EPFL

Rock Physics

From mm. to Km. scale

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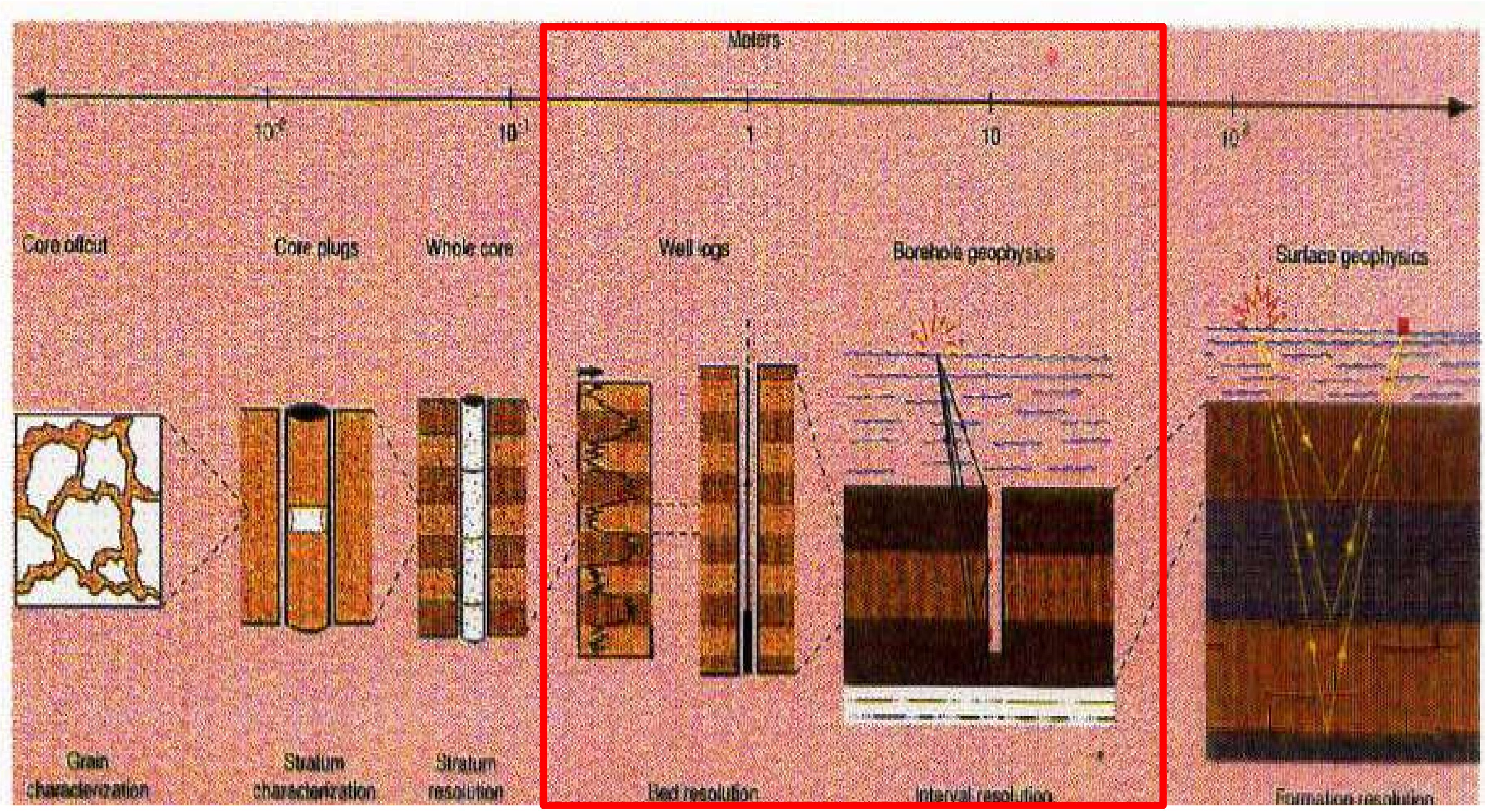
5 . Introduction to borehole geophysics (logging)

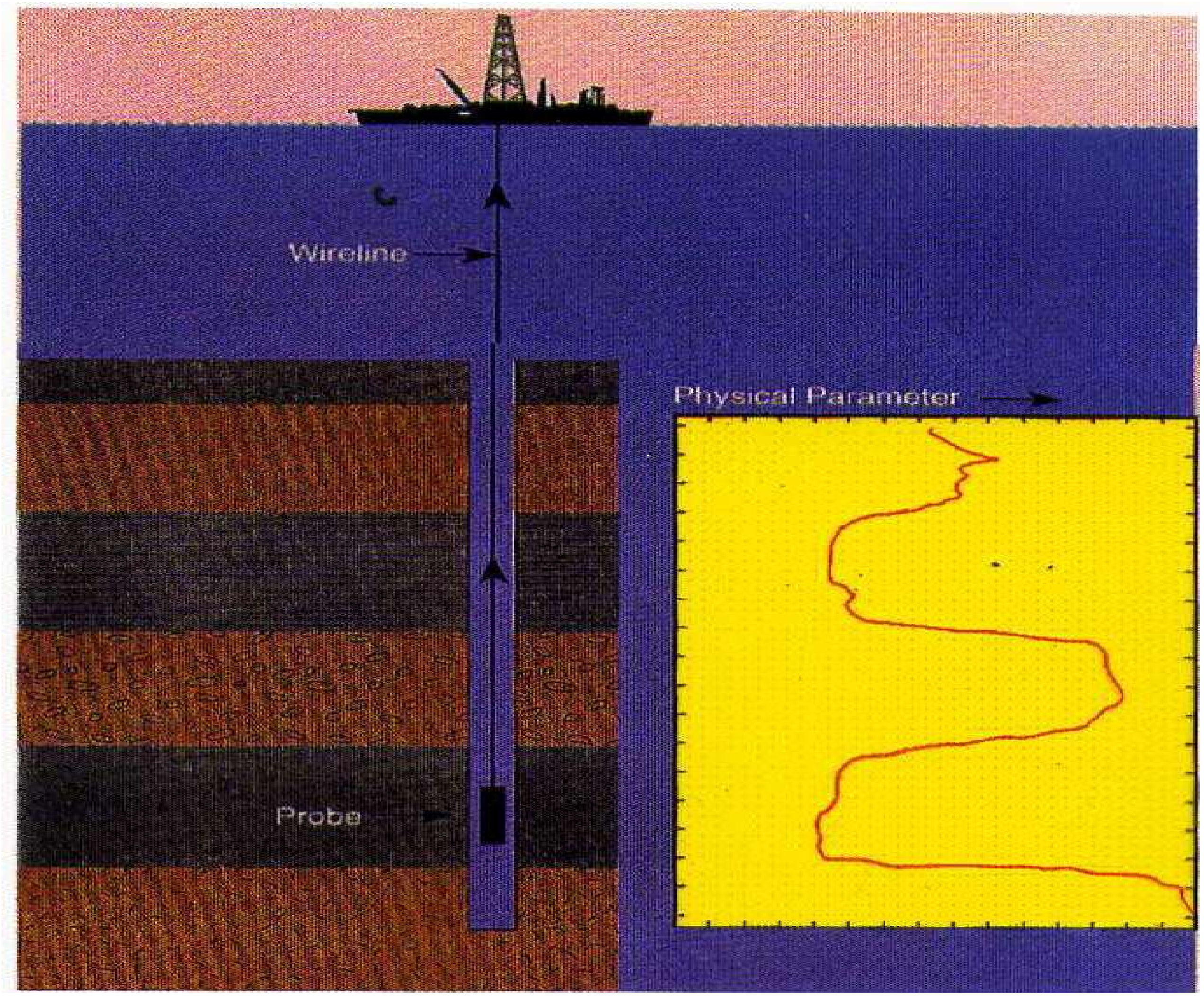
Some slides from P. Glover and S. Gautier.

