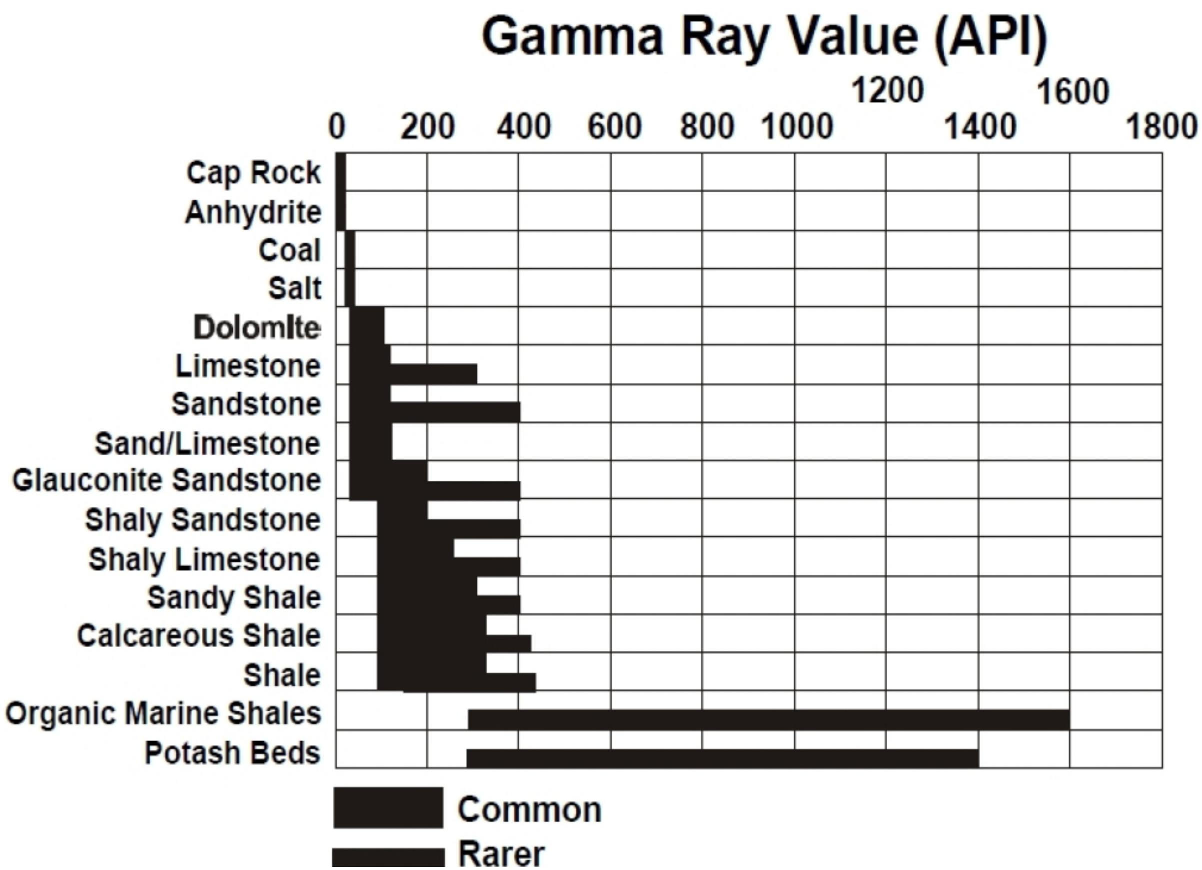
Gamma Ray Logs

The table below shows the range of gamma ray measurements opposite the various rocks.

Clean sand	**20~30 API**
Shaly sand	**30~50 API**
Shale	**>70 API**
Limestone	**15~20 API**
Dolomite	**16~20 API**
Coal	**13~15 API**
Anhydrite	**<10 API**
Volcanic	**> 130 API**

Gamma Ray Logs

Gamma ray values from common lithologies.



Gamma Ray Logs

Gamma Ray (GR) logs measure the natural radio activity in formation (rocks), used for identifying lithologies sand for correlating zones.

Shale free sandstone and carbonates have low concentrations of radioactive materials and give low gamma ray readings.

As shale content increases, the gamma ray log response increase, GR log reflects shale or clay content.

Typical modern gamma ray tools

Name	Symbol	Company
Gamma ray log	GR	all
Spectralog	SL	Western Atlas
Natural gamma ray spectrometry	NGS	Schlumberger
Spectral gamma ray	SGR, CSNG	Halliburton
Spectral gamma sonde	SGS	B.P.B.

