GAMMA RAY LOG

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RADIOACTIVITY LOGGING METHODS

- Radioactive logs are based on the nuclear radiations of the formations (radioactive elements) and for detecting possible productive horizon and evaluating their reservior properties
- Radioactivity logs are mainly of 3 types :

1) gamma ray log which measures the radioactivity of the formations

2) the neutron gamma ray log which measures the radioactivity induced artificially in the formations by bombarding the rocks with neutrons from a neutron source

3) The formation density log which is based on the measurements of scattered gamma rays from the formations , irradiated by a gamma rays source.

- All these types of logging , the radioactivity is measured in terms of gamma –ray emmision with the help of either Geiger –Muller tubes or scintillation counters

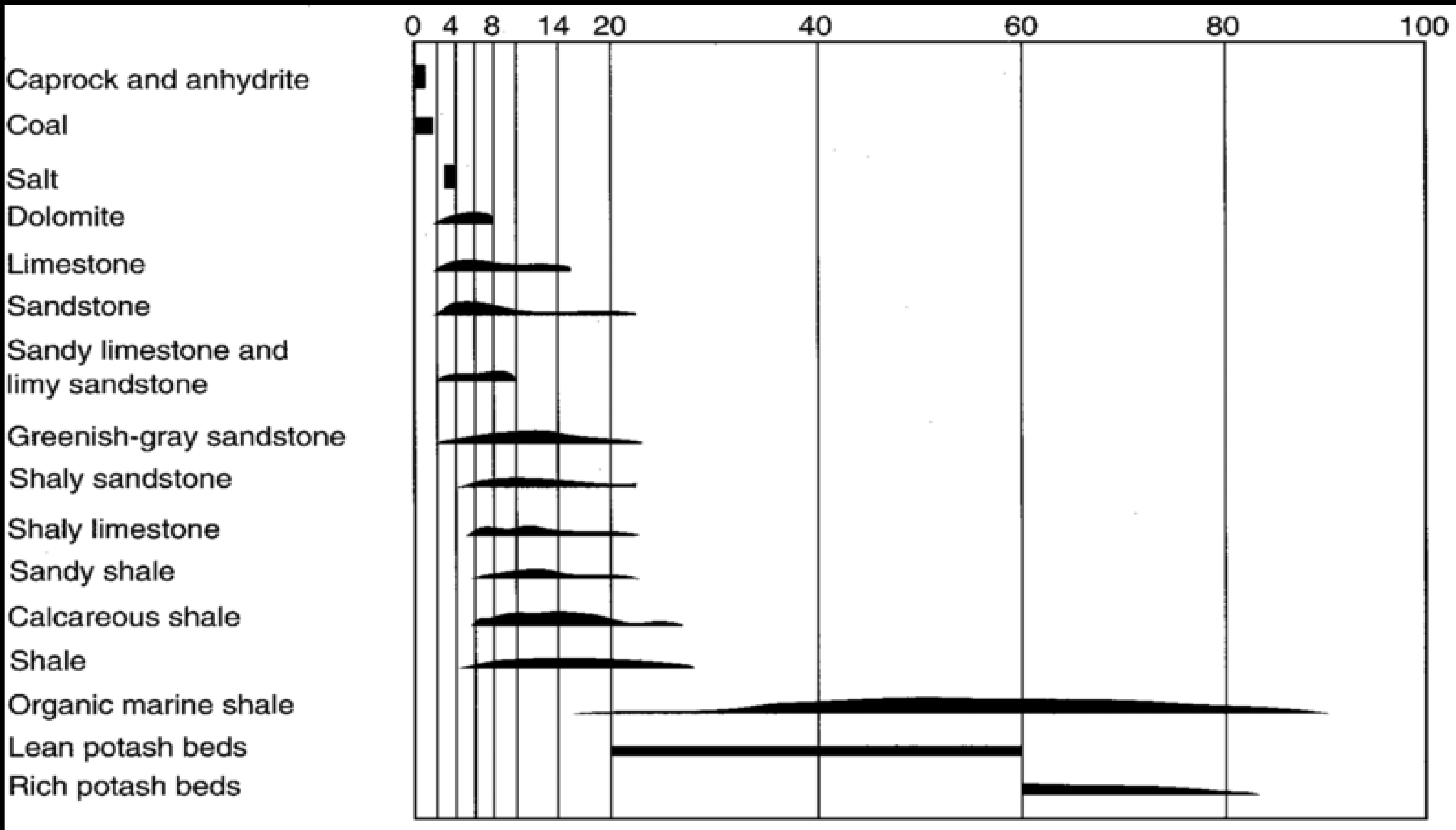
Gamma Ray Log

The gamma ray tool measures natural radiation from the rock which primarily comes from K, U, Th. Because these elements are present in shale but usually absent in siliceous ss and carbonates, the log is used as an estimator of shale content.

Gamma ray logs measure natural radioactivity of formations. They can be used for identifying lithologies and correlating zones. Shale-free sandstones and carbonates have low concentrations of radioactive material and give low gamma ray readings. As shale content increases, the gamma ray log response increases because of the concentration of the radioactive material in shale.

In Fig. 1, the distributions of radiation levels observed by Russell are plotted for numerous rock types. Evaporites (NaCl salt, anhydrites) and coals typically have low levels. In other rocks, the general trend toward higher radioactivity with increased shale content is apparent. At the high radioactivity extreme are organic-rich shales and potash (KCl). These plotted values can include beta as well as gamma radioactivity (collected with a Geiger counter). Modern techniques concentrate on gamma ray detection.