➢ Borehole geophysics



➢ **Borehole geophysics**

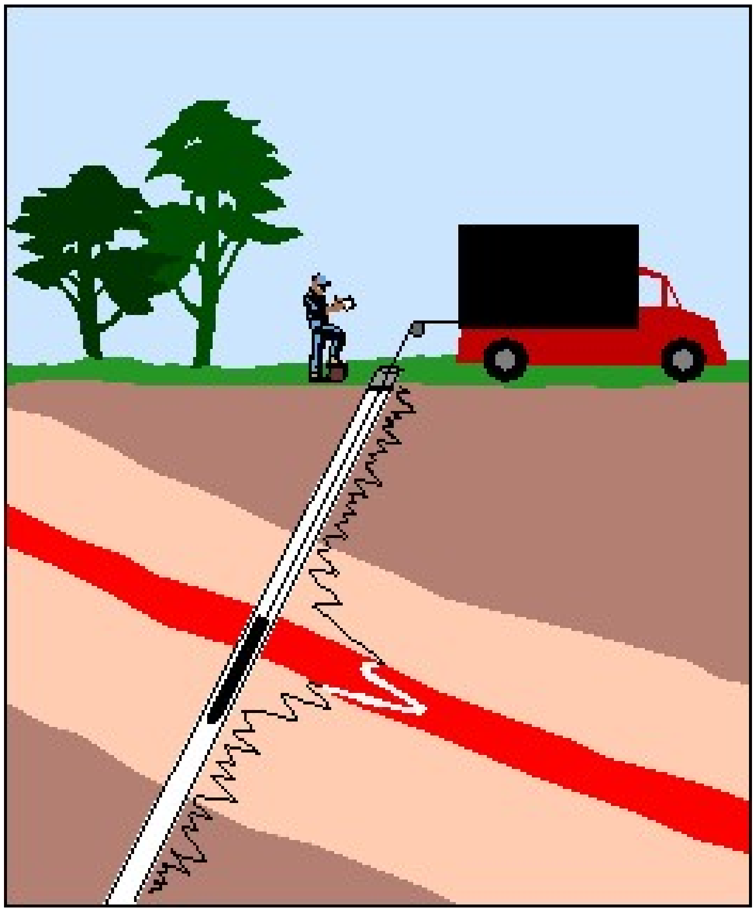
Give accurate and representative data on the physical properties of the rock formations and fluids encountered in a borehole.



- **<u>logging</u>**

  A *log* is a continuous recording of a geophysical parameter along a borehole.

➢ logging



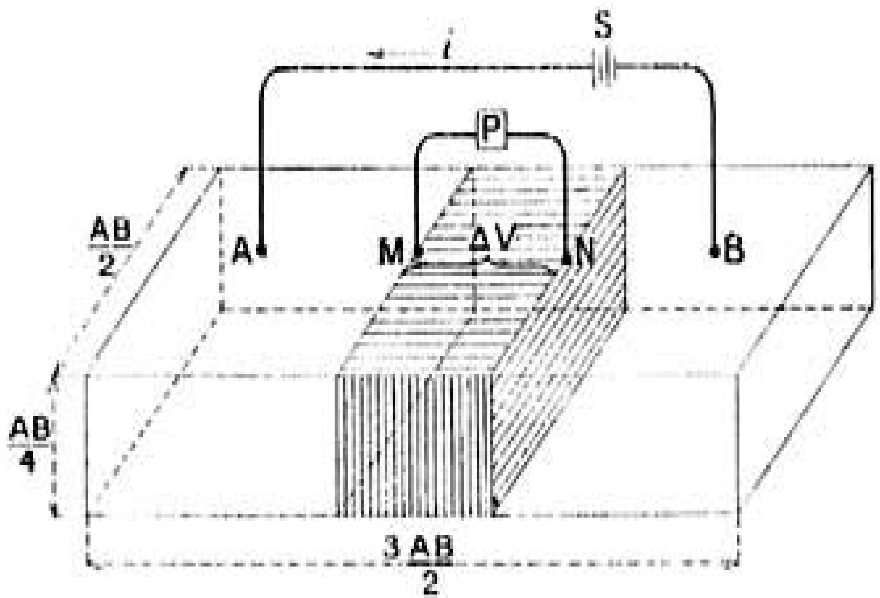
Physical parameters α=f(z)

basic physical parameters that can be measured down-hole with

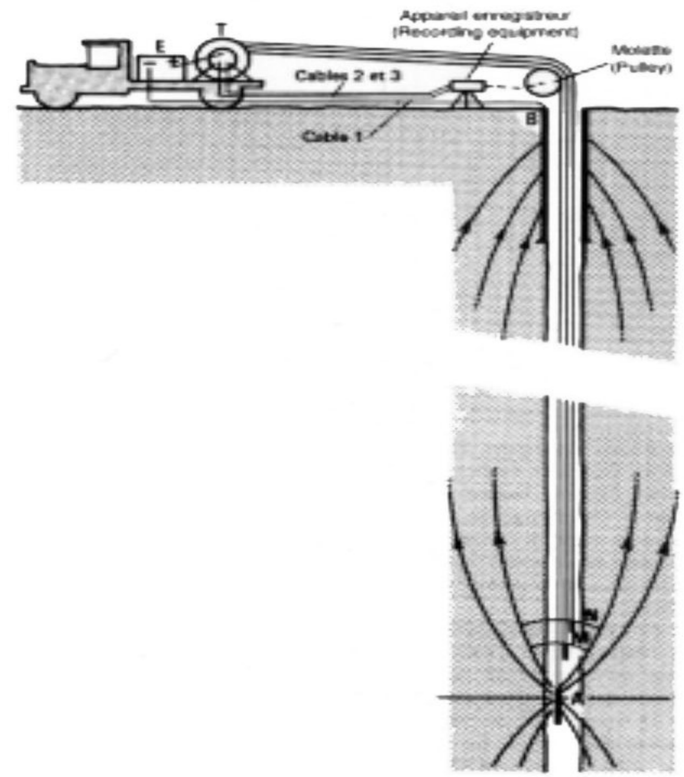
(a) size of the borehole
(b) orientation of the borehole
(c) temperature,
(d) pressure,
(e) natural radioactivity of the rocks,
(f) acoustic properties of the rocks,
(g) attenuation offered by the rocks to radioactivity generated from the tool
(h) electrical properties of the rocks.

➢ **A bit of history**

1911: first measure of electrical conductivity at the surface



1927: first measure of electrical conductivity in a borehole

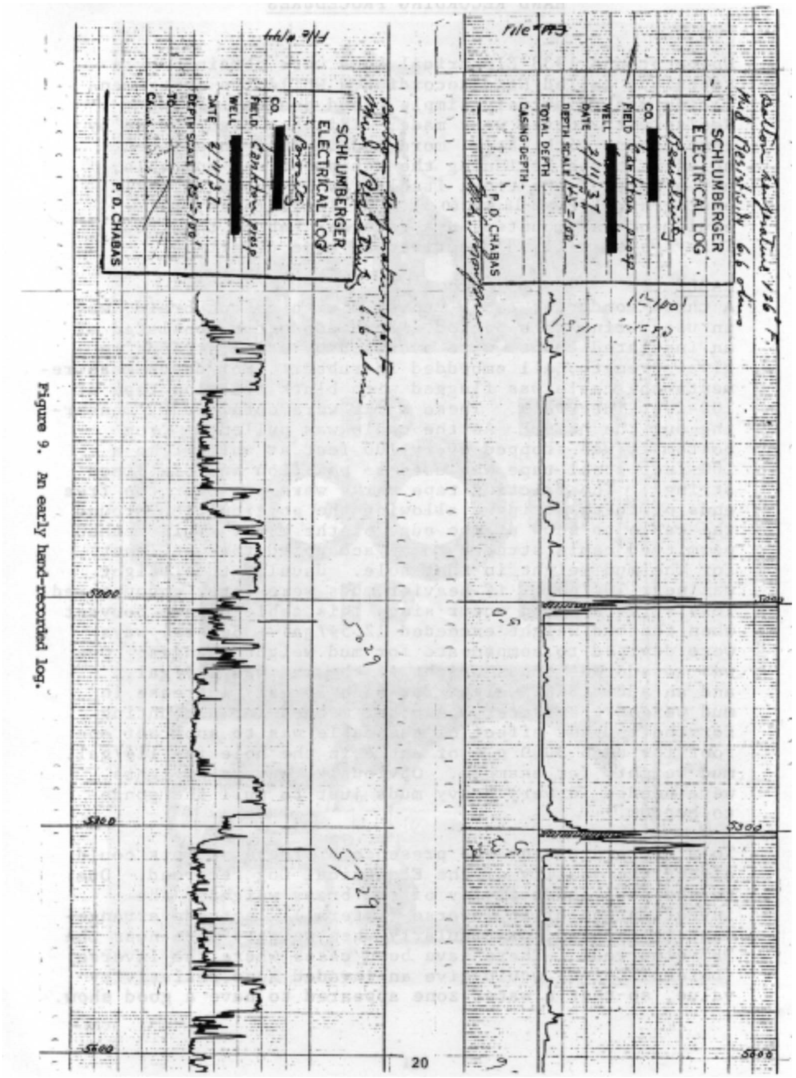


Objective: identification of the geological formations + fluid (oil)