Gamma Ray Log Presentation

The total gamma ray log is usually recorded in track 1 with the caliper log, bit size and SP log.

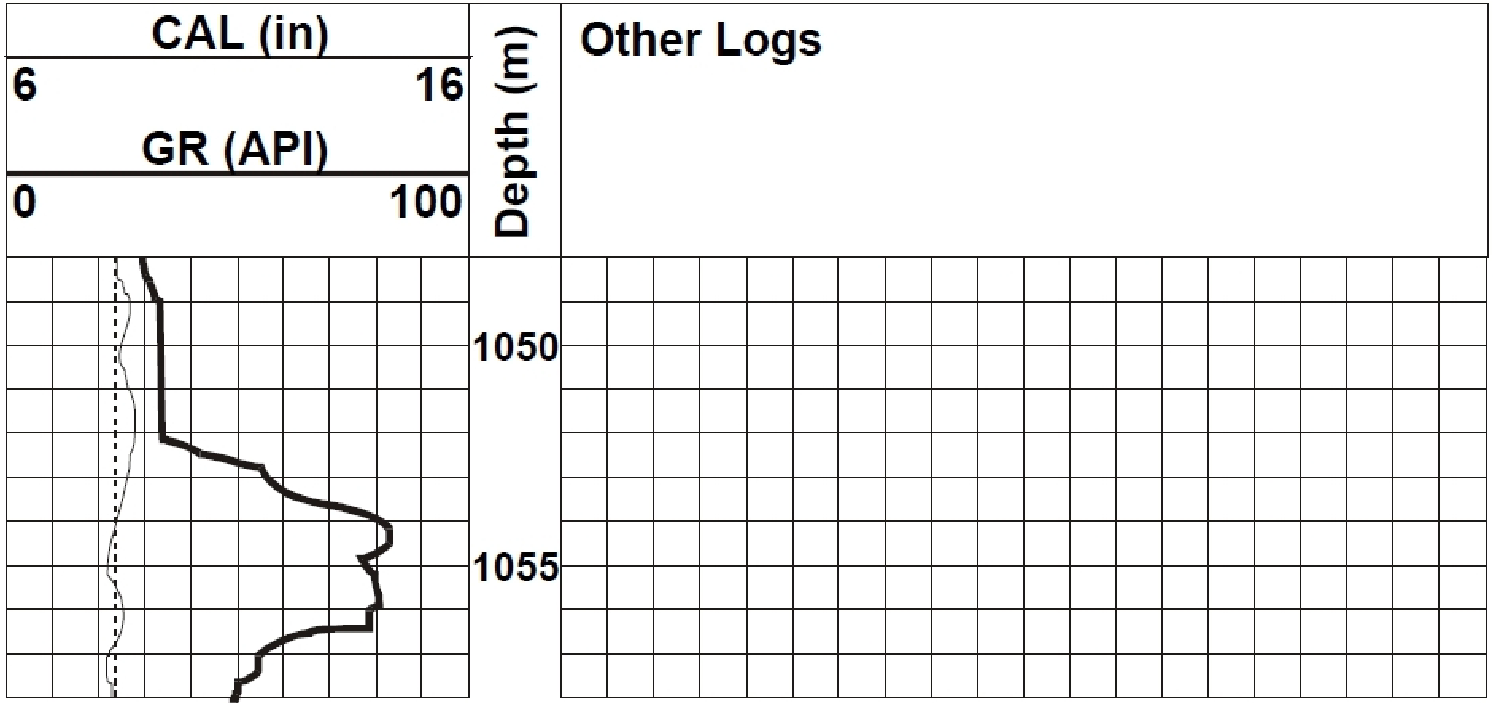
In this case, the other tracks most often include resistivity, density, neutron or sonic logs (Fig).

Although the API scale goes from 0 to 200 API, it is more common to see 0 to 100 API and 0 to 150 API used in log presentations, as data greater than 150 API is not common, and can always be handled by the use of wrap-around.

When gamma ray logging is carried out through the cement casing, a scale of 0 to 50 API is most often used, as a result of the lower values measured due to the attenuation of the gamma count rate by the casing.

Natural Gamma Ray Log (GR) is only recording total GR count rates and does not sort the GR pulses according to its energy.

Gamma Ray Log Presentation



Depth of Investigation

The gamma rays are attenuated by Compton scattering by all materials between the atom that emitted the gamma ray and the detector, which includes the rock itself and the drilling mud.

