
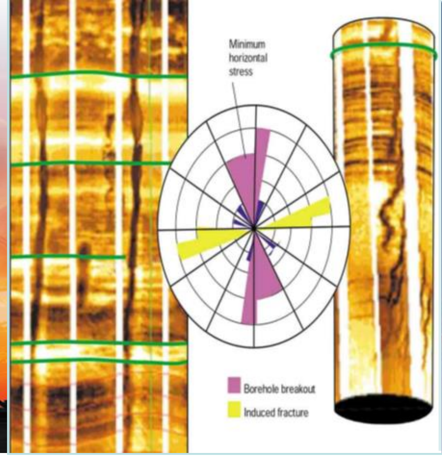

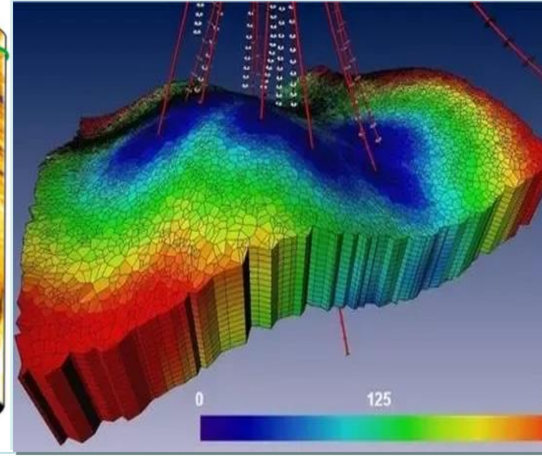

# Fundamentals of petroleum Engineering

## Part : 2-b
## Cased Hole Logging

By
Petroleum Engineer
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Iraq / Missan / 2020

# Contents

**Contents**
Part 2-b
Cased Hole
Logging

# Contents- cased hole logging

1. **Introduction to cased hole logging**
2. Cement Logs
3. Casing inspection log
4. Spectral Noise Tool ( SNL)
5. Production logging tool ( PLT)
6. Reservoir saturation tool

