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 - 9

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TEACHING OUTLINE

Week 4

Tutorial 12 – Logging tools, natural gamma ray measurement

Tutorial 13 – Natural gamma ray tool, application

AGENDA

- GR tool depth of investigation, typical response
- Volume of shale and correction

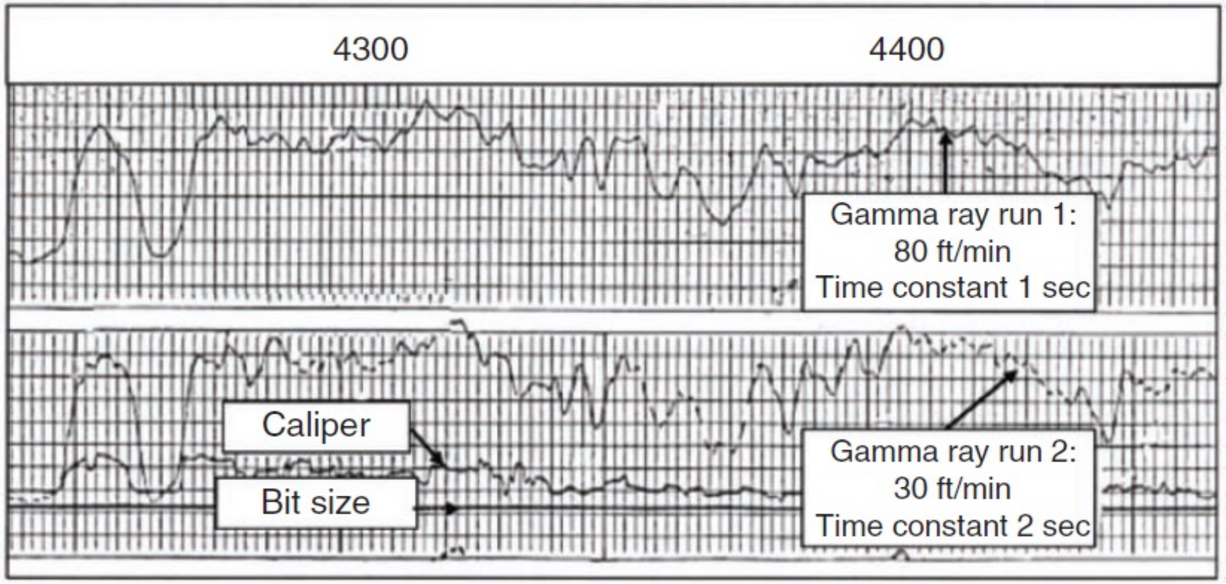
LOGGING SPEED & TIME CONSTANT

- Radioactive emissions are random, and hence fluctuate in an unpredictable way with time. If the count rates are high, this causes no real problems as there are sufficiently many counts in a reasonable time interval for the fluctuations to average out.
- In gamma ray logging, the count rate is low, so the fluctuations have to be taken into account.
- For each measurement depth, the tool must linger long enough to measure enough count in order to obtain good quality data. In gamma ray logging a time averaging procedure is adopted to minimize the statistical fluctuations.
- The output from the detector is measured as a gamma ray count rate, which is averaged over a time defined by a time constant T_c.

Grover, 2010

LOGGING SPEED & TIME CONSTANT

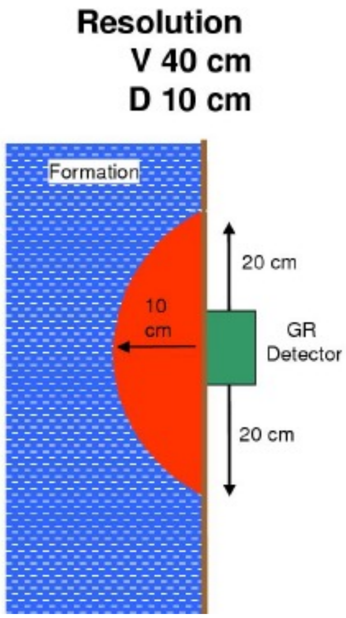
- Gamma rays can be counted for a very short interval of time, resulting in a poor estimate of real count rate
- Alternatively, they can be counted for a long time, resulting in a more accurate estimate of the count rate at the expense of an inordinately long measurement time period.