RELATING RADIOACTIVITY TO ROCK TYPES



Origin and Sources of GR

Gamma Rays are bursts of high-energy electromagnetic waves that are emitted spontaneously by some radioactive elements (unlike Alpha and Beta rays of low energy)

Correlation curves (Lithology curves) :
Gamma Ray log m**easures natural radioactivity of formation due to the radioactive material disintegration (decay) :**

- **Potassium (K) (isotope of atomic wt. 40)**
- **Uranium (U)**
- **Thorium (Th)**

Indicates shale and clay present in sedimentary and igneous rocks.

Properties of GR

- GR emittion is not at constant rate and speed, but at random, because it is a natural phenomena. Thus, logging speed should be slow to reduce this effect.

GR tool

- GR sonde contains a detector to measure Gamma radiation originating in the volume of the formation near the sonde.
- They are two types:
  - Geiger Mueller counters : used in the pasts
  - Scintillation counters : now used for this measurement; they are much more efficient than the Geiger Mueller counters used in the past, and they offer good formation detail.

Origin and Sources of GR, cont

- Radioactive elements tends to concentrate in shale and clays due to their structure and origin.
- Clean formation usually have very low level of radioactivity, unless local radioactive contaminants such as volcanic ash or granite wash or organic matter is present, or formation waters contain dissolved radioactive salts.

Gamma Ray Log ; uses

- Gamma ray log is measurement of natural radioactivity in formation verses depth.
- It measures the radiation emitting from naturally occurring U, Th, and K.
- It is also known as shale log and as shale indicator.
- GR log reflects shale or clay content.
- Clean formations have low radioactivity level.
- Correlation between wells,
- Determination of bed boundaries, and sand count.
- Evaluation of shale content within a formation,
- Mineral analysis,
- GR log can be run in both open and cased hole

Table 1 lists some of the common rock types and their typical content of potassium, uranium, and thorium.

TABLE 13.15—COMMON ROCK TYPES AND THEIR TYPICAL CONTENT OF POTASSIUM, URANIUM, AND THORIUM

	Potassium (%)	Uranium (ppm)	Thorium (ppm)
Rock and mineral carbonates			
Range	0.0–2.0	0.1–9.0	0.1–7.0
Calcite, chalk, limestone, dolomite (pure)	<0.1	<1.0	<0.5
Dolomite (west Texas)	0.1–0.3	1.5–10	<2.0
Limestone (clean)			
Florida	<0.4	2.0	1.5
Cretaceous (Texas)	<0.3	1.5–15	<2.0
Hunton Lime (Oklahoma, Texas)	<0.2	<1.0	<1.5
Sandstones, range	0.7–3.8	0.2–0.6	0.7–2.0
Beach sands (Gulf Coast)	<1.2	0.84	2.8
Atlantic coast (Florida, North Carolina)	0.37	3.97	2.8
Atlantic coast (New Jersey, Massachusetts)	0.3	0.8	2.07
Shales typical range	1.6–4.2	1.5–5.5	8–18
Minerals			
Allanite		30–700	500–5000
Apatite		5–150	20–150
Epidote		20–50	
Monzanite		500–5000	$(2.5–20)\times10^4$
Sphene		100–700	100–600
Xenotime		$500–3.4\times10^4$	low
Zircon		300–3000	100–2500
Clays			
Bauxite		3–30	10–130
Glauconite		5.08–5.3	
Bentonite	<0.5	1–20	6-50
Montmorillonite	0.16	2–5	14–24
Kaolinite	0.42	1.5–3	6–19
Illite	4.5	1.5	
Mica			
Biotite	6.7–8.3		<0.01
Muscovite	7.9–3.8		<0.01
Feldspars			
Plagioclase	0.54		<0.01
Orthoclase	11.8–14.0		<0.01
Microcline	10.9		<0.01
Quartz (silica)	<0.15	<0.4	<0.2

Potassium, uranium, and thorium contents of typical rocks and minerals (after Bigelow[138]).

- Potassium is an abundant element, so the radioactive K^{40} is widely distributed (Table 2).
- Potassium, feldspars and micas are common components in igneous and metamorphic rocks.
- Immature sandstones can retain an abundance of these components. In addition, potassium is common in clays.
- Under extreme evaporitic conditions, KCl (sylvite) will be deposited and result in very high radioactivity levels.
- Uranium and thorium, on the other hand, are much less common. Both U and Th are found in clays (by absorption), volcanic ashes, and heavy minerals.
- Potassium (K) is the most abundant radioactive element and is present in micas, clays, feldspars and glauconite. Glauconitic and arkosic sandstones produce an elevated GR response in addition to shale, and shaly sandstones.