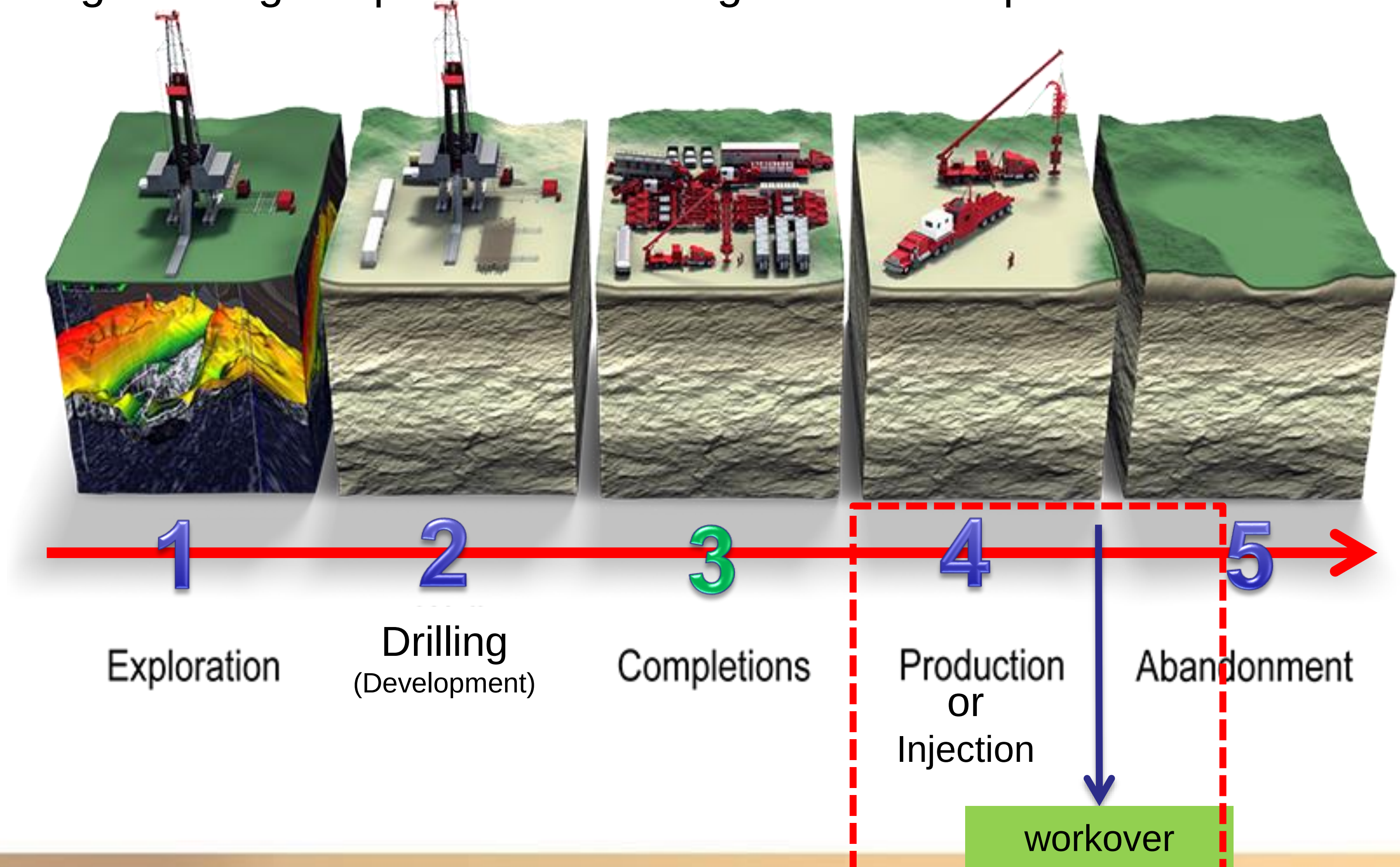
# Introduction to cased hole logging

## 1-Application of cased hole logging

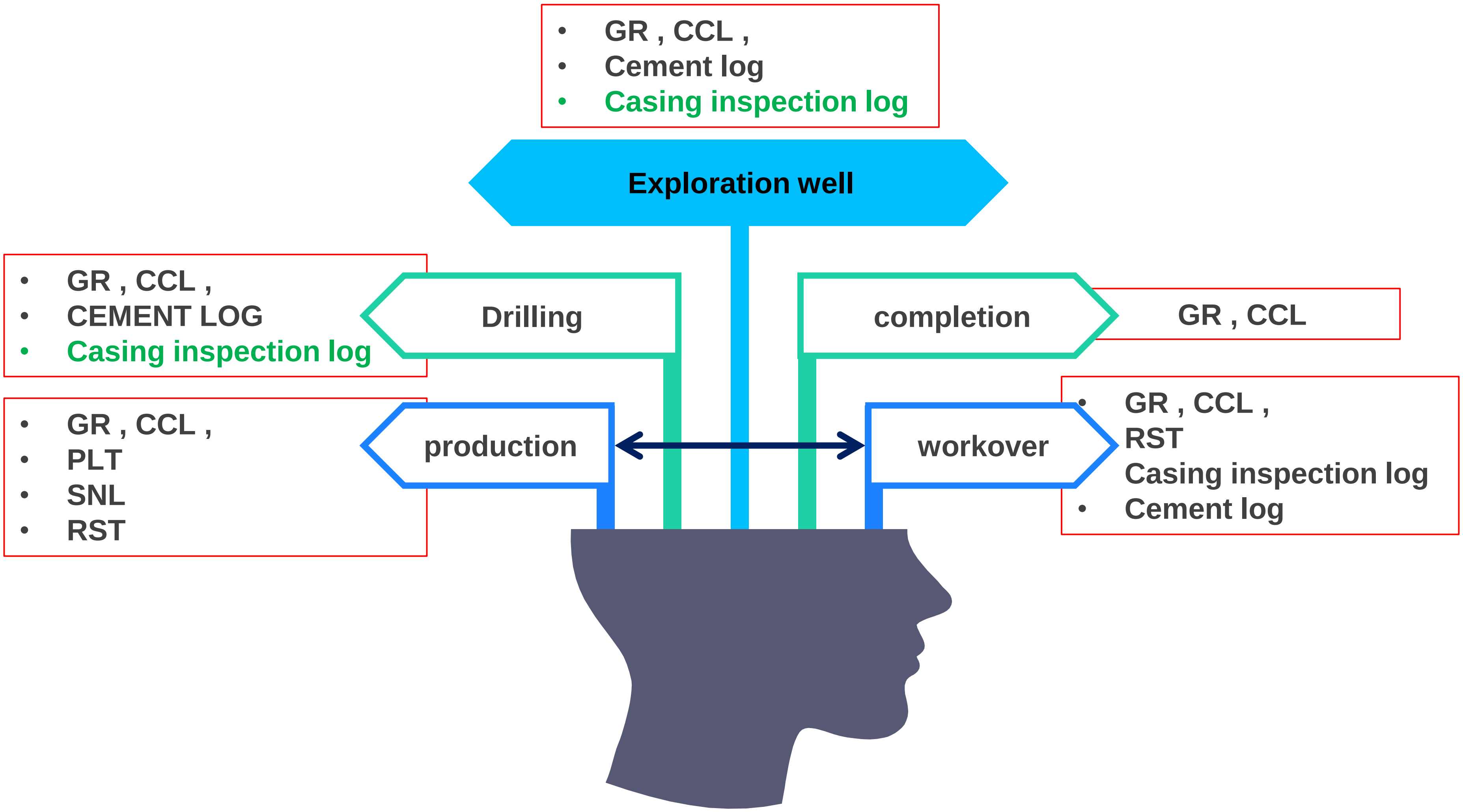
- Primary cement evaluation
- Monitoring and evaluation of the remaining oil saturation
- Production profile logging interpretation of single-phase & multi-phase
- Injection profile logging interpretation
- Casing inspection
- Diagnostic well problem ( packer leak , cross flow , channeling , water problem … etc )