The degree of attenuation depends upon the number density of atoms in the material, and this is related to the density of the material.

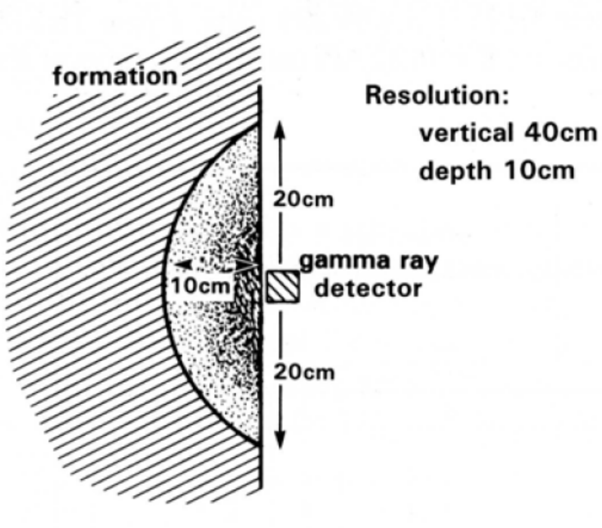
A maximum depth of investigation for the tool that depends upon formation and mud density

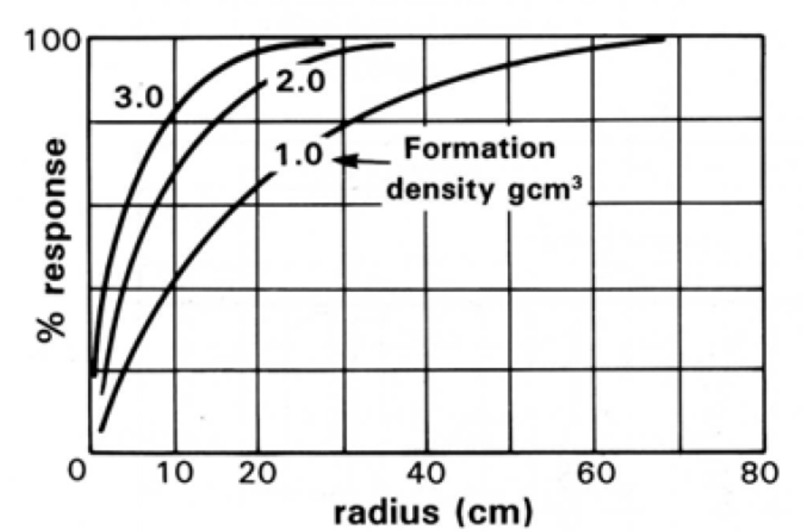
Approximately 50% of the gamma ray signal comes from within 18 cm, increasing to 75% from within 30 cm (1 foot).

Depth of Investigation

- Depth of investigation of GR tool. Average volume from which radiations are detected.

- Depth of investigation shown to be dependent on formation density





Vertical Resolution

There are three factors governing the vertical resolution:

The size of the detector, which is quite small (about 5-10 cm diameter).

The effect of the time constant; for conventional logging, with the product of logging speed and time constant set to 1 foot, the contribution to degradation in the vertical resolution from his cause is 1 foot.

The hemispherical zone of sensitivity of the sensor. Hence, the vertical resolution of the tool is just over 3 foot (90 cm). This is quite a high vertical resolution for an open-hole tool, and so the gamma ray tool is good at defining thin beds, for fine correlation, and for depth matching between logging runs.

Unwanted Effects on Gamma Ray Logs

Gamma ray logs are subject to several perturbing effects including:

- Sonde position in the hole (Centering/ Eccentering)
- Hole size;
- Mud weight;
- Casing size and weight; and
- Cement thickness.