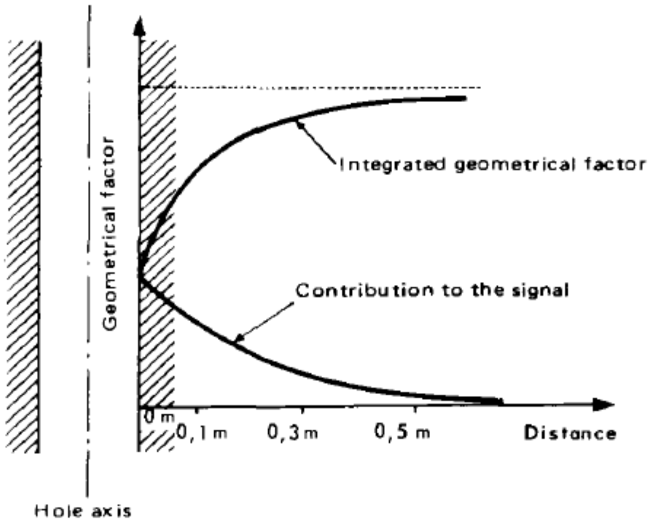


Grover, 2010

RADIUS OF INVESTIGATION & BOREHOLE ENVIRONMENT

- GR response influenced by (i) sonde position (ii) borehole size, (iii) mud density, (iv) casing size and weight and (v) cement thickness
- 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
- For average values of drilling mud and formation density, we can say that approximately 50% of the gamma ray signal comes from within 18 cm (7 inches) of the borehole wall, increasing to 75% from within 30 cm (1 foot)
- Radius of investigation varies between 5 to 20 cm
- Roughly, in vertical direction 20 cm and below the detector and 10 cm laterally





VERTICAL RESOLUTION

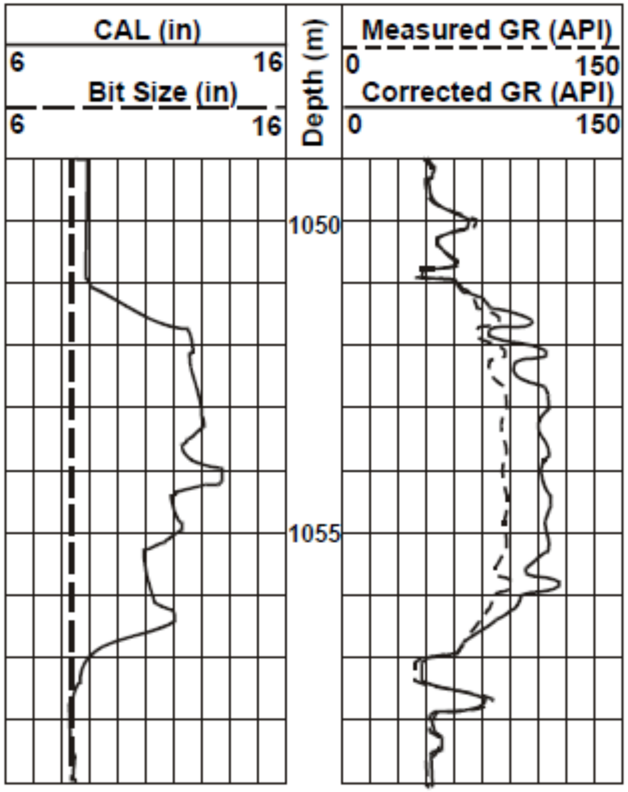
- The size of the detector, which is quite small (about 5-10 cm diameter)
- For conventional logging, with the product of logging speed and time constant set to 1 foot, the contribution to degradation in the vertical resolution from this cause is 1 foot
- The hemispherical zone of sensitivity of the sensor. As the sensor is sensitive to gamma rays from a hemispherical zone, and its approximate depth of investigation of about 30 cm (1 foot) for formations of average density, we can see that the degradation in vertical resolution from this source will be about 2 foot

MUD TYPE

- Mud may be consisting of NaCl, KCl, bentonite, barite, etc.
- Bentonite is radioactive, and will introduce a shift in reading levels, roughly constant if the borehole is uniform
- KCl solution, on the other hand, will invade permeable sections. The next result will be an overall increase in gamma radioactivity because of the mud-column, and an additional increase wherever filtrate has penetrated the formation