# When do cased hole logging ?

We can do the cased hole logging in all stages of well life , but almost using it during the production to diagnostic some problems



# When do cased hole logging ?



# Choosing cased hole logging

Choosing the cased hole logging depend on Reservoir Surveillance plan or to diagnostic well problem , depend on well status

## Well status

### Flowing wells

**PLT**

1. Production rate
2. Injection rate
3. Fluid type
4. Cross flow
5. Casing leak

**SNL**

1. Channel behind casing
2. fracture
3. Packer leak
4. Casing leak

### Shut-in wells

**MIT**

Check casing damage

**CBL , URS**

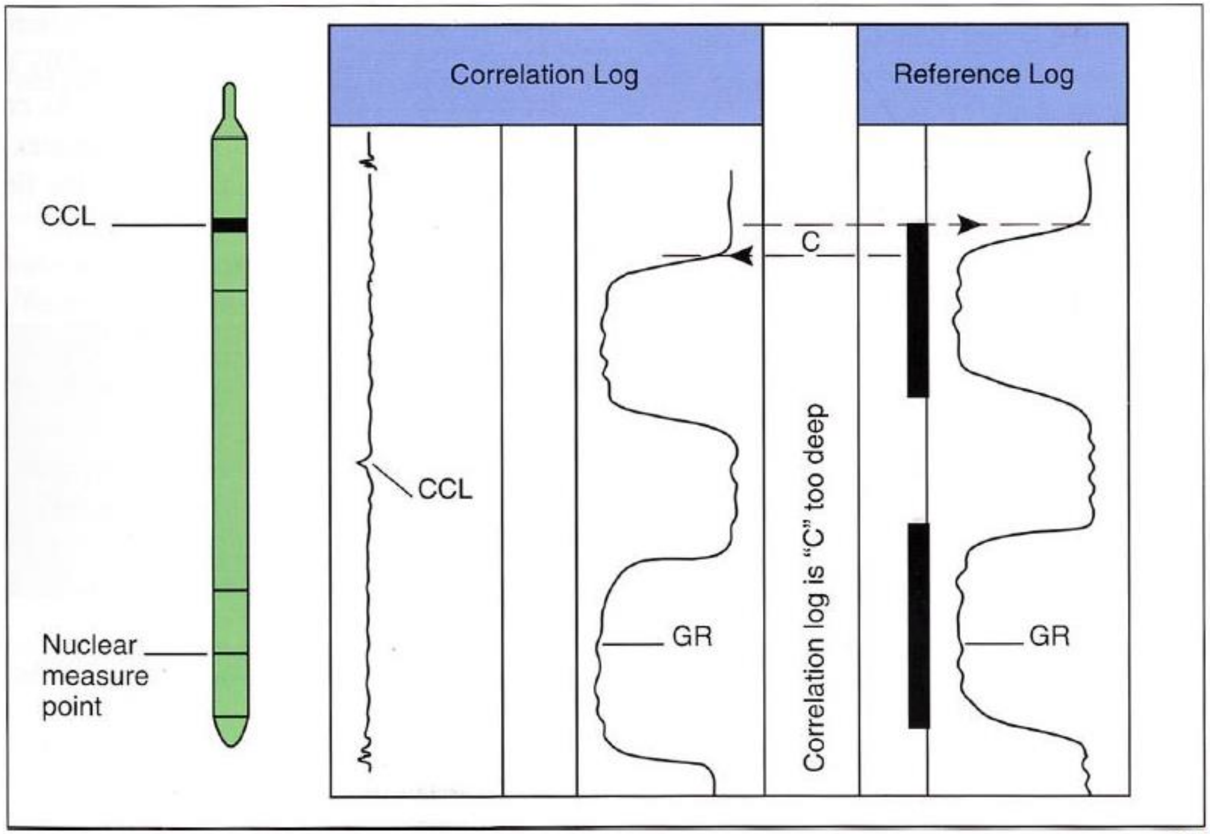
Check cement behind casing

**RST**

Formation evaluating behind casing

# GR , CCL for depth Control

**Note :** GR & CCL using with all cased hole logging for depth control ( depth correction ) , below example for depth correction before perforation operation :