A bit of history

- First electrical log at Pechelbronn (Fr) , 1927

(cf. Schlumberger)



➢ Definition

Well

Drill bit

Casing

➢ Logging

When:

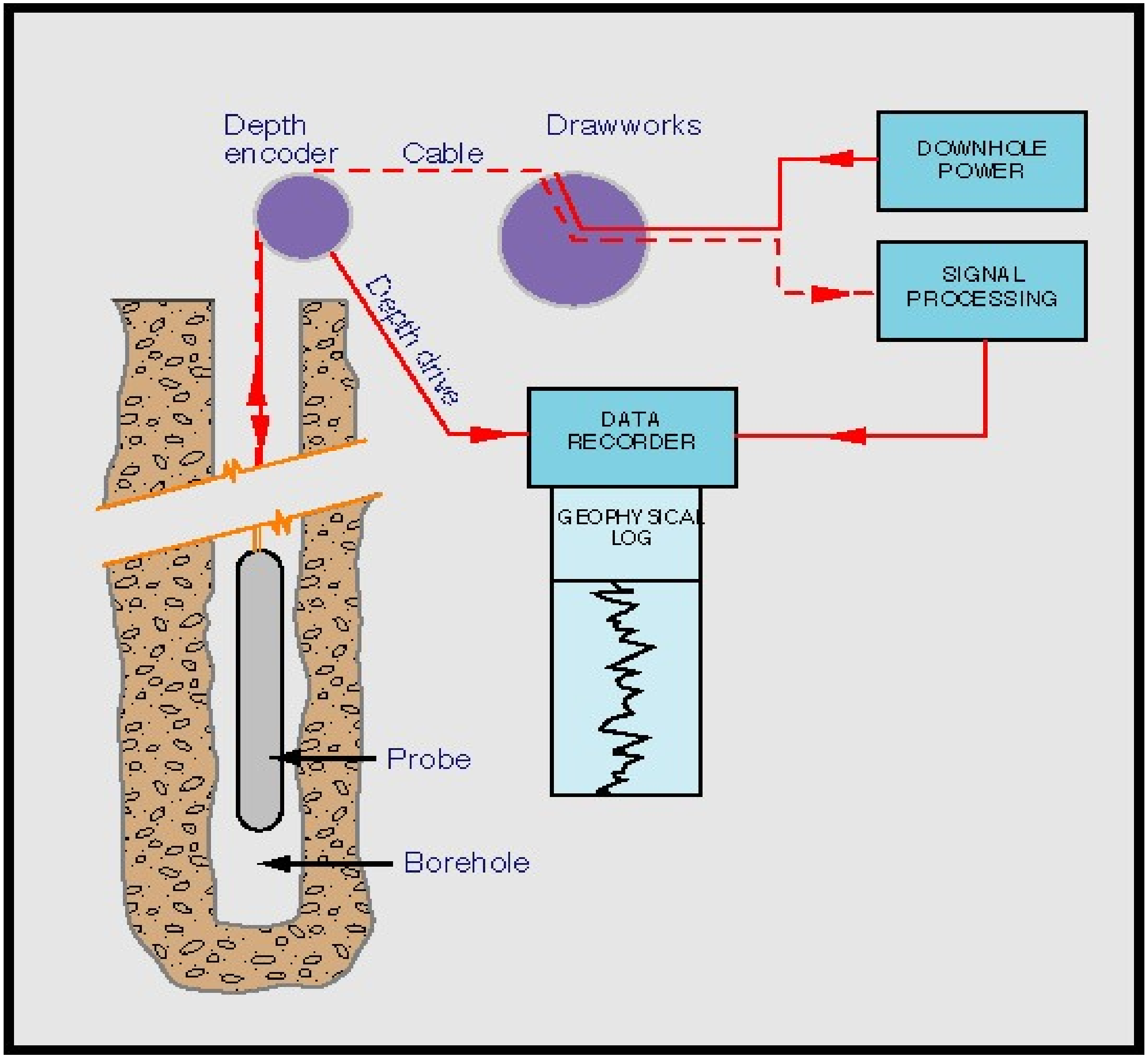
- 1) in between drilling episodes (open-hole logs)
- 2) before casing (open-hole logs)
- 3) at the end of drilling ((open-hole logs)
- *4) after casing (cased-hole logs).*

Best data quality

Recent developments also allow some measurements to be made during drilling.

- ***Measurement while drilling (MWD)*** ➔ low band-width radio communication
- ***Logging while drilling (LWD)***

➢ **Experimental arrangement**



➢ Experimental arrangement

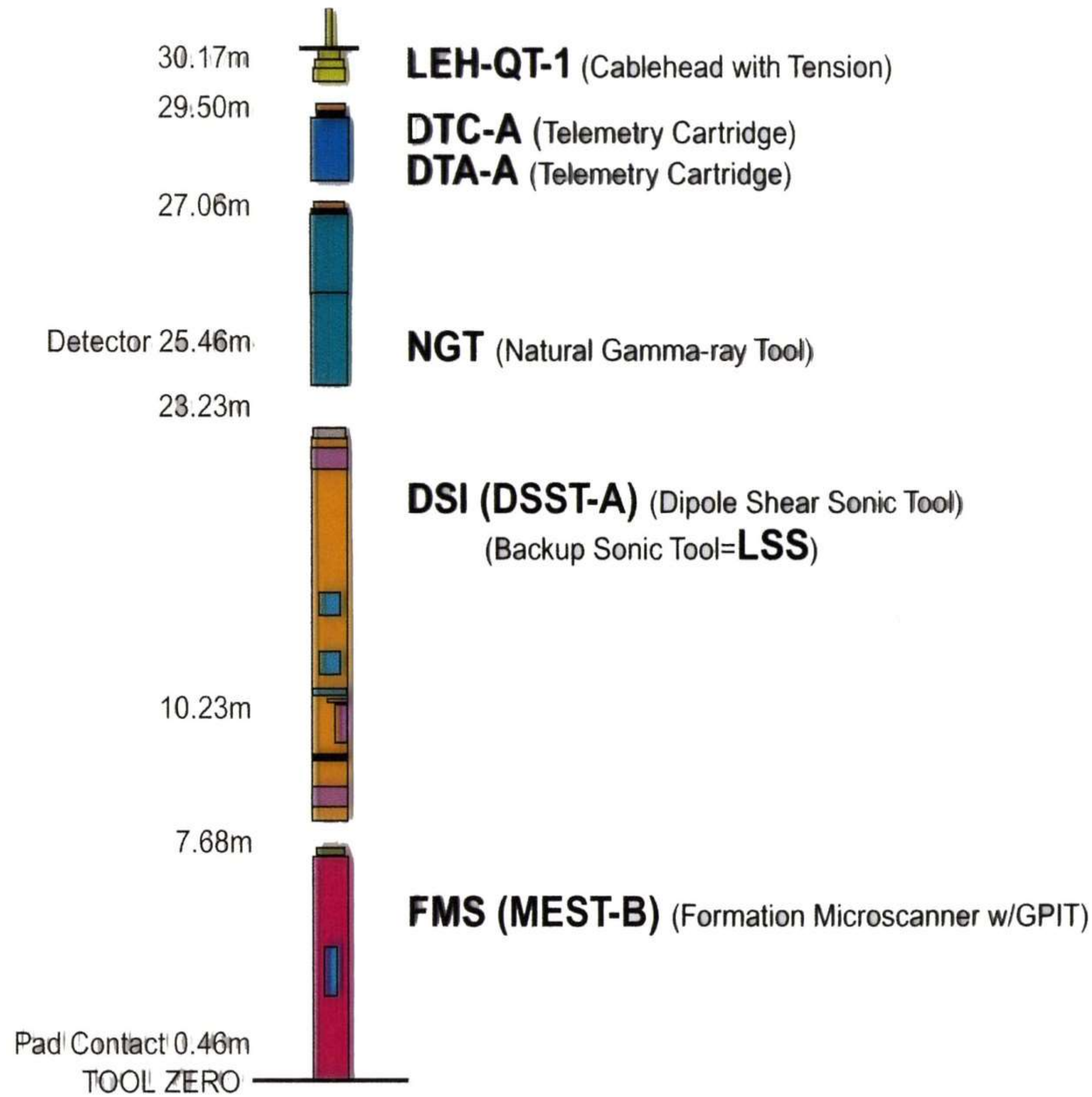
➢ **JOIDES Resolution (IODP)**

➢ JOIDES Resolution (IODP)

➢ Tools

There are a plethora of logging tools now available. There can be split into the following types:

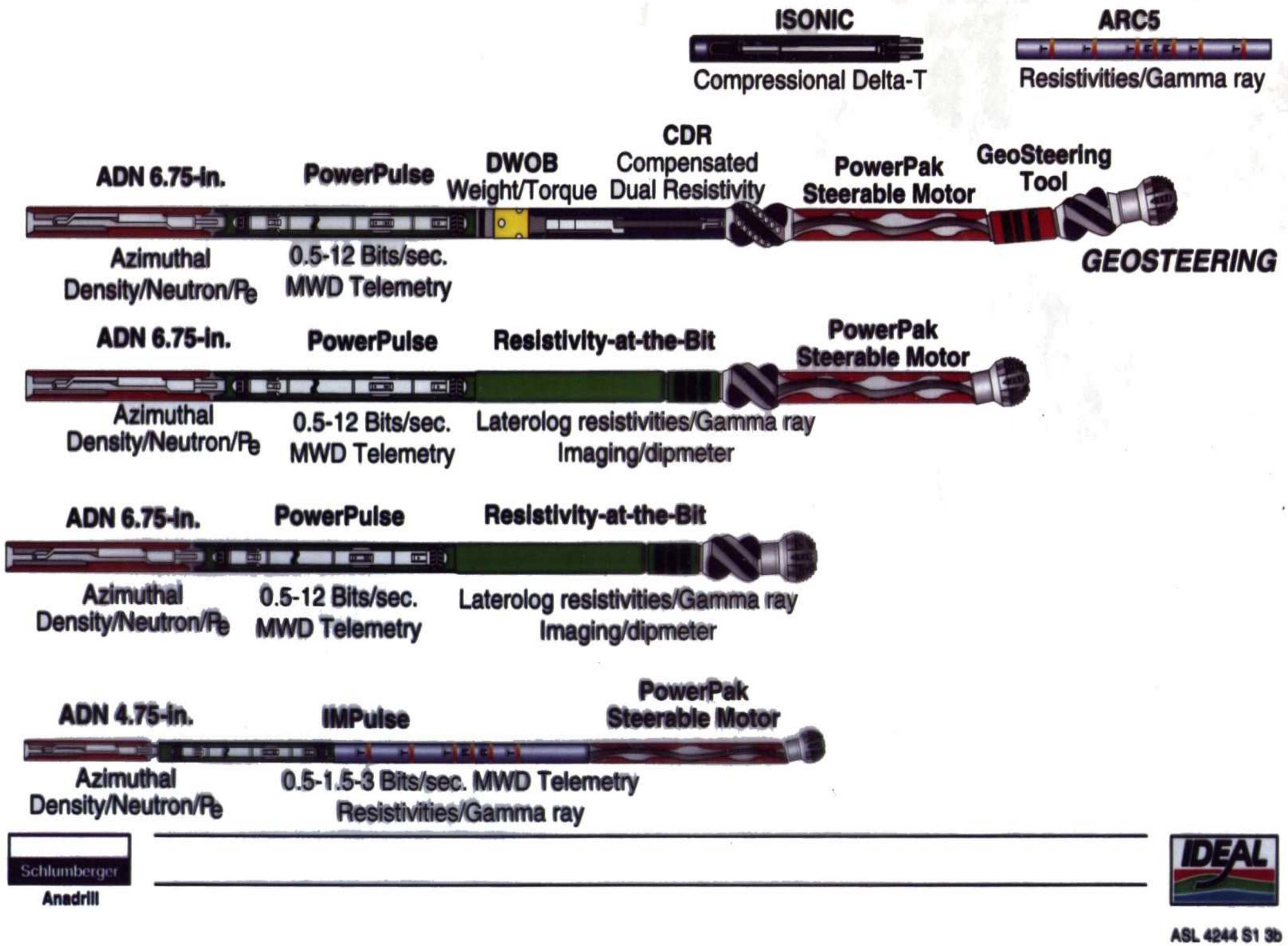
- Standard open-hole tools (diameter 3 to 4 inches)
- Slim hole tools (diameter 1.6875 to 2 inches)
- Cement-logging tools (work through cement casing)
- Production tools (pressure flow rate, used during production
- LWD tools



➢ Tools

Tool	Physical Measurement	Use	Comments
Logging conditions			
Temperature (BHT)	Temperature	Borehole temperature for resistivity calculations.	Corrected with Horner plot
Pressure (PRESS)	Fluid pressure	Fluid pressure for formation volume factor calculations.	Incorporated in RFT
Caliper (CAL)	Borehole diameter	Data quality, in situ stress tensor, lithology and permeability indicator	Available in 2, 4, or multi-arm versions.
Lithology			
Gamma Ray (GR)	Natural radioactivity of the formation.	Shale indicator and depth matching	Can read through casing.
Spontaneous Potential (SP)	Sand/shale interface potential.	Permeable beds Resistivity of formation water	Does not work in conductive muds, or offshore.
Porosity			
Sonic (BHC, LSS)	Velocity of an elastic wave in the formation.	Effective (connected) porosity	Compaction, gas and vugs, calibration of seismic data.
Density (FDC, LDT)	Bulk density of the formation.	Total porosity	Used to calculate synthetic seismograms.
Neutron (SNP, CNL)	Hydrogen concentration in the formation.	Total porosity (shale increases measured porosity, gas reduces measured porosity)	Can read through casing.
Resistivity			
Simple electric log (SN, LN, Lat)	Resistivity of flushed, shallow and deep zones respectively.	Used in water saturation calculations.	Now obsolete, not focussed, can't be used in oil based muds, prone to invasion.
Induction Logs (IES, ISF, DIL, DISF, ILm, ILd)	Conductivity of the formation.	Conductivity and resistivity in oil based muds, and hence calculation of water saturation.	Focussed devices. Use in oil based and fresh water muds. Range of depths of investigation. (Vertical resolution 5-10 ft.)
Laterologs (LL3, LL7, DLL, LLs, LLd)	Resistivity of the formation.	Resistivity in water based muds, and hence calculation of water saturation.	Focussed devices. Use in salt water based muds. Range of depths of investigation. (Vertical resolution 2-4 ft.)
Microlog (ML)	Resistivity of mudcake and flushed zone.	Indicator of permeability. Detector of thin beds.	(vertical resolution about 1 ft.)
Micro-laterolog (MLL)	Resistivity of flushed zone.	Measures R_{xo}	Not good with thick mudcakes.
Proximity Log (PL)	Resistivity of flushed zone.	Measures R_{xo}	Not good if invasion is small.
Micro-spherically focussed log (MSFL)	Resistivity of flushed zone.	Measures R_{xo}	Part of DLL-R_{xo} tool.
Imaging Logs. There is a range of imaging logs based upon sonic, visual, electrical and NMR measurements that are beyond the scope of this course.			

➢ LWD tools


ISONIC
Compressional Delta-T
ARC5
Resistivities/Gamma ray
ADN 6.75-in.
PowerPulse
DWOB
Weight/Torque
CDR
Compensated
Dual Resistivity
PowerPak
Steerable Motor
GeoSteering
Tool
Azimuthal
Density/Neutron/Pe
0.5-12 Bits/sec.
MWD Telemetry
GEOSTEERING
ADN 6.75-in.
PowerPulse
Resistivity-at-the-Bit
PowerPak
Steerable Motor
Azimuthal
Density/Neutron/Pe
0.5-12 Bits/sec.
MWD Telemetry
Laterolog resistivities/Gamma ray
Imaging/dipmeter
ADN 6.75-in.
PowerPulse
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Azimuthal
Density/Neutron/Pe
0.5-12 Bits/sec.
MWD Telemetry
Laterolog resistivities/Gamma ray
Imaging/dipmeter
ADN 4.75-in.
IMPulse
PowerPak
Steerable Motor
Azimuthal
Density/Neutron/Pe
0.5-1.5-3 Bits/sec. MWD Telemetry
Resistivities/Gamma ray
Schlumberger
Anadrill
IDEAL
ASL 4244 S1 3b