BOREHOLE QUALITY

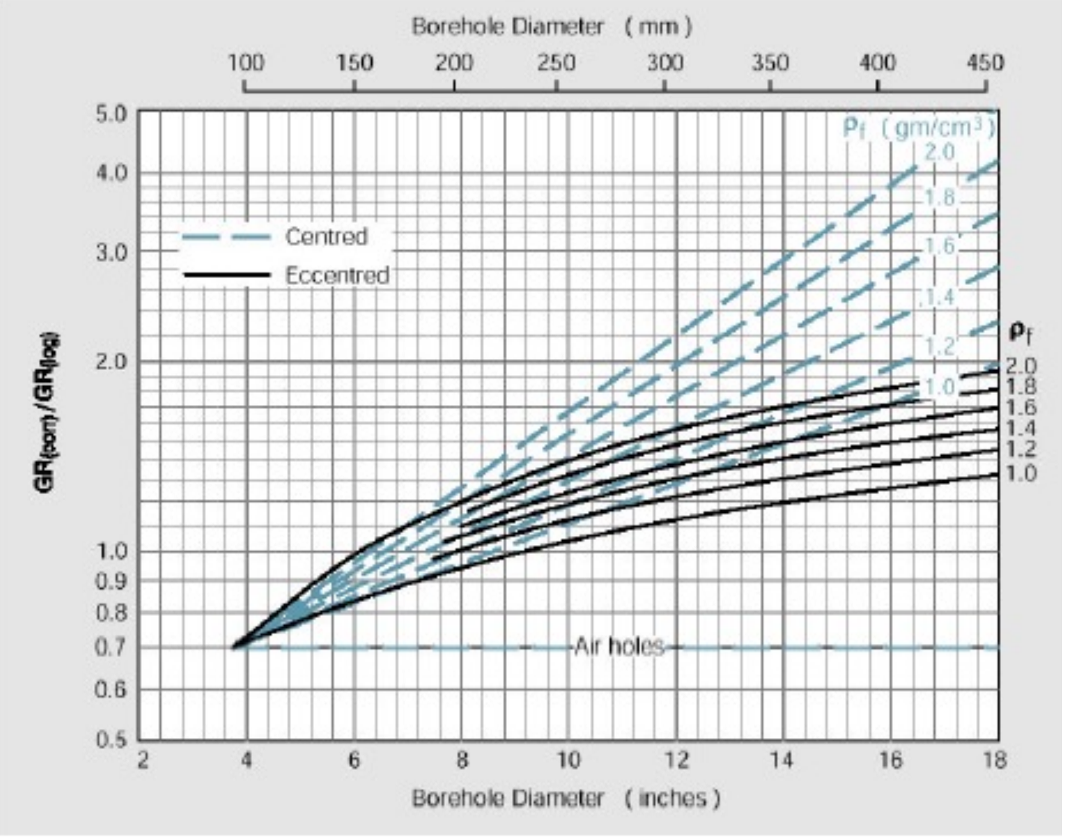
- The gamma ray log usually runs centered in the borehole
- When the borehole suffers from caving, the gamma ray log can be badly affected. In intervals that suffer from caving, there is more drilling mud between the formation and the gamma ray detector to attenuate the gamma rays produced by the formation
- Denser the mud, greater the underestimation due to increased Compton scattering effect



Ryder, 1996

GR CORRECTION – HOLE CONDITION

- Owing to caving, GR correction can be made if the caliper log for the well is known.
- Correction charts are available for each logging companies' tool for a range of drilling fluids and tool geometries