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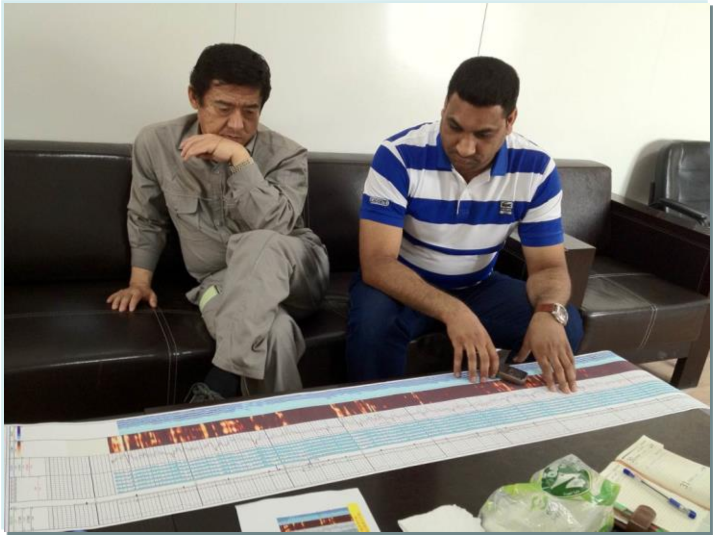


# Type of cement log

**Many  types for cement log see bellow table**

| No | Log | Full name | Company |
|---|---|---|---|
| 1 | CBL | Cement Bond Log | Many companies |
| 2 | SBT | Segmented Bond Tool | Backer Hughes |
| 3 | URS | Ultra sonic redial scanner | Weatherford |
| 4 | RIB | Radius Incremented Bond | AWALCO |
| 5 | RBT | Radial Bond Too | Halliburton |
| 6 | CAST | Circumferential Acoustic Scanning Tool | Halliburton |
| 7 | USI | Ultrasonic Image | Schlumberger |
| 8 | SCMT | Slim Cement Mapping Tool | |