➢ Mud invasion

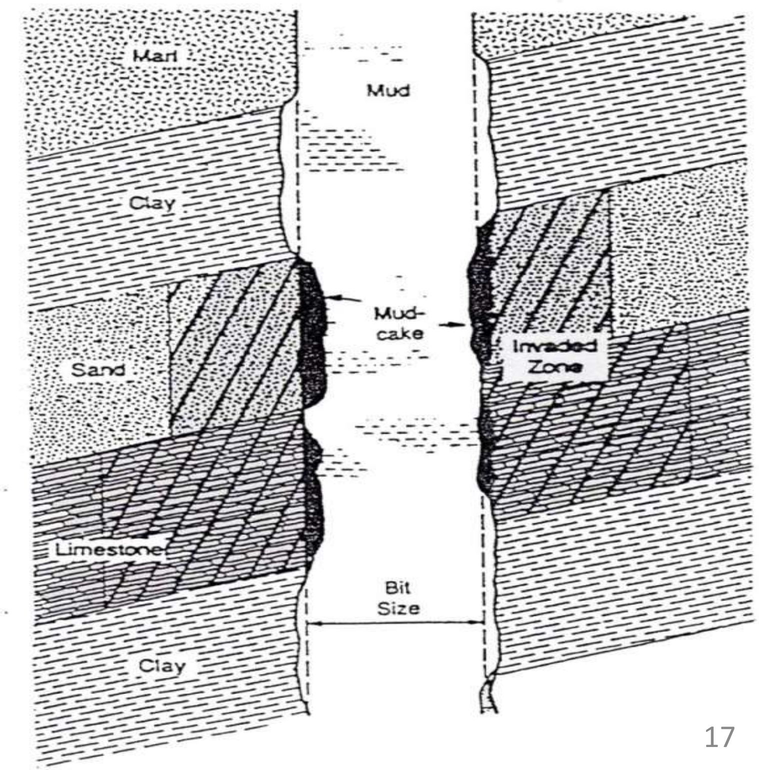
Drilling muds are used during drilling for at least 4 reasons:

- To lubricate the drill bit.
- To remove drilled material away from the drill bit and transport them to the surface.
- To counteract the fluid pressure in the rock.
- Stabilize the wellbore.

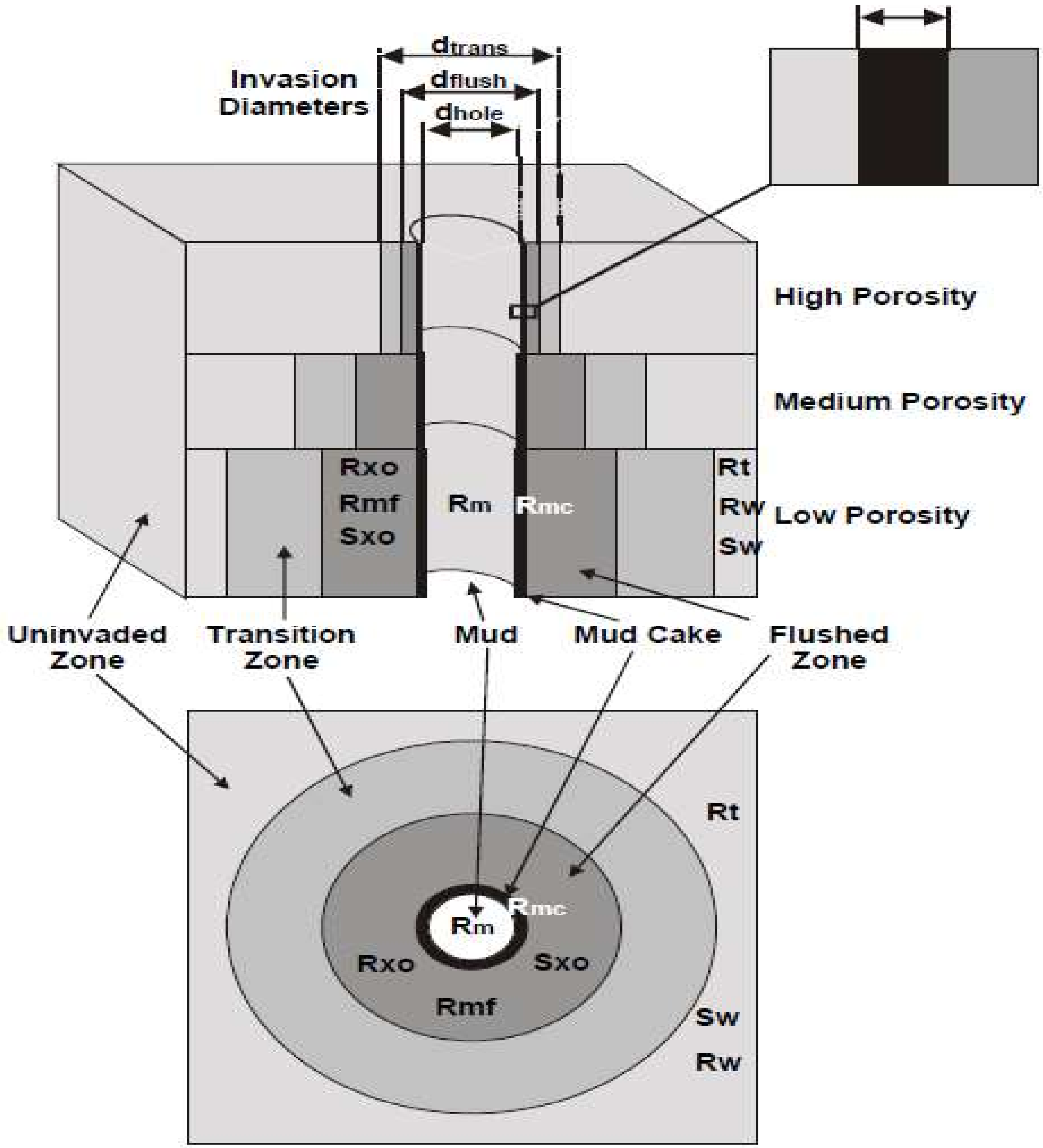
-Drilling muds > fluid pressure

- Mud flow into the formation =invasion (mud filtrate)
- Mud left at the surface = mud cake