Uses of the Total Gamma Ray Log

Determination of the general Lithology

Determination of Shale Content

Depth Matching

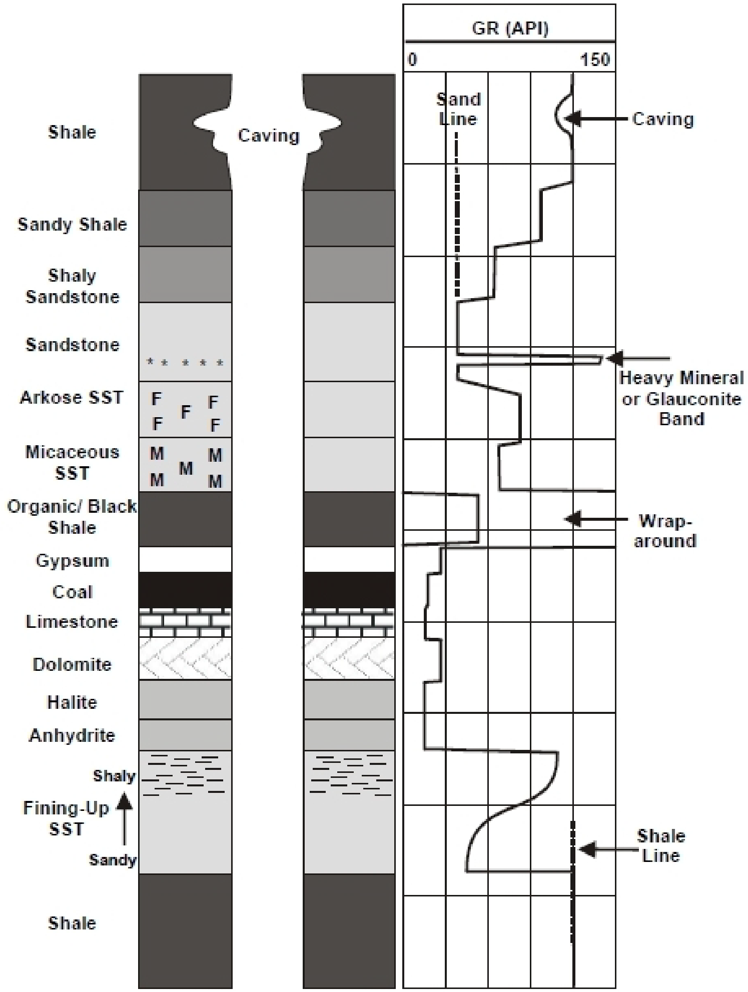
Cased Hole Correlations

Recognition of Radioactive and non-Radioactive Mineral Deposits

Facies and Depositional Environment Analysis

Uses of the Total Gamma Ray Log

1-Determination of the general Lithology



Uses of the Total Gamma Ray Log

2-Determination of Shale Content

- **IGR =** $$\frac{GR\log - GR\min}{GR\max - GR\min}$$
- Where:
- **IGR** = Gamma Ray Index (dimensionless)
- **GRlog** = Gamma Ray Reading of Formation
- **GRmin** = Minimum Gamma Ray (clean sand or carbonate)
- **GRmax** = Maximum Gamma Ray (shale)

Uses of the Total Gamma Ray Log

$$V_{Shale} = \frac{I_{GR}}{3.0 - 2.0 \cdot I_{GR}}$$

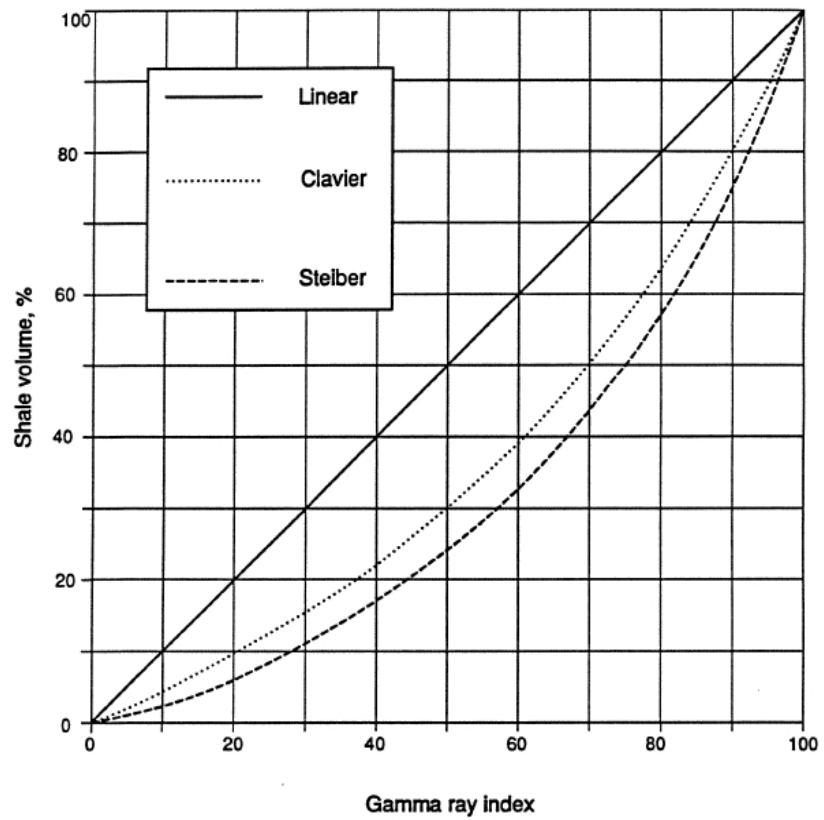
Clavier: $V_{Shale} = 1.7 \left[3.38 \cdot \left(I_{GR} + 0.7 \right)^2 \right]^{0.5}$