# Logging Operation

Logging operation

**Pre- logging operation**

1. Selected type of cement log
2. Operation type depend on well type ( vertical , horizontal , sidetrack .. Etc

**After logging Operation**

1. Cement evaluation
2. Remedial plan ( if need )

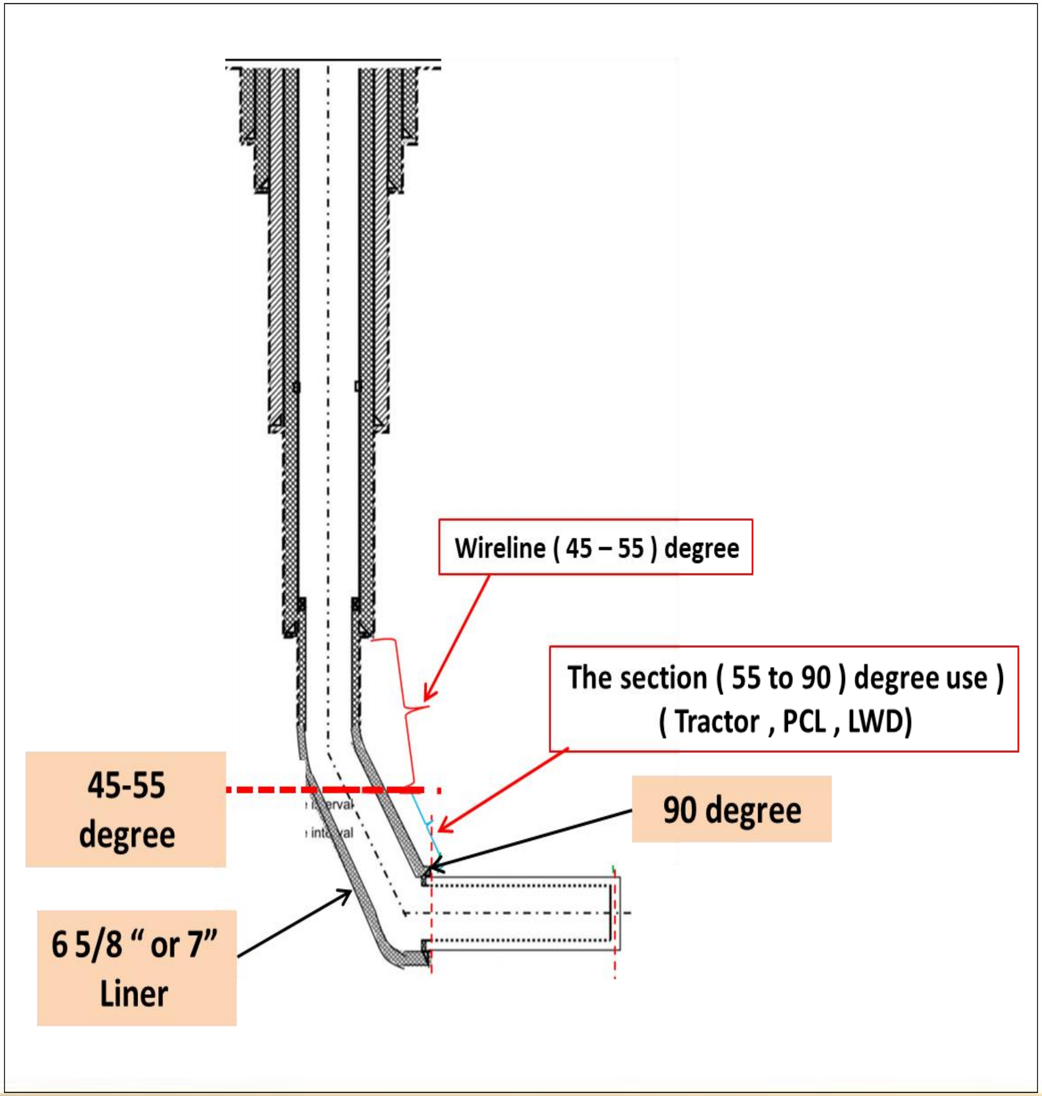
# Before Logging Operation

Logging operation in vertical wells

Can run the logging tools to TD smoothly with any problem

Logging operation in vertical wells

- Logging tools in horizontal wells can reach 45-55 degree
- The final inclination for horizontal section ( 89 – 90 ) degree
- To cover last section ( 55 – 90 ) degree should use another methods such as ( tractor , **PCL** , LWD )



# Before Logging Operation

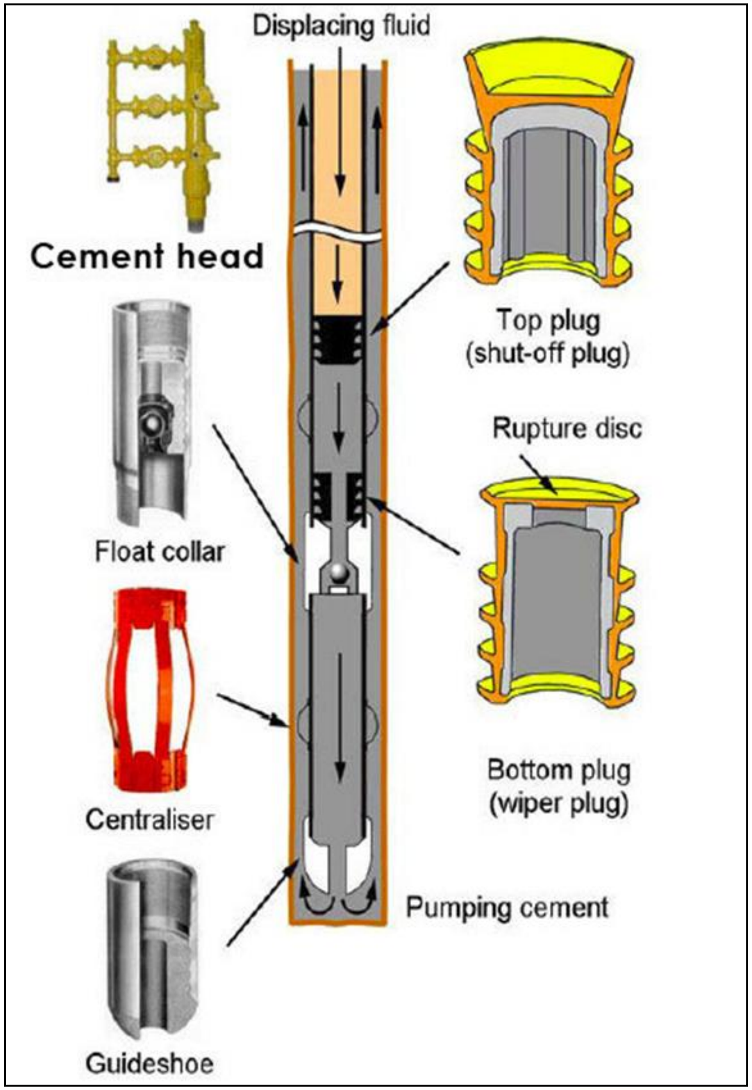
Before do cement log should flow this steps :