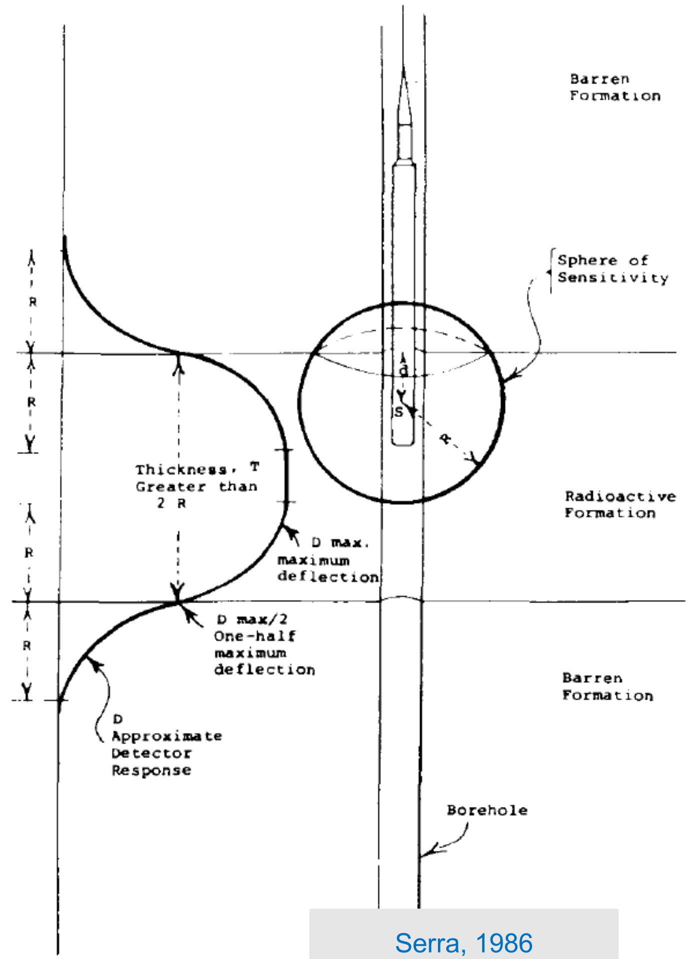


Gamma ray log correction chart for a 3.75-inch tool in an 8-inch hole with a KCl-free drilling mud with a mud weight of *RHO*RHO_f g/cm3 as a function of borehole diameter (courtesy of Reeves Wireline Ltd.).

Grover, 2010

RADIUS OF INVESTIGATION & BOREHOLE ENVIRONMENT

- In a homogeneous formation, the volume of investigation is approximately a sphere centered on the detector
- Some deformation from the spherical will be introduced by the finite size of the detector and the presence of the borehole.
- The radius **r** of this "sphere" depends on the gamma-ray energy and the densities of both the formation and the mud and becomes smaller as the energy decreases or the densities increase.
- Because of finite volume of investigation, bed boundaries are not defined sharply, provided the sphere (or deformed ovoid, to be more exact) is not completely clear of the radioactive bed, some gamma activity will be measured

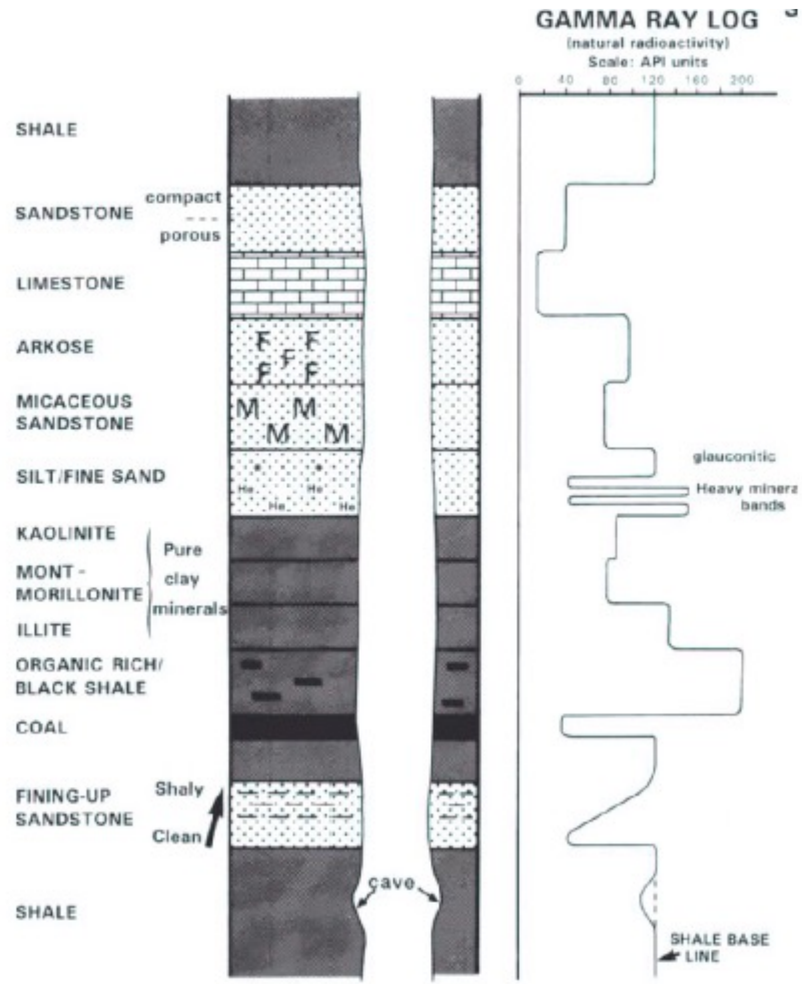


Serra, 1986

TYPICAL RESPONSE

- Typical GR response of various rock types
- Shales show high GR response because of presence of ^{40}K radio isotopes in the lattice structure of clay minerals