TABLE 13.16—DISTRIBUTION OF POTASSIUM

Material	Potassium Content by Weight (average)	Range
Sylvite	54	
Potash	44.9	
Langbeinite	20	
Microcline	16	
Kainite	15.1	
Carnallite	14.1	
Orthoclase	14	
Polyhalite	12.9	
Muscovite	9.8	
Biotite	8.7	
Illite	5.2	3.51–8.31
Arkose (sandstone)	4.6	4.4–5.1
Synite	4.53	
Glauconite	4.5	3.2–5.8
Granite	4.0	2.0–6.0
Norite	3.3	
Granodiorite	2.90	
Shale	2.7	1.6–9.0
General igneous rock	2.6	
Grayrock (sandstone)	1.5	1.2–2.1
Diorite	1.66	
Basalt	1.3	
Sandstone	1.1	5.1
Gabbro	0.87	
Diabase	0.75	
Kaolinite	0.63	0–1.49
Limestone	0.27	0–0.71
Montmorillonite	0.22	0–0.60
Orthoquartzite (sandstone)	0.08	0–0.12
Dolomite	0.07	0.03–0.1
Dunite	0.04	
Sea Water	0.035	

Additional reported potassium content and ranges for rocks and minerals (after Bigelow[135]).

- **Cementation and secondary alteration may precipitate uranium and thorium bearing minerals in sandstones and carbonates which could be mistaken for shale and bypassed as a potential reservoir.**

Types:

- Natural
- Spectral

Thorium, Uranium, Potassium

COMPTON SCATTERING

In passing through a matter, gamma rays experience successive Compton scattering collisions with atoms of the formation material losing energy with each collision. After the gamma ray has lost enough energy, it is absorbed by means of the photoelectric effect via an atom of the formation. Thus, natural gamma rays are gradually absorbed and their energies degraded as they pass through the formation. The rate of absorption varies with formation density. Two formations having the same amount of radioactive material per unit volume, but having different densities will show different radioactivity levels; the less dense formations will appear to be slightly more radioactive. The GR log response after appropriate corrections for borehole is proportional to the weight concentrations of the radioactive material in the formation

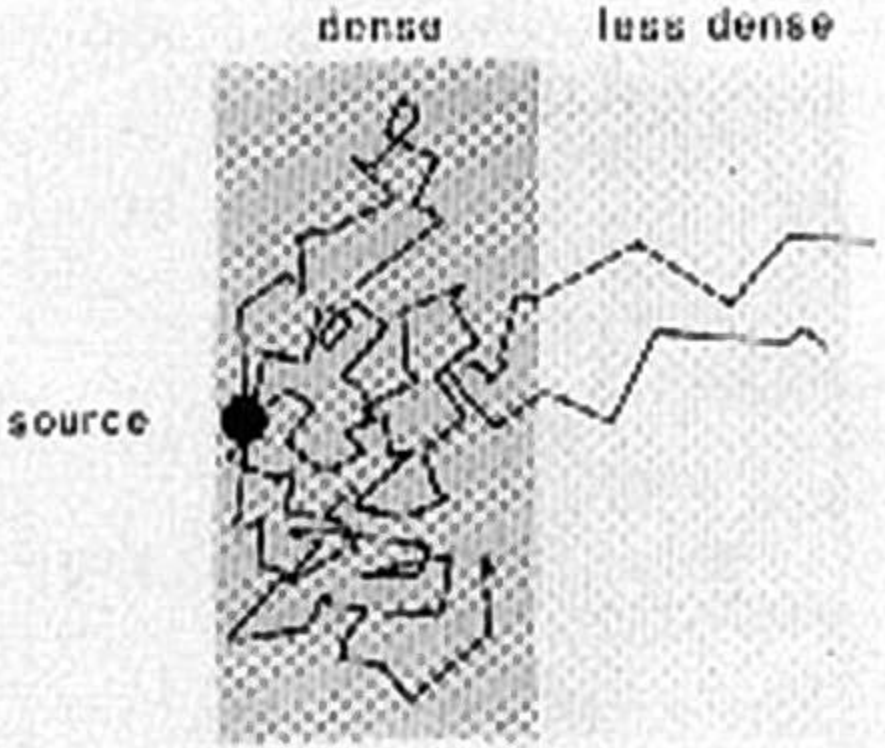


Figure 7.3 Schematic drawing of the Compton scattering of gamma rays. The effect is more marked in denser matter (cf. Lavenda, 1985).

USES

Quantitative uses –

Volume of shale determination,

Volume of radioactive minerals

Qualitative uses - Lithology identification

- Radioactivity of sandstones
- Radioactivity of carbonates
- - Radioactivity of evaporties
- - Mineral identifications
- - Unconformities - Correlation - Facies identification - Identification of dertital minerals - Depositional environment - Fracture identification - Source rock identification

Gamma Ray Log Uses

- Generally, a gamma ray log indicates the amount of shale present
- Low Natural Radioactivity
  - Sandstone
  - Limestones
  - Dolomites
  - Minimum reading at salt & anhydrite (few API units)
- High Natural Radioactivity
  - Shales, Mica , Feldspar, Volcanic, Gamma ray logs can be run in both openhole and cased-hole environments.