1. Wait for cement not less than 24 hours

2. Drill cement Dawn hole cement equipment (Float collar , Float shoe , DV , top plug , bottom plug )

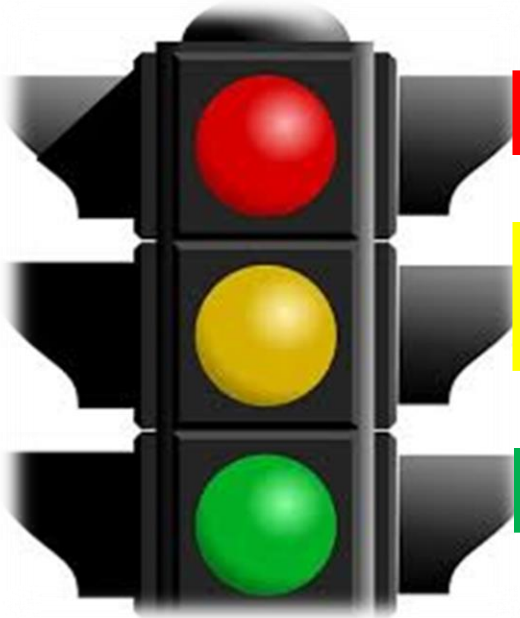
3. Do casing scrapper ( Optional )

4. Avoid FIT ( formation integrity test ) before logging operation , this test do after logging operation to avoid destroy the cement behind casing .



# After Logging Operation

After received the cement logging results should do cement evaluation report according to standard

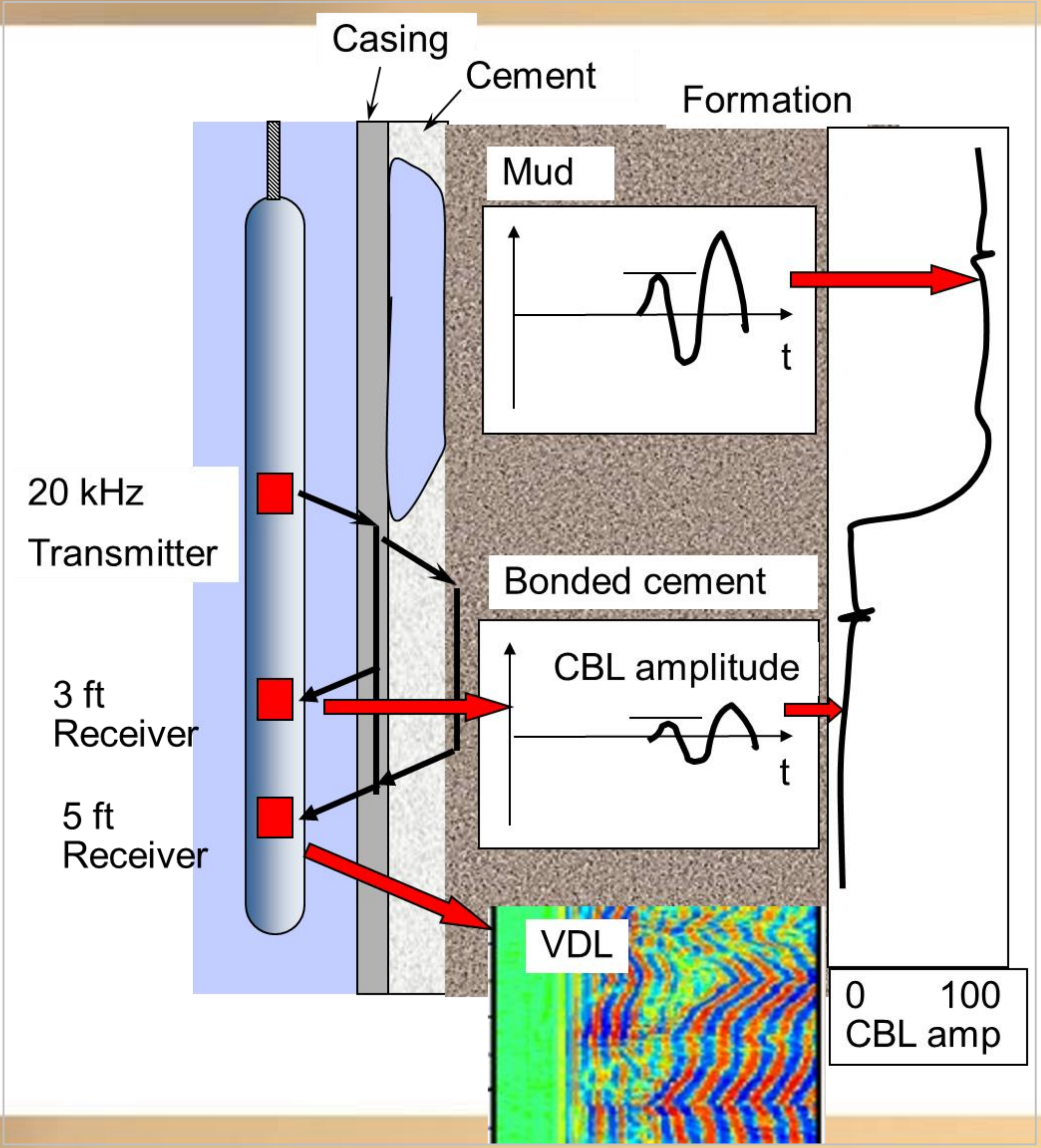


Poor ( Bad ) : STOP ( cant Pass )