➔ Disturb rock properties

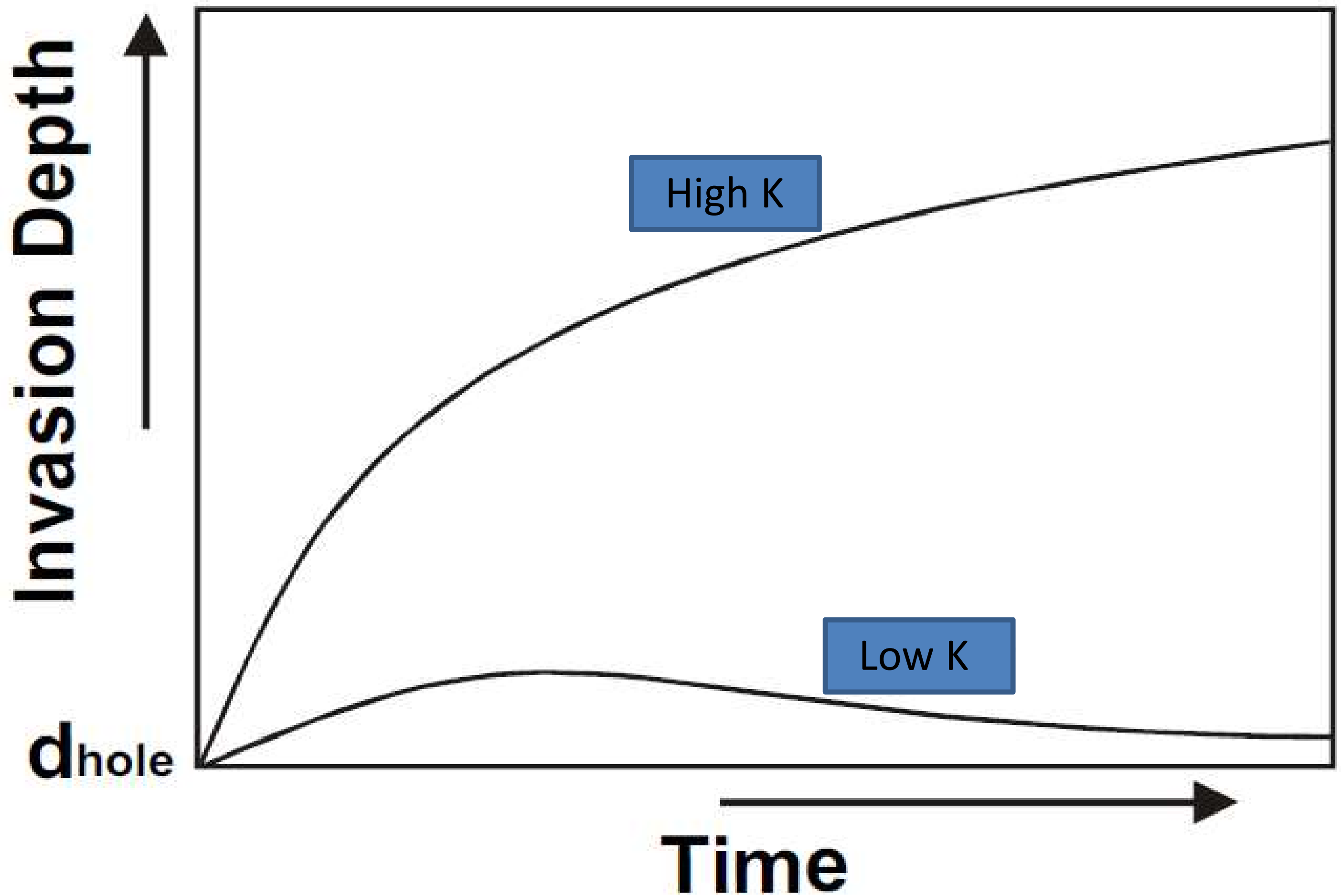


➢ Mud invasion

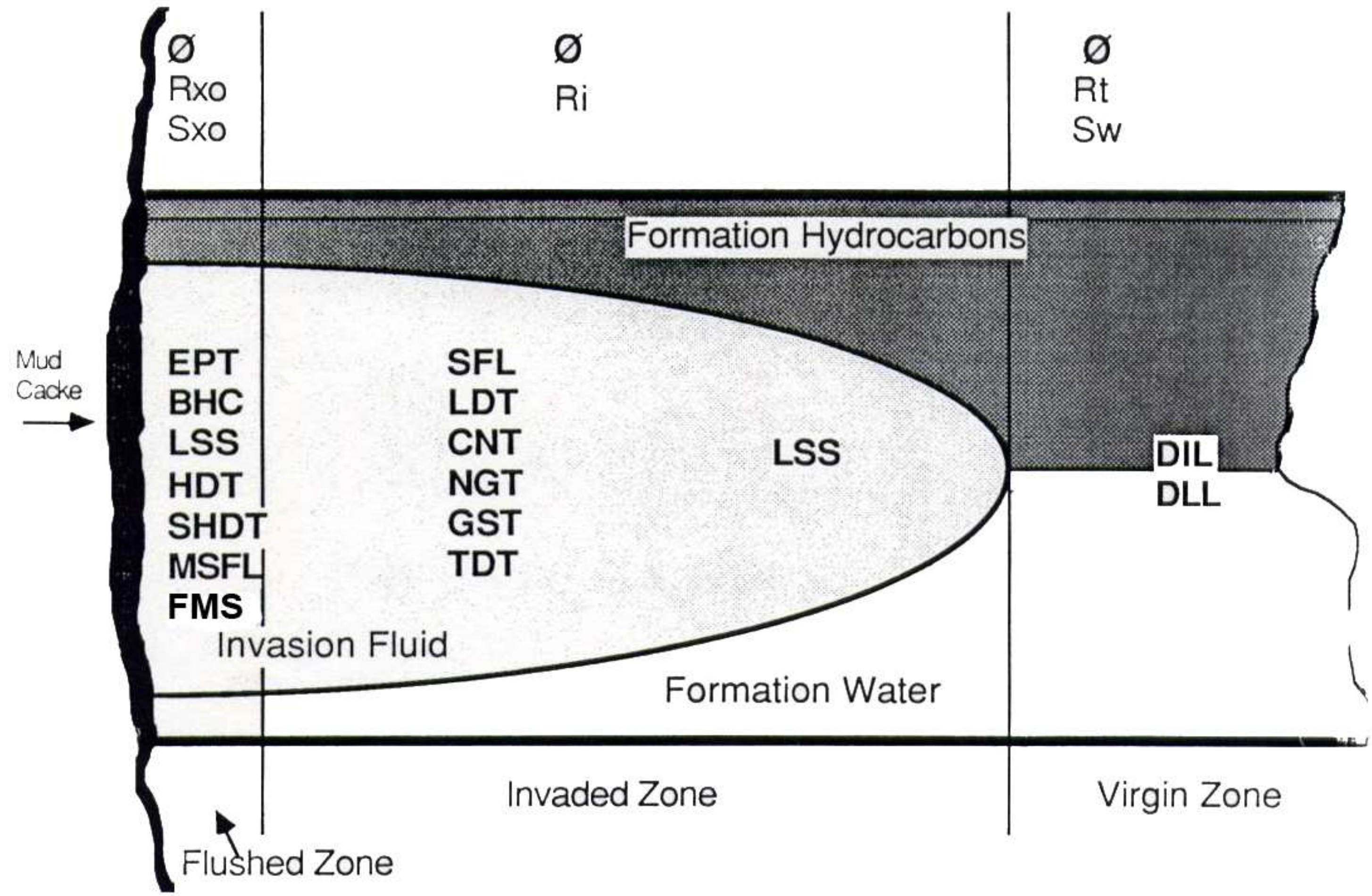


➢ Mud invasion

- The depth of invasion is related to the permeability of the rock.

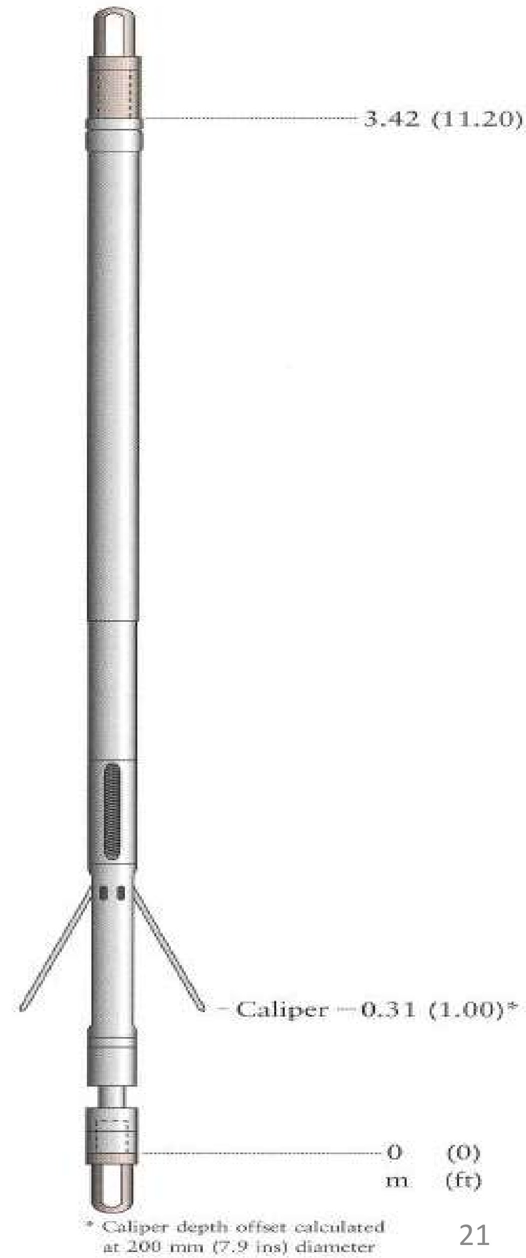


➢ Physical parameters influcenced by mud invasion



Caliper log

The ***Caliper Log*** is a tool for measuring the diameter and shape of a borehole. It uses a tool which has 2, 4, or more extendable arms. The arms can move in and out as the tool is withdrawn from the borehole, and the movement is converted into an electrical signal by a potentiometer.



➢ Factors influencing caliper responses

Hole Diameter	Cause	Possible Lithologies
On Gauge	Well consolidated formations Non-permeable formations.	Massive sandstones Calcareous shales Igneous rocks Metamorphic rocks
Larger than Bit Size	1. Formation soluble in drilling mud. 2. Formations weak and cave in.	1. Salt formations drilled with fresh water. 2. Unconsolidated sands, gravels, brittle shales.
Smaller than Bit Size	1. Formations swell and flow into borehole. 2. Development of mudcake for porous and permeable formations.	1. Swelling shales. 2. Porous, permeable sandstones.

➢ Uses of the Caliper Log

The commoner uses of the caliper log are as follows:

- Contributory information for lithological assessment
- Indicator of good permeability and porosity zones (reservoir rock) due to development of mudcake in association with gamma ray log.
- Calculation of mudcake thickness, $\boldsymbol{h_{mc}} = \frac{\boldsymbol{d_{bit} - d_h}}{\boldsymbol{2}}$, where *h* stands for the hole, in inches.
- Measurement of borehole volume, $\boldsymbol{V_h} \approx \frac{\boldsymbol{d_h^2}}{\boldsymbol{2}} + \mathbf{1.2}\%$ in litres per metre.
- Measurement of required cement volume, $\boldsymbol{V_{cement}}$ **~ 0.5 X ($\boldsymbol{d_h^2}$– $\boldsymbol{d^2}$ *casing*) + 1%,** in litres per metre.