Gamma Ray Log & NGS

*Standard gamma ray logs measure the total natural radioactivity of a formation.
*Information from cased hole logs:

- Gamma Ray Log - same as open hole log;

*Natural Gamma Ray Spectrometry Log
-used to identify clay types and clay volumes, and is a better shale indicator than GR;

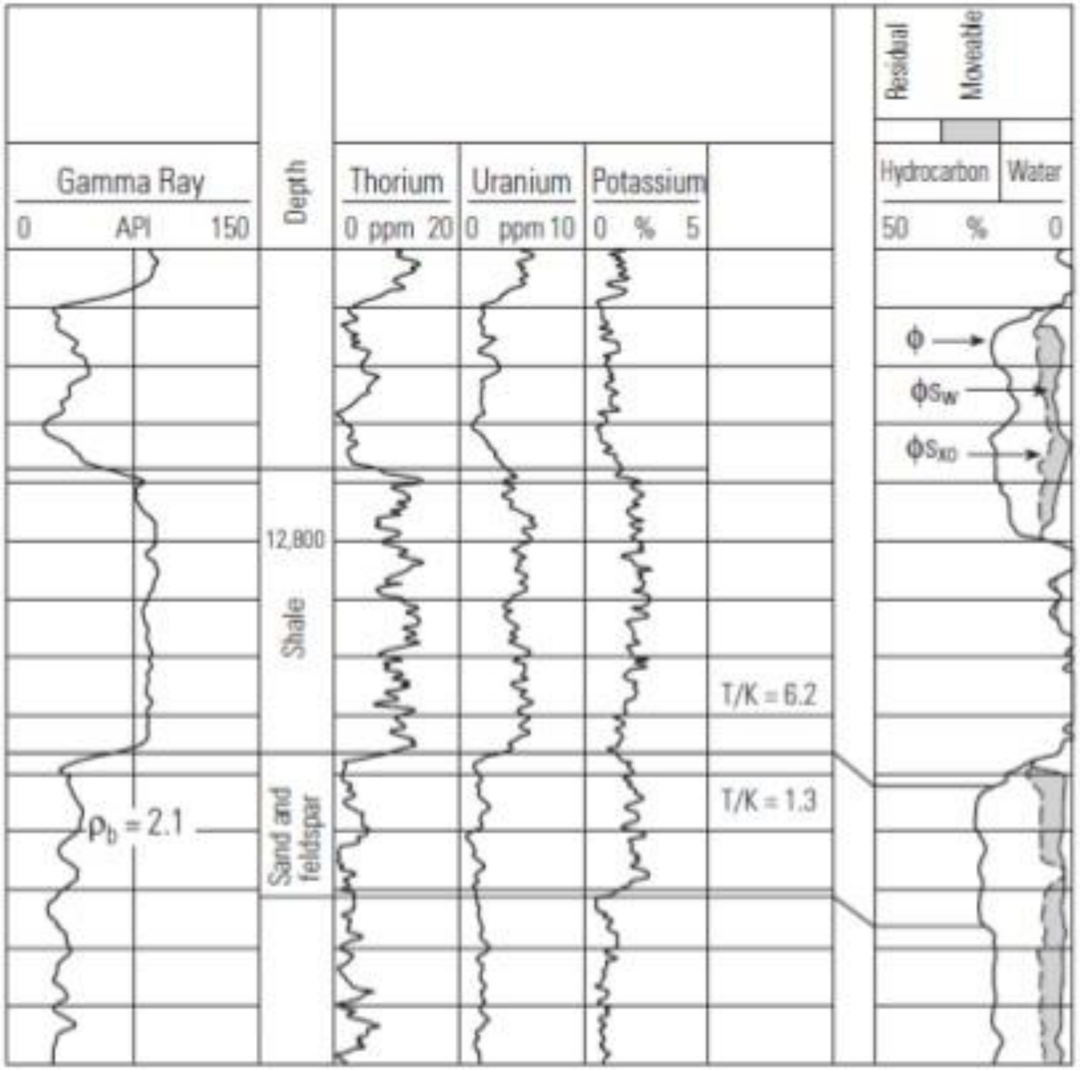


Fig. 11.8 A log showing the effect of feldspar on the spectral and total gamma ray logs. Adapted from Ellis [13].

Vsh (shaliness Calculation)

Vsh from the GR is calculated by:

$$Vsh(GR) = \frac{GR - GRclean}{GRshale - GRclean}$$

Where

Vsh(GR) = Volume fraction of shale from Gamma Ray, fraction

GR= GR reading of log at depth of interest

GRclean = GR reading of clean rock

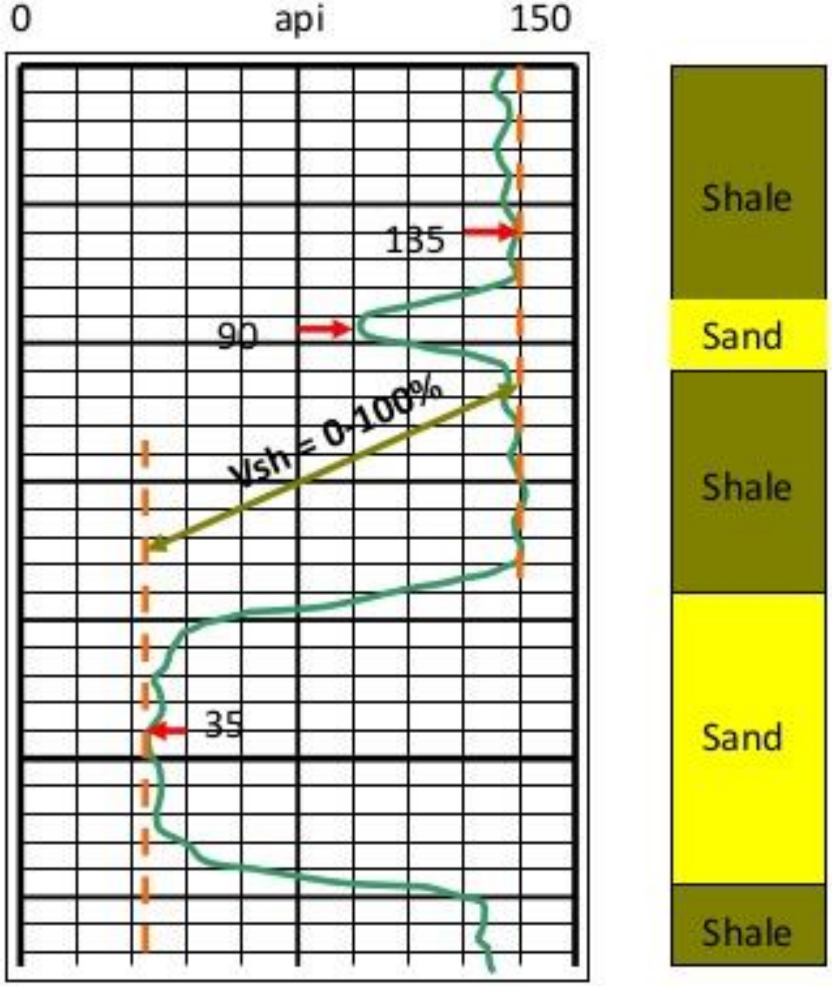
Grshale = GR reading of 100% shale

The interpreter chooses Grclean, Grshale, and GR off the log.

- GRclean is typically 20 to 50 API units
- Grshale is typically 90 to 120 API units

Note that one could use chart divisions instead of API units to calculate Vsh (will get the same answer).

Shale volume



1) Pick a clean GR response

2) Pick a shale GR response

3) Scale between

$$Vsh = \frac{GR_{log} - Gr_{clean}}{GR_{shale} - Gr_{clean}}$$

GR 90 -> Vsh = 55%

Various Equation for V shale Calculation

HAMPSON-RUSSELL
A CGGVeritas Company

The nonlinear responses are :

- **Larionov (1969) for Tertiary rocks :**

$$V_{sh} = 0.083(2^{3.7 I_{GR}} - 1)$$

Vshale_Larionov_Tertiary_Rock.prs

- **Steiber (1970) :**

$$V_{sh} = \frac{I_{GR}}{3 - 2 \times I_{GR}}$$

Vshale_Steiber.prs

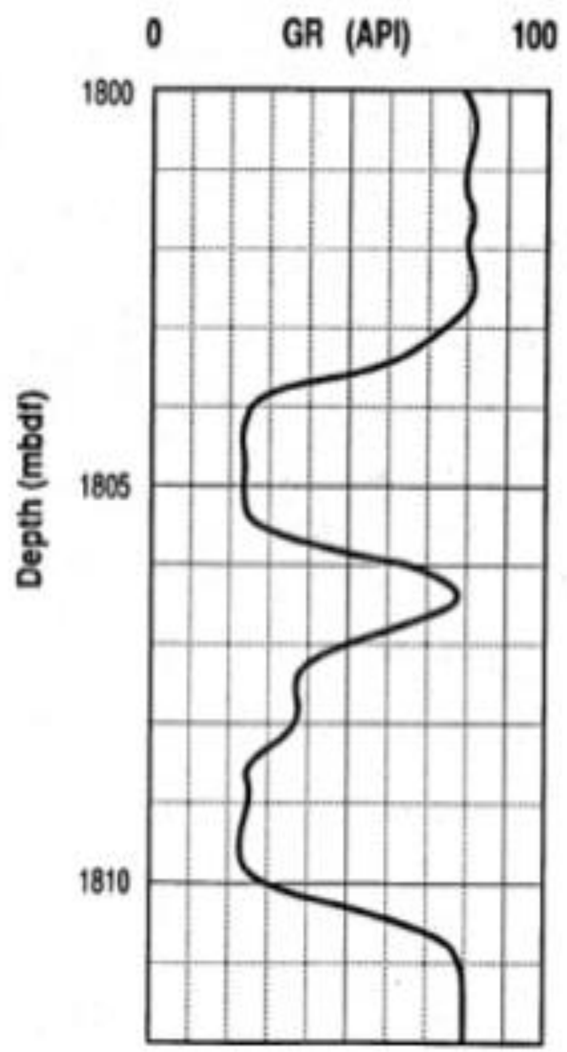
- **Clavier (1971) :**

$$V_{sh} = 1.7 - \left[(3.38 - (I_{GR} + 0.7)^2\right]^{\frac{1}{2}}$$

Vshale_Clavier.prs

- **Larionov (1969) for older rock :**

$$V_{sh} = 0.33 \times (2^{2 I_{GR}} - 1)$$



From cutting descriptions on the mudlog it is known that the logged interval on the left consists of sands interbedded with shales.

Determine:

A) Tops and Bottoms of the sand (reservoir) sections.

B) Thicknesses of the individual sand layers.

h1 =
h2 =

C) Total thickness of sand (= Net reservoir).