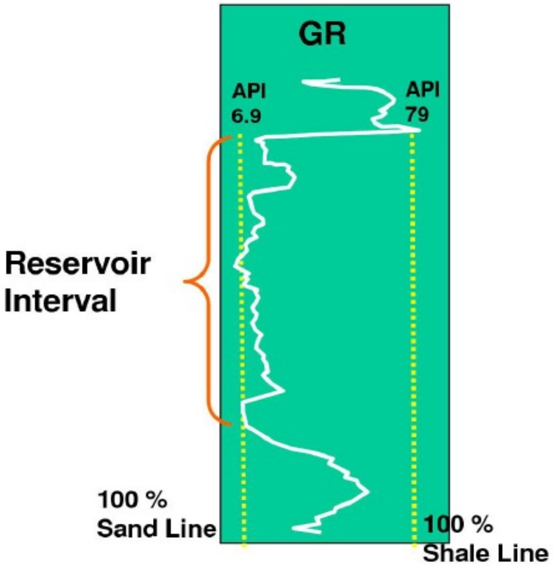
Rock Type	GR Reading	Rock Type	GR Reading
Sandstone	10 -20	Limestone	5 - 10
Dolomite	10 - 20	Shale	80 - 140
Halite	0	Sylvite(KCl)	500
Coal	0	Mica	100- 170

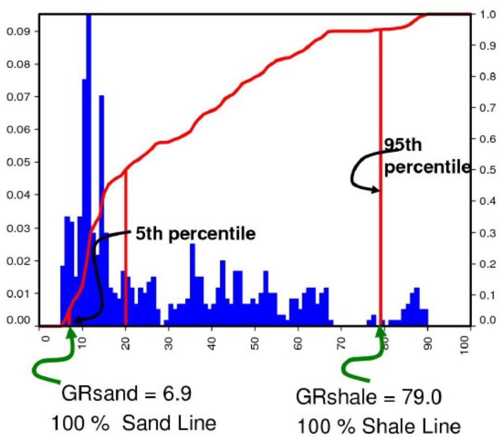


Ryder, 1996

VOLUME OF SHALE

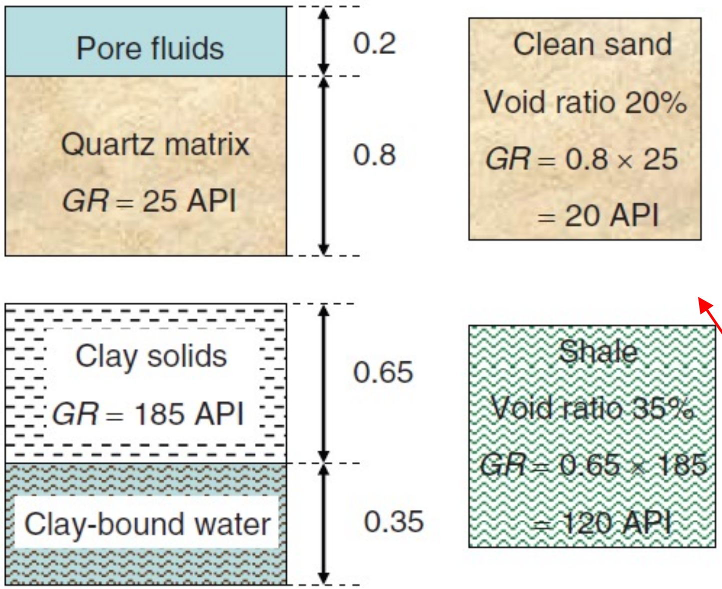
- GR log is used to estimate volume of shale of the studied formation (V_{sh}) or Volume of clay (V_{clay})
- Sand and shale base lines are assumed to represent 100% sand and shale ($GR_{sand} = GR_{min}$, $GR_{shale} = GR_{max}$
- $V_{sh} = \dfrac{GR - GR_{min}}{GR_{max} - GR_{min}}$, this is also known as GR Index equation (I_{GR})