• Indication of hole quality for the assessment of the likely quality of other logs whose data quality is degraded by holes that are out of gauge.

➢ Uses of the Caliper Log

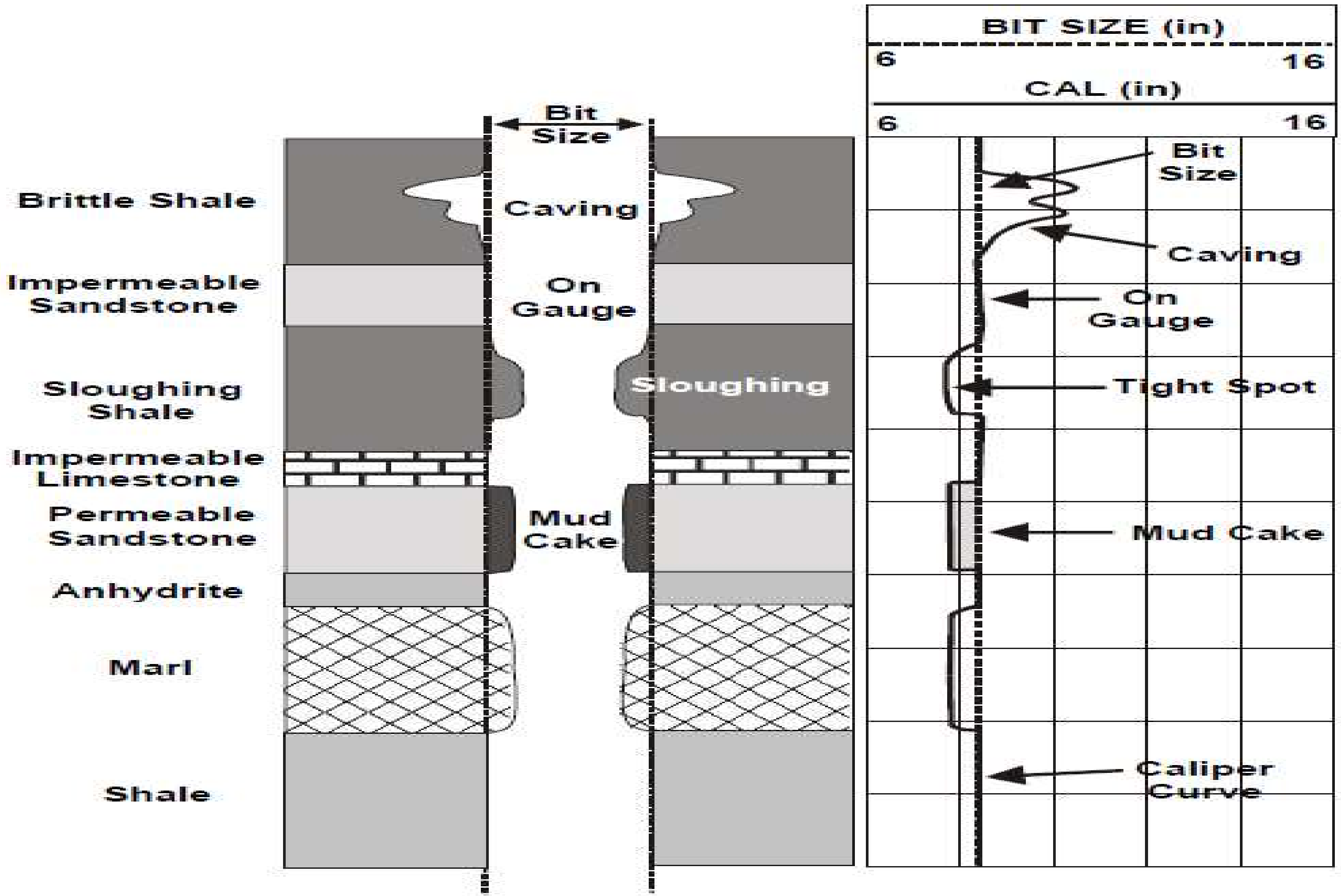


Figure 9.3 Typical caliper responses to various lithologies.

➢ Others logs

- Scalar data (1D) (m- scale resolution)
- Geophysical images (3D) (cm- scales resolution)