Net reservoir = h1 + h2 =

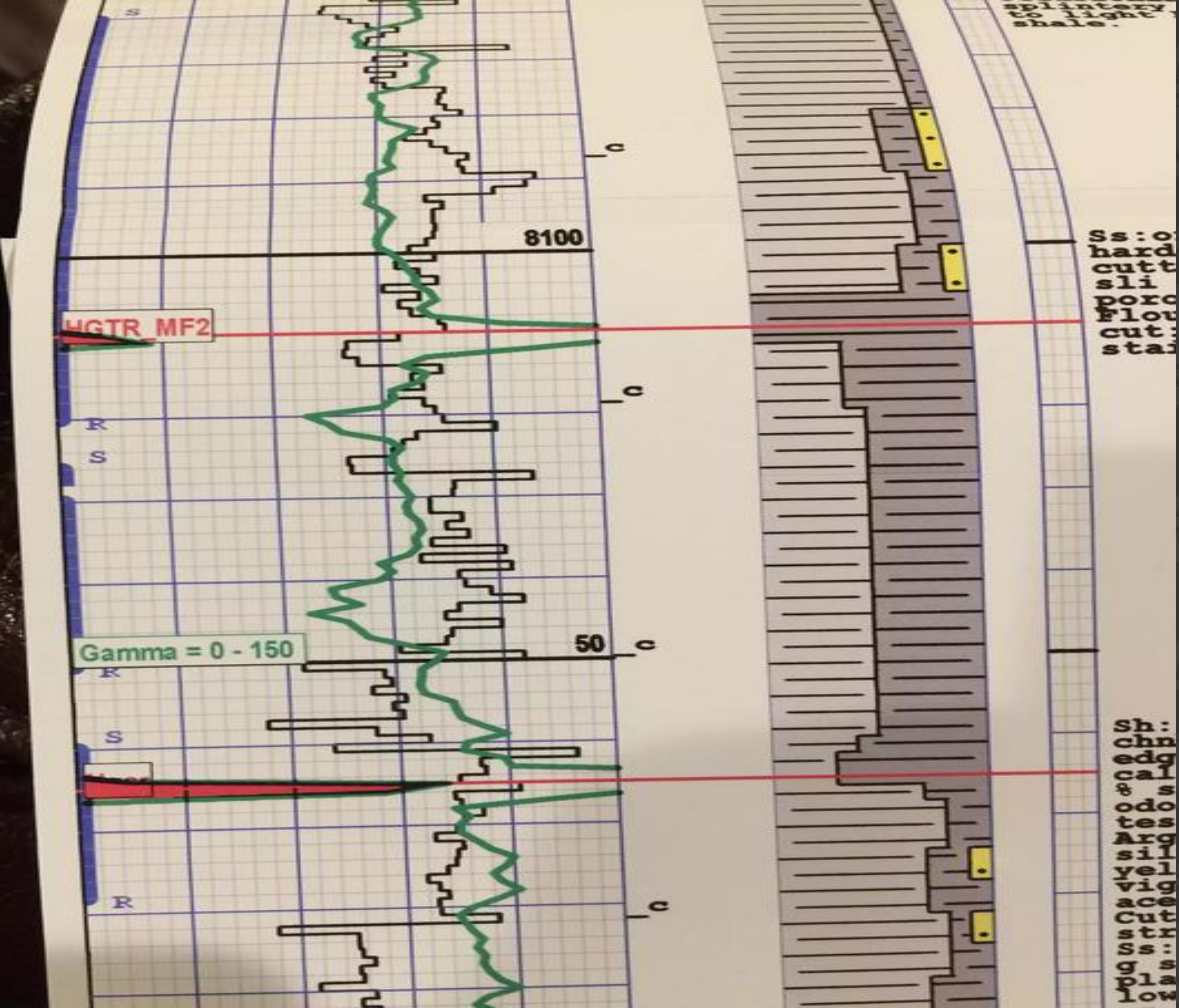
D) Fraction of reservoir within the total sand sequence (= Net / Gross)

N/G = (h1 + h2) / H =

HOT SHALE

- Normal readings in most formations vary between 5 and 200 units. Shales measure high numbers while sands, limes and dolomites (reservoirs) measure low numbers.
- Occasionally a shale will measure 300, 400 or more units. This makes them "hot". The Woodford shale, a primary source rock across much of the US, will run the measurement off the scale and beyond calibrated levels. These shales are also commonly known as black shales vs the normal gray or brown.
- The reason behind both color and radioactivity is the presence of organic material having uranium. These shales were derived from 'swamp' material containing a high concentration of plant life which, after a very long exposure to high pressure and temperature becomes the source of the hydrocarbons we drill for today.

- A hot shale is one that gives a strong kick on the gamma log. These are typically thin a (a few feet) and more radioactive than regular shakes. They also tend to be wide spread and so make excellent structural/stratigraphic markers.