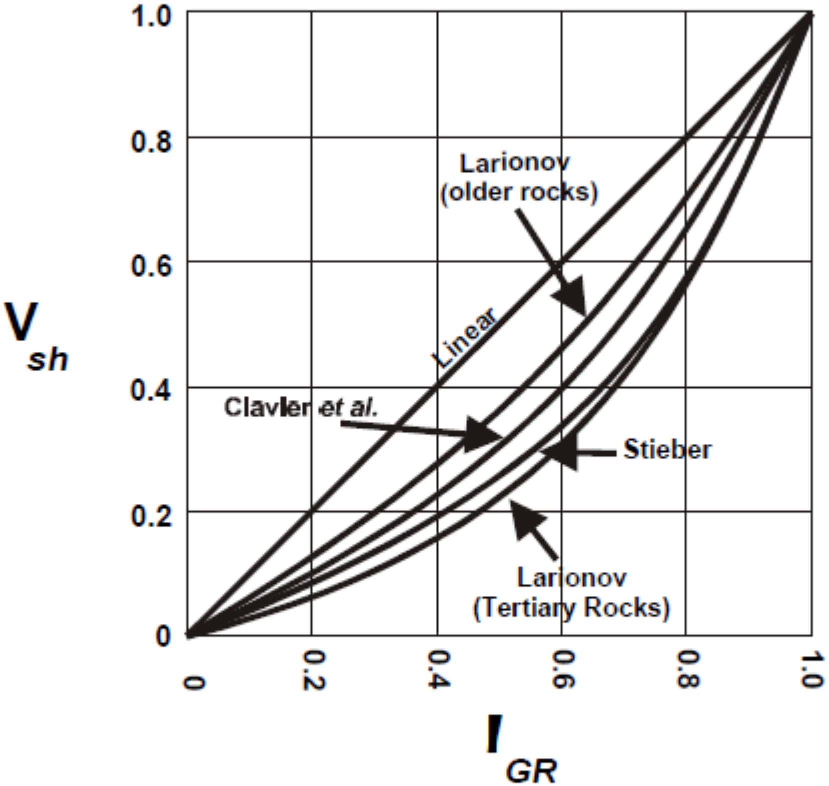




CORRECTION FOR GEOLOGICAL AGE

- Natural radioactivity behavior is directly to related to the geological age. Therefore, for accurate estimation of Vsh, correction is proposed.





Logging tool can measure lower GR value of a formation containing pore space (right side). Intrinsic GR value would be slightly higher (left side).

DEPOSITIONAL ENVIRONMENT

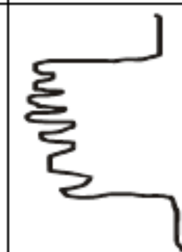
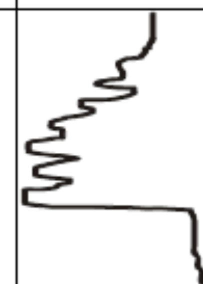
- Depositional environments refer to the specific geological settings in which sediments accumulate and form rock.
- In the context of sandstone reservoirs, these environments significantly influence reservoir characteristics, including porosity, permeability, and hydrocarbon distribution. Common depositional environments for sandstone reservoirs include fluvial, deltaic, marine, and aeolian settings.
- Well Log Interpretation
- Core Analysis
- Seismic stratigraphy
- Petrographic Analysis

GR Log Pattern	Cylindrical/ Boxcar	Funnel	Bell	Symmetrical	Serated/Irregular
GR Trend	Left Right Low GR High GR	Coarse Up & Sharp top	Fine Up & Sharp base	Hour Glass	Saw Teeth
Sediment Supply	Agrrading	Prograding	Retrograding	Prograding & Retrograding	Aggrading
Depositional Environment (Common)	Fluvial channels Carbonate shelf, Reef, Submarine canyon fill, Prograding delta distributaries, Aeolian dunes, evaporite fill of basin	Crevasse splay, River, Mouth bar, Delta front, shoreface, Submarine fan lope	Fluvial Ppoint bar, Tidal point bar, deep tidal channel fill, Deltaic channels, proximal deep sea settings, Tidal flats	Reworke offshore bar, regressive to transgressive shore face delta,	Fluvial flood plain, Storm dominated shelf, mixed Tidal flat, Debris flow, Canyon fill, Deep marine-slope