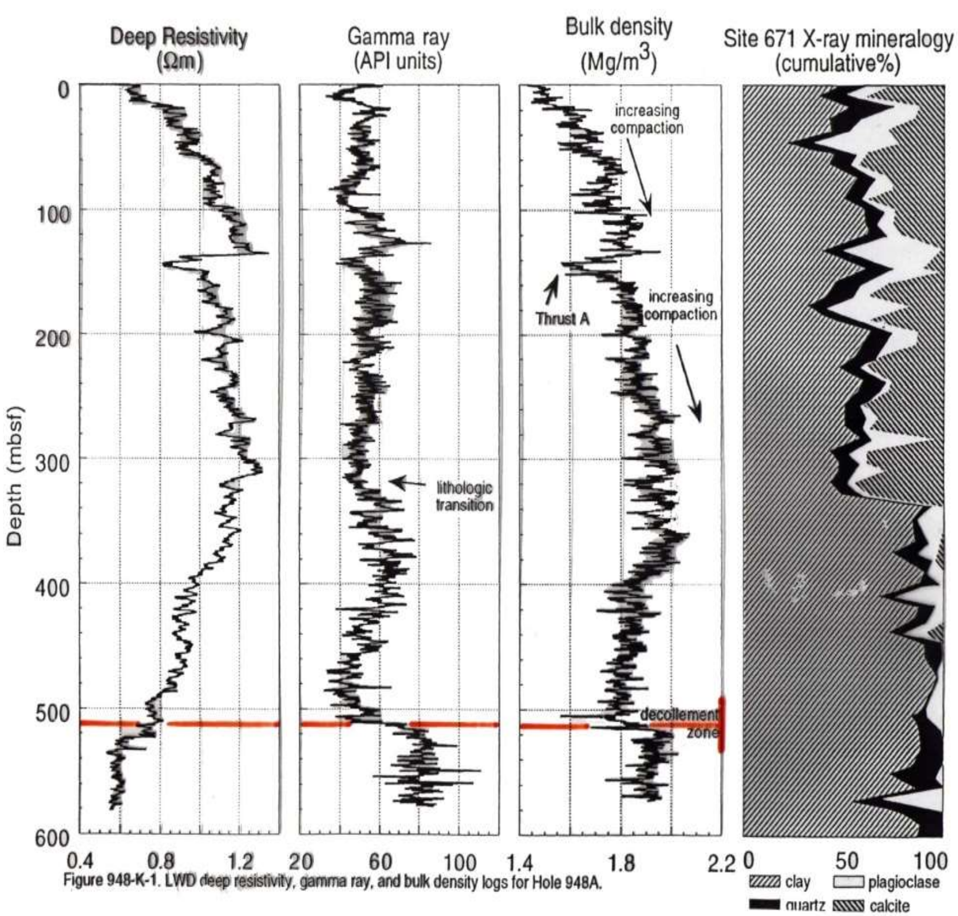
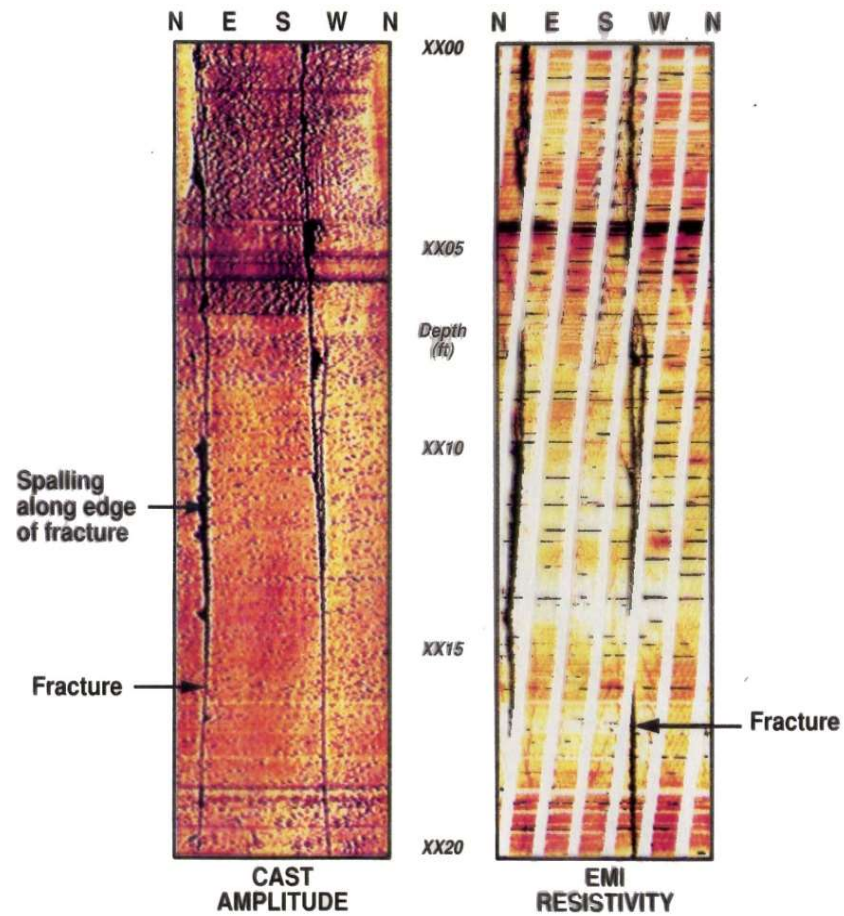
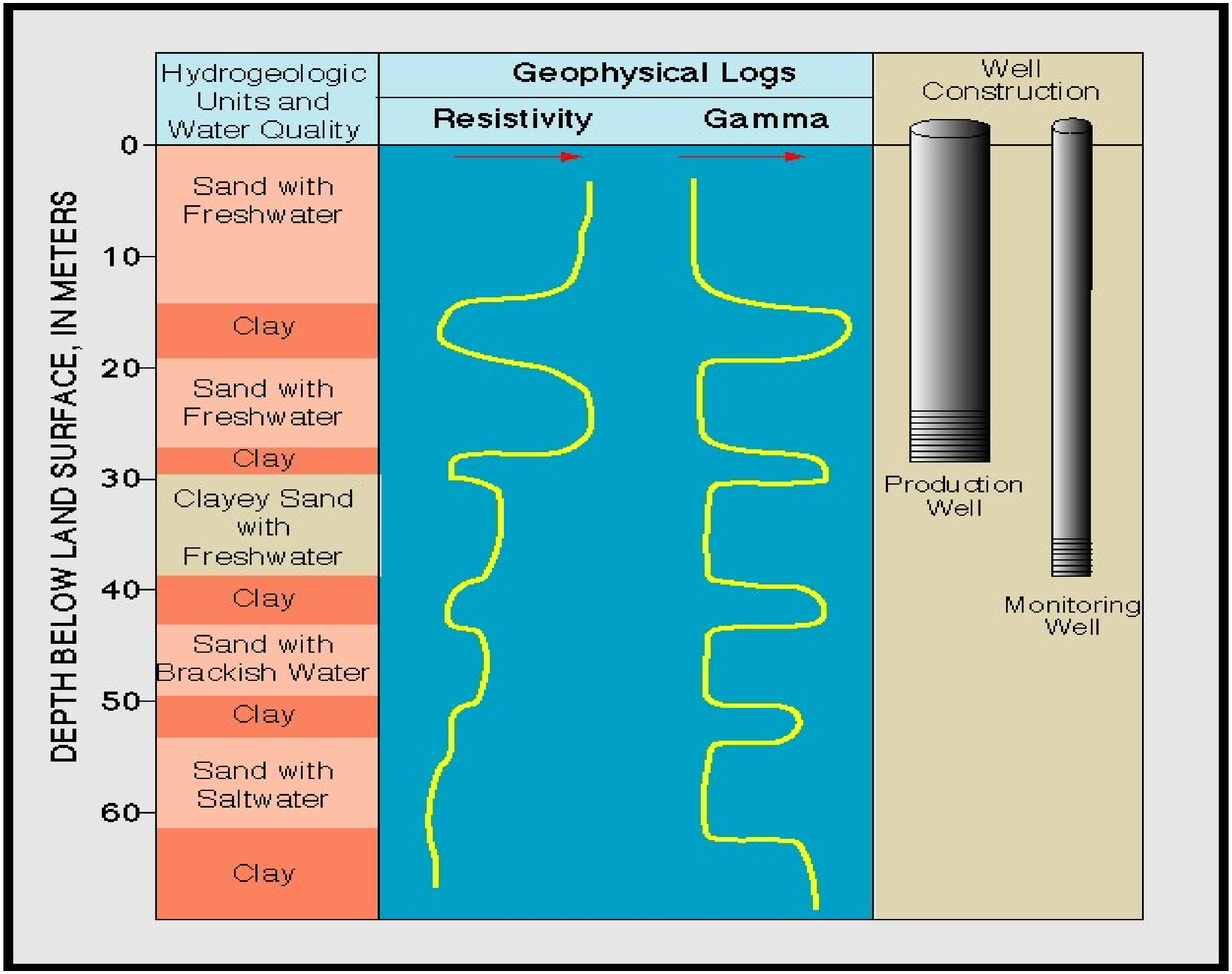


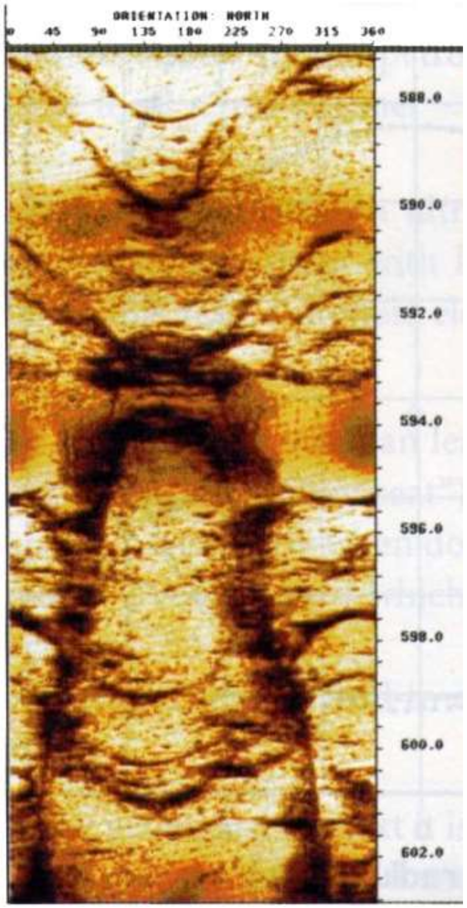
Figure 948-K-1. LWD deep resistivity, gamma ray, and bulk density logs for Hole 948A.

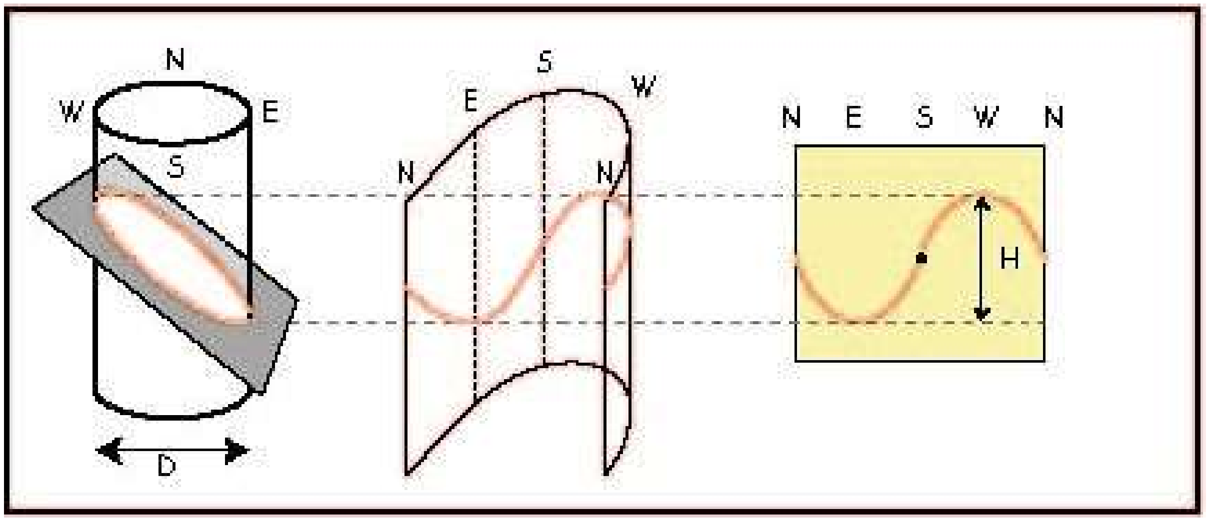


➢ **Scalar data (1D)**



➢ Borehole Images





$$\mathbf{D}ip = tan\left(\frac{H}{D}\right)$$

- **The course!**

  - Nuclear logs (Porosity)
  - Sonic logs (acoustic properties)
  - Resistivity logs (electrical properties)