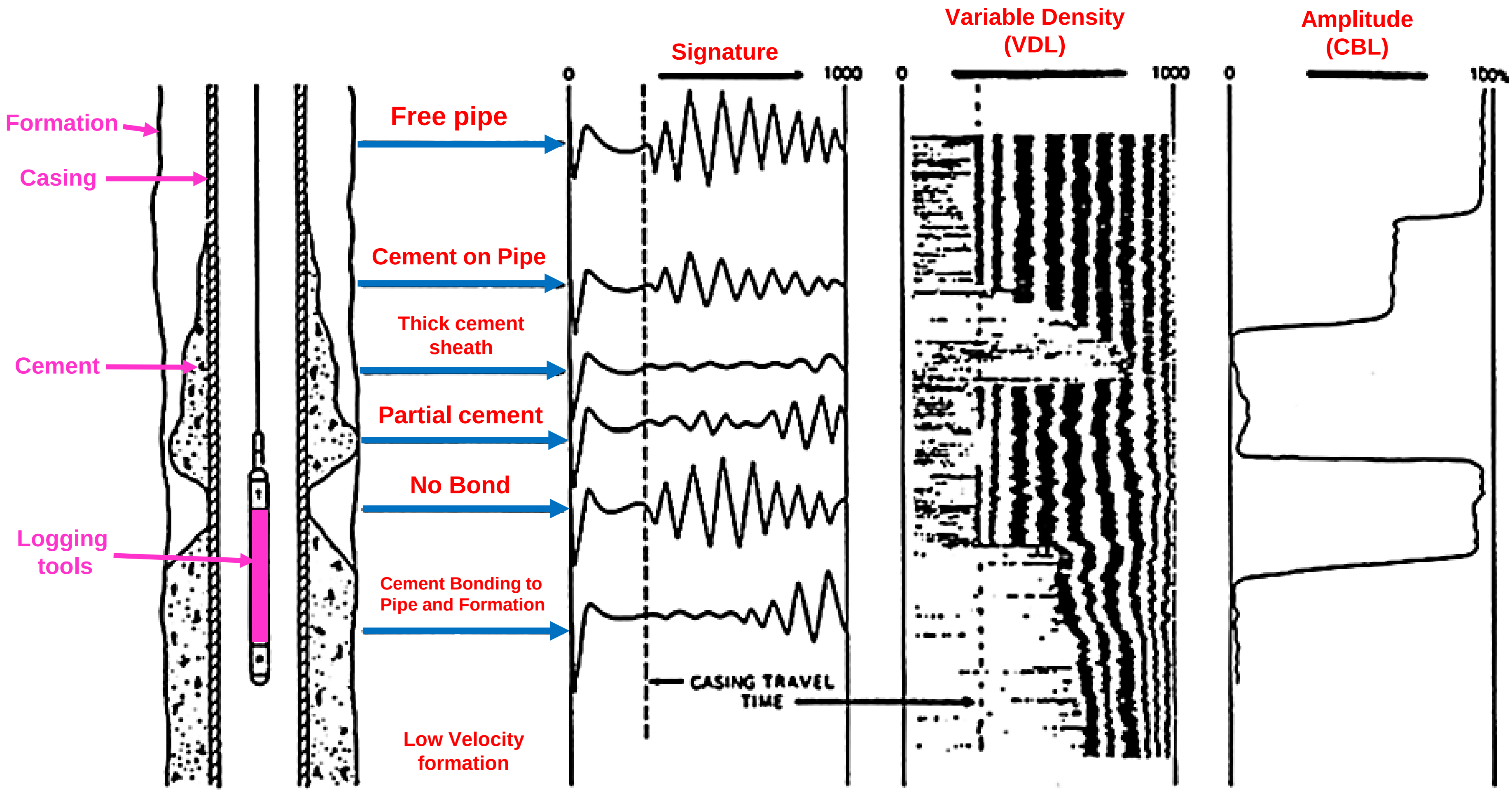
Medium to Good cement with good isolation in pay zone  : can pass