Larionov (Tertiary Rocks:

$$V_{Shale} = 0.083 \cdot \left(2^{3.7 \cdot I_{GR}} - 1\right)$$

Larionov (Older Rocks) :

$$V_{Shale} = 0.33 \cdot \left[\left(2^{2 \cdot I_{GR}}\right) - 1.0\right]$$



Uses of the Total Gamma Ray Log

3-Depth Matching

The gamma ray tool is run as part of almost every tool combination.

It has a high reliability and a high vertical resolution.

The tool will also show a useful decrease when opposite casing.

For all these reasons, the tools is commonly used to **match the depths** of data from a given depth interval made at different times with different tool combinations.

Uses of the Total Gamma Ray Log

4-Cased Hole Correlations

A different type of depth matching relates open hole measurements to cased hole and production logging measurements.

Clearly, we would want to match accurately the depths at which open-hole data are taken and the depths at which cased-hole or production logging data are taken.

The gamma ray log and the Casing Collar Locator allow this matching to be performed, ensuring that accurate depth control is maintained during cased-hole logging, and while perforating the correct depths.

Note that the gamma ray readings will be less in the cased holes due to the attenuation of gamma rays by the cement casing

Uses of the Total Gamma Ray Log

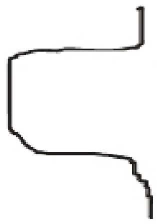
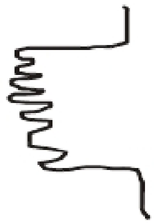
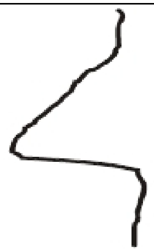
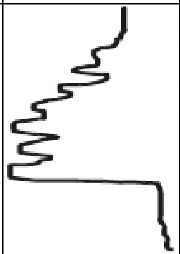
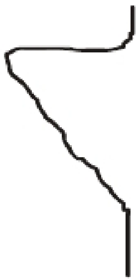
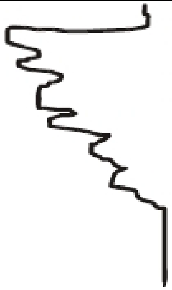
5-Recognition of Radioactive and non-Radioactive Mineral Deposits

Formations with extremely low natural radio activities are the non-radioactive evaporites (salt, anhydrite and gypsum), and coal beds.

While some extremely high radioactive bearing zone (rich of radioactive elements); rich heavy mineral rock beds, rich organic shale zones.

Uses of the Total Gamma Ray Log

6-Facies and Depositional Environment Analysis

Shape	Smooth	Environments	Serrated	Environments
Cylinder Represents uniform deposition.		Aeolian dunes Tidal sands Fluvial Channels		Deltaic distributaries Turbidite channels Proximal deep-sea fans
Bell Shape Fining upwards sequences.		Tidal sands Alluvial sands Braided streams Fluvial channels Point bars		Lacustrine sands Deltaic distributaries Turbidite channels Proximal deep-sea fans
Funnel Shape Coarsening upward sequences.		Barrier bars Beaches Crevasse splays		Distributary mouth bars Delta marine fringe Distal deep-sea fans