8100
HGTR_MF2
Gamma = 0 - 150
50

FACIES & DEPOSITIONAL ENVIRONMENT

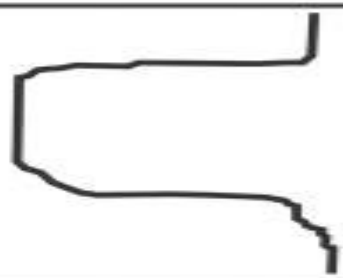
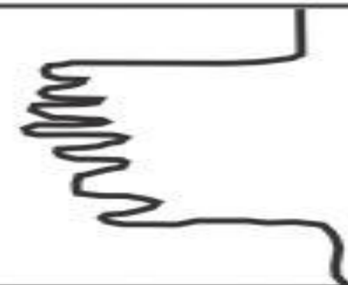
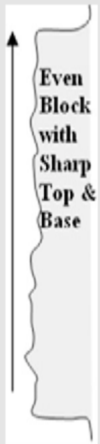
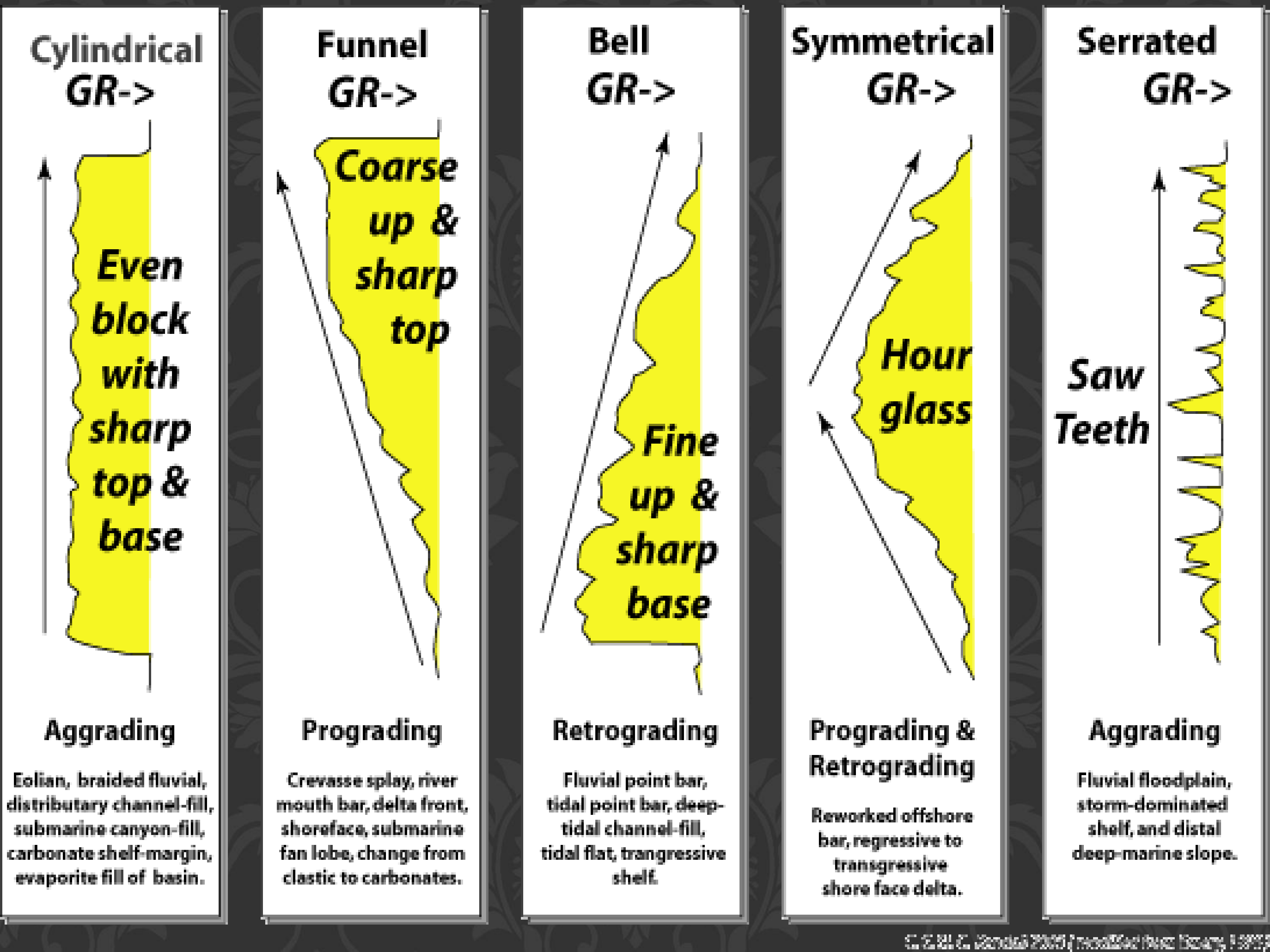
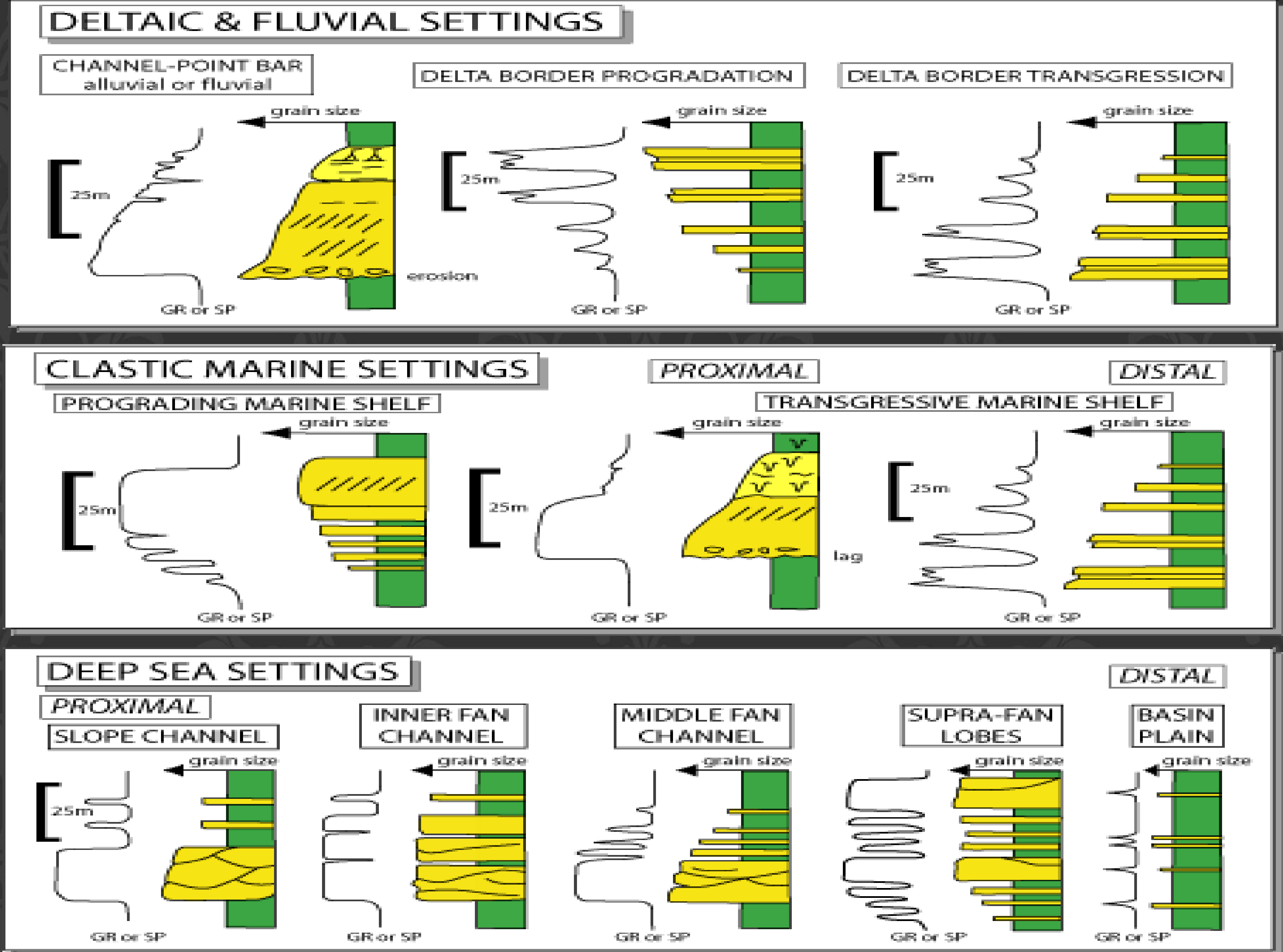
Shape	Smooth	Environments	Serrated	Environments
Cylinder Represents uniform deposition		Aeolian dunes Tidal sands Fluvial Channels		Deltaic distributaries Turbidite channels Proximal deep-sea fans
Bell Shape Fining upwards sequences		Tidal sands Alluvial sands Braided streams Fluvial channels Point bars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