Radwan, 2021

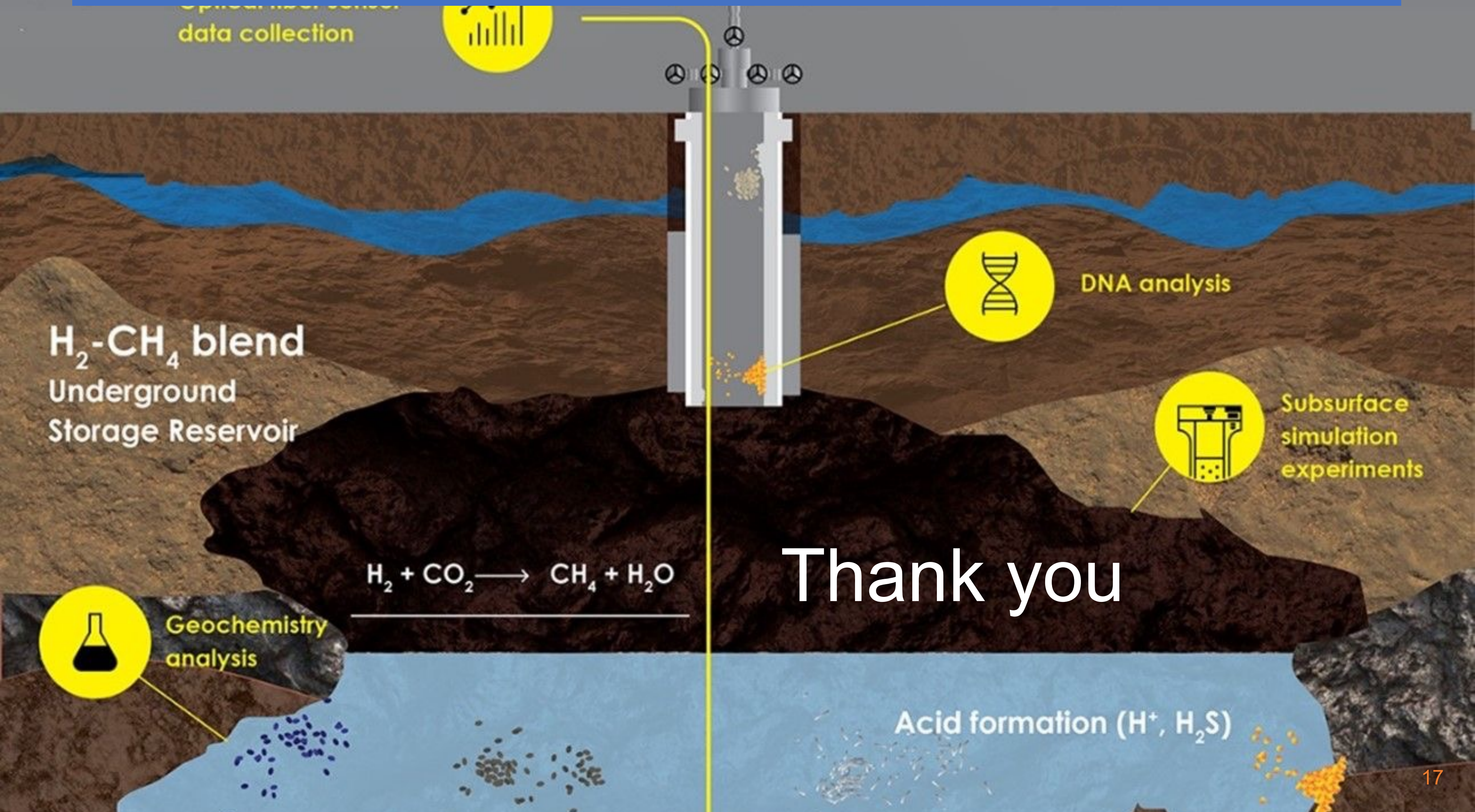
DEPOSITIONAL ENVIRONMENT

- Practically the shaliness often does not change suddenly but occurs gradually with depth.
- Such gradual changes are indicative of the litho-facies and the depositional environment of the rock and are associated with changes in grain size and sorting that are controlled by facies and depositional environment as well as being associated with the shaliness of the rock.

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

Grover, 2010

END OF LECTURE



Thank you