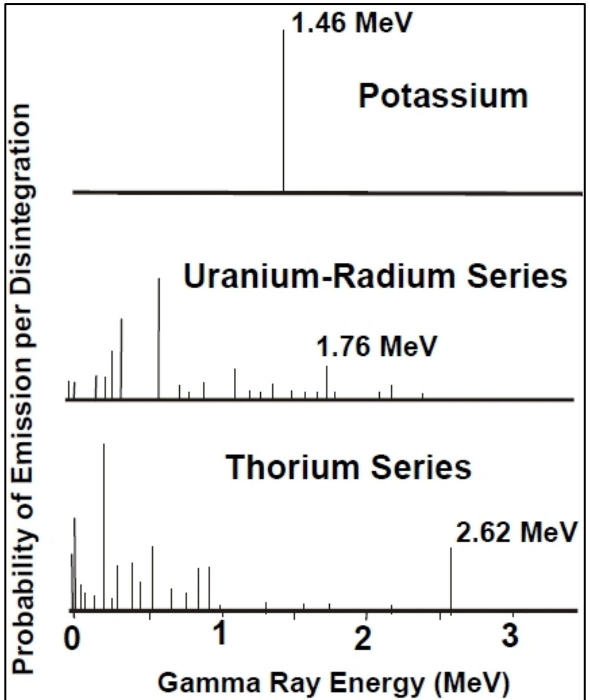
Spectral Gamma Ray Log

Spectral Gamma Ray Log, or **N**atural **G**amma Ray **S**pectrometry **(NGS)**

It records the Gamma Ray pulses in certain length of energy window, which can be used to detect each of Uranium, Thorium and Potassium count rates

The gamma ray log is record of a formation radioactivity emanates from naturally-occurring **U**, **Th** and **K**, that they emit photons with no mass and no charge but great energy.

Gamma ray emission energy spectra



Spectral Gamma Ray Log

The simple Gamma Ray log gives the radioactivity of three elements combined.

The spectral gamma ray shows the amount of each individual element contributing of its radioactivity.

Relative abundance of the earth's crust**:**

- **K**= 2.95%,
- **Th**=12 ppm
- **U**= 3 ppm

Potassium is the most abundant of the three in the rock, but its contribution in relative to its weight is small. (**3 photons/g/s**)

A small quantity of **Uranium** has a large effect on the overall radioactivity,.(**26000 photon/g/s**)

The main purposes of Spectral GR Log

Differentiate between shales and potassium salts

Calculate shale and clay mineral content

Detect arkosics and units (Study reservoir)