Table 1 – The direct correlation between facies and a variety of other log shapes relative to the sedimentological relationship (modified after [4,5,8,9]).

Type of log motif shape	Cylindrical/box shape	Funnel shape	Bell shape	Symmetrical shape	Serrated/saw tooth shape
Sediment supply	Aggradation	Progradation	Retrogradation	Petrograding & retrograding	Aggrading
GR trend					
Characteristic	Sharp top and base with consistent trend	Abrupt top with coarsening upward trend	Abrupt base with fining upward trend	Ideally rounded base and top	Irregular pattern/spikes of GR log
Grain size	Relative consistent lithology	Grain size increases	Grain size decreases	Cleaning upward trend change into dirtying up sequence from top	Inter-bedded shale's and sands
Depositional Environment	Aeolian (sand dunes), fluvial channels, carbonate shelf (thick carbonate), reef, submarine canyon fill, tidal sands, prograding delta distributaries	Crevasse splay, river mouth bar, delta front, shoreface, submarine fan lobe	Fluvial point bar, tidal point bar, deltaic distributaries, proximal deep sea, setting	Sandy offshore bar, transgressive shelf sands and mixed tidal flats environment	Fluvial flood plain, mixed tidal flat, debris flow and canyon fill



Cylindrical
GR->
Even block with sharp top & base
Aggrading
Eolian, braided fluvial, distributary channel-fill, submarine canyon-fill, carbonate shelf-margin, evaporite fill of basin.
Funnel
GR->
Coarse up & sharp top
Prograding
Crevasse splay, river mouth bar, delta front, shoreface, submarine fan lobe, change from clastic to carbonates.
Bell
GR->
Fine up & sharp base
Retrograding
Fluvial point bar, tidal point bar, deep-tidal channel-fill, tidal flat, trangressive shelf.
Symmetrical
GR->
Hour glass
Prograding & Retrograding
Reworked offshore bar, regressive to transgressive shore face delta.
Serrated
GR->
Saw Teeth
Aggrading
Fluvial floodplain, storm-dominated shelf, and distal deep-marine slope.



DELTAIC & FLUVIAL SETTINGS
CHANNEL-POINT BAR alluvial or fluvial
DELTA BORDER PROGRADATION
DELTA BORDER TRANSGRESSION
grain size
25m
erosion
GR or SP
CLASTIC MARINE SETTINGS
PROXIMAL
DISTAL
PROGRADING MARINE SHELF
TRANSGRESSIVE MARINE SHELF
lag
DEEP SEA SETTINGS
SLOPE CHANNEL
INNER FAN CHANNEL
MIDDLE FAN CHANNEL
SUPRA-FAN LOBES
BASIN PLAIN