Recognize clay mineral types and map clay content

Identify clay depositional environments

Detrital: high thorium/low uranium ratios

Marine: low thorium/high uranium ratios

Correlate structural and stratigraphic features

Spectral Gamma Ray Log

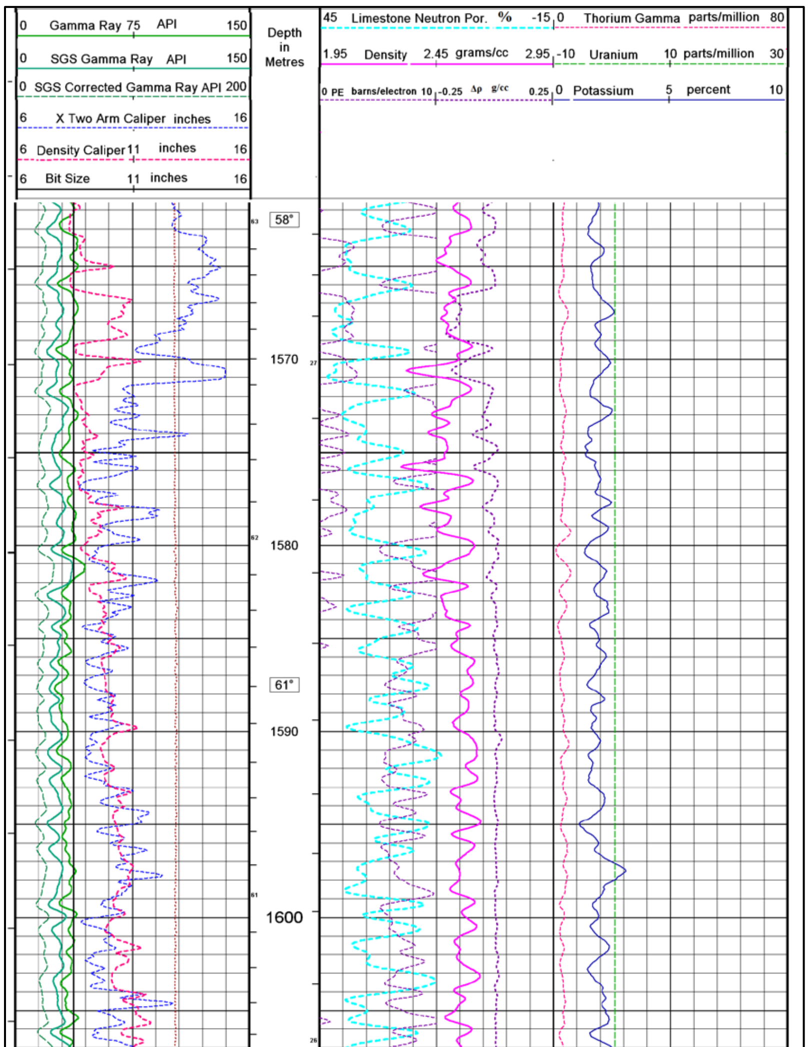
Log Presentation

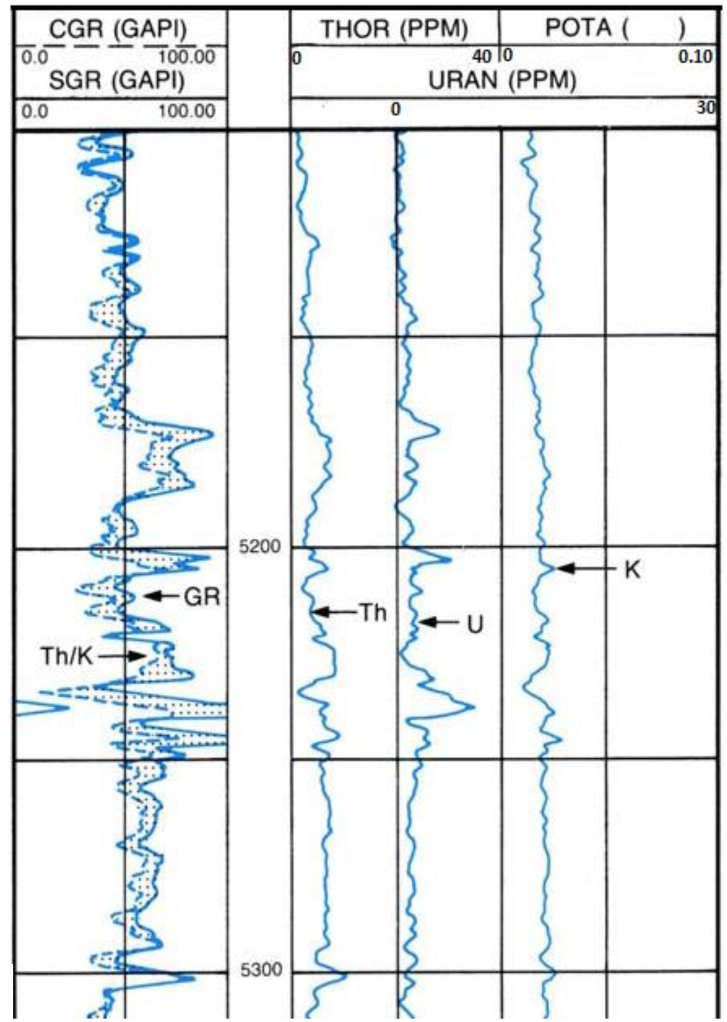
The format for reporting the spectral gamma ray data is more complex than for the total gamma ray log because it contains much more detailed information.

Track 1 is used to record the derived total gamma ray log (***SGR***), which is a sum of **all** the radiation contributions, as well as the computed gamma ray log (***CGR***), which is the sum of the "**K**" and "**Th**" responses, leaving out the contribution from **Uranium.**

Tracks 2 and 3 are used to record the calculated abundances the individual contributions for each of K^{40}, U^{238}, and Th^{232}.

Spectral Gamma Ray Log





Spectral Gamma Ray Log

The potassium is reported as a percentage (%), while U238and Th232are reported in parts per million (ppm).

The scale of **U**, and **Th**in **ppm** from **0 -20**, while K40scaled in % with range **0 -5**.

The **SGR**, standard gamma ray (is the same simple gamma ray log, reconstructed from the elemental values (**U**, **Th** and **K40**),

Their contribution in gamma ray emission:

1ppm **U** equivalent to 8.09 API

1ppm **Th** equivalent to 3.93 API

1% **K**=16.32 API.

The computed Gamma Ray (**CGR**) represents the contribution of only the **Th** and **K**in API units without **U**. The difference between **SGR** and **CGR** is the contribution of **U**, in API units.

Occurrence of Radioactive Elements

Potassium (K)common in:

Clay minerals: in illite (5.2%) >> Kaolinite(0.63%), Glauconite4.5%, Smectite0.225%, Chlorite 0.00%.

Evaporat Example sylvite(KCl) 52.5%, Carnallite14.1%, Polyhalite12.9%

Feldspar, high in K-Feldspar ($KAlSi_3O_8$), and Shale 2% -3.5%

Thorium (Th):

Sourced from acidic & intermediate igneous rock.

High in Bauxites (residual soil).

Clay minerals, (in Kaolinite>> illite, and Smectite)

In heavy minerals (Zircon, Sphen, Thorite, Epidote)

Occurrence of Radioactive Elements

Uranium (U)

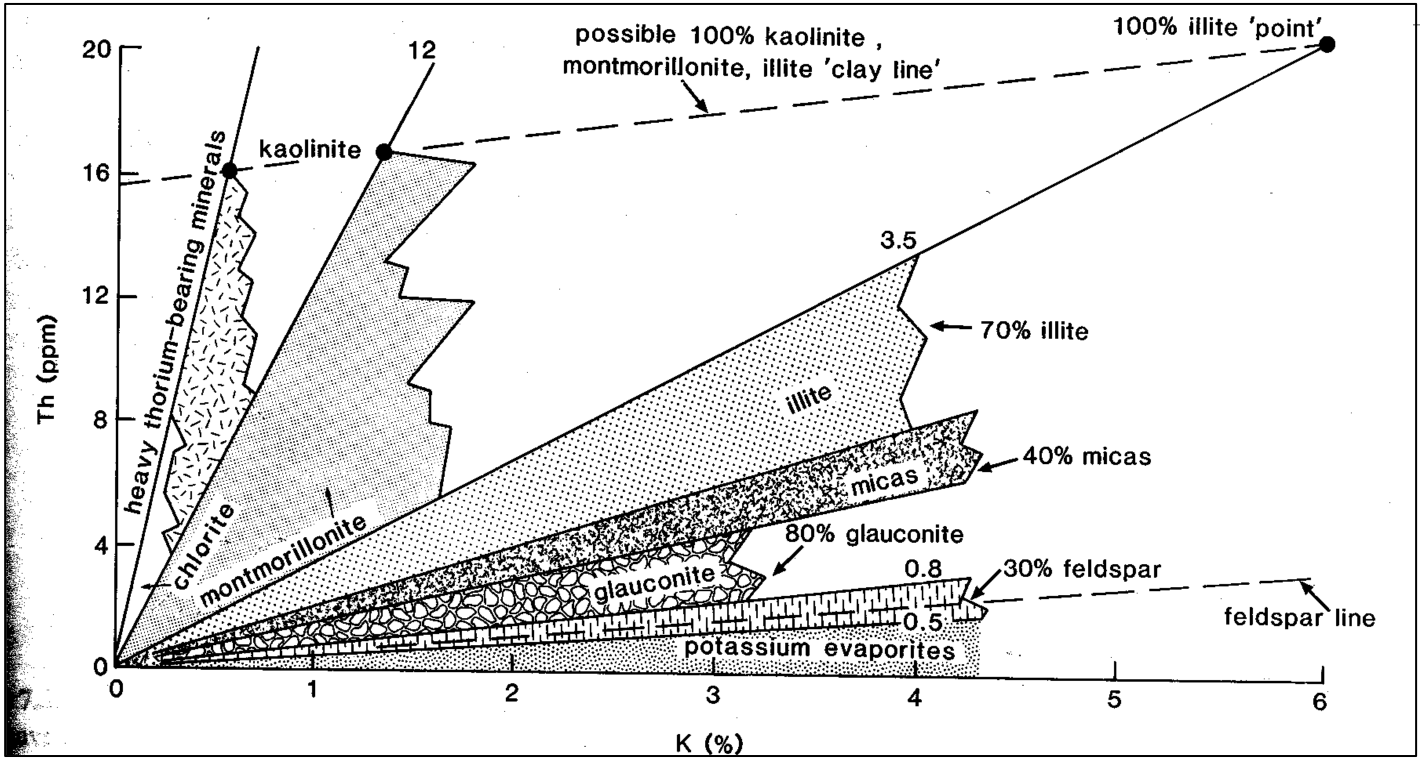
Sourced from acidic igneous rocks

Carried in solution, attached to clay particles (River sediments).

pass into sea water sediments by chemical precipitation in reducing environment (PH 2.5-4.0), stagnant, anoxic, slow rate of deposition…black shale

Most of above points are ideal condition to accumulation of the organic matters, so most of the rich organic source rock (black shale) characterized by high radiations.

Occurrence of Radioactive Elements



The figure shows using of NGS log (**K** & **Th** content) to predict mineralogy of claystone and shale rocks.

Occurrence of Radioactive Elements