Good cement : can pass

# (CBL/VDL) principle

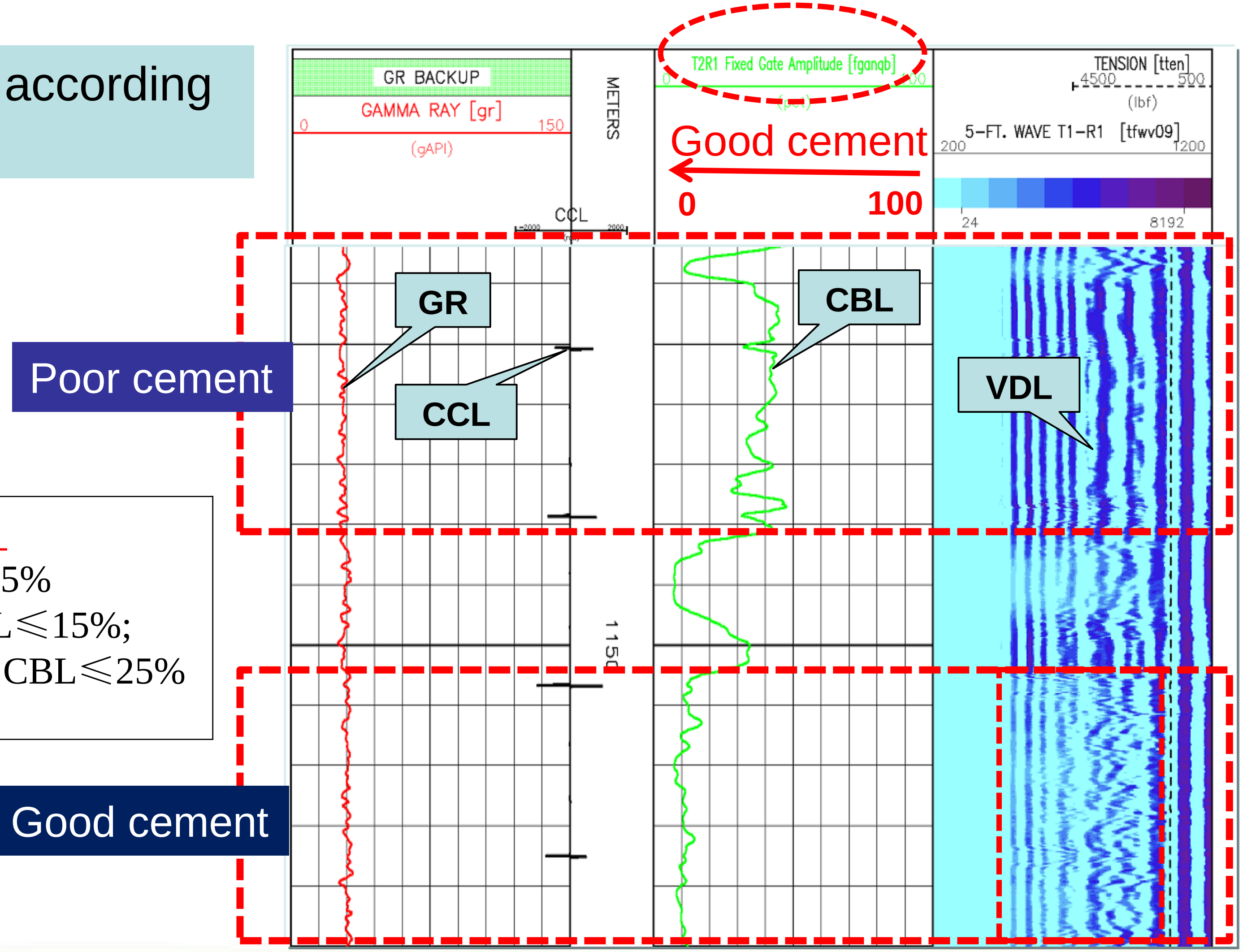


# (CBL/VDL) principle



# CBL , VDL , GR , CCL

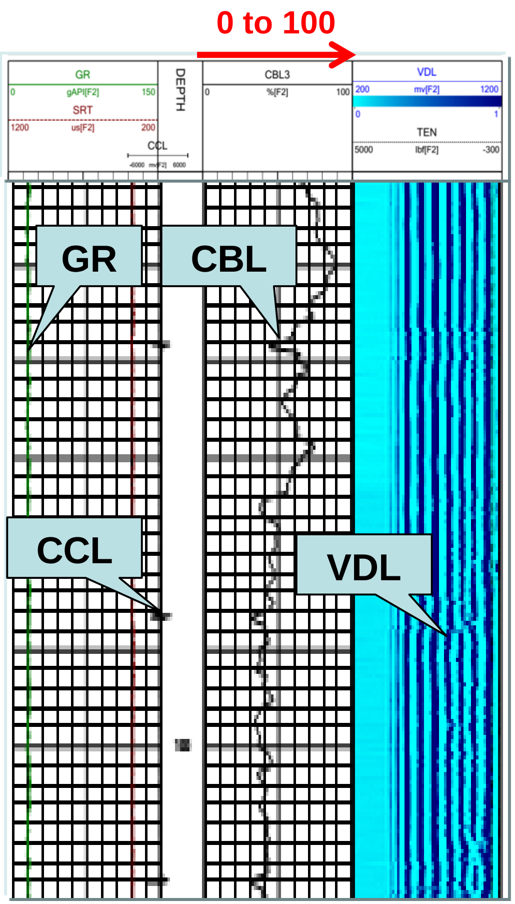
Cement evaluation according to CBL and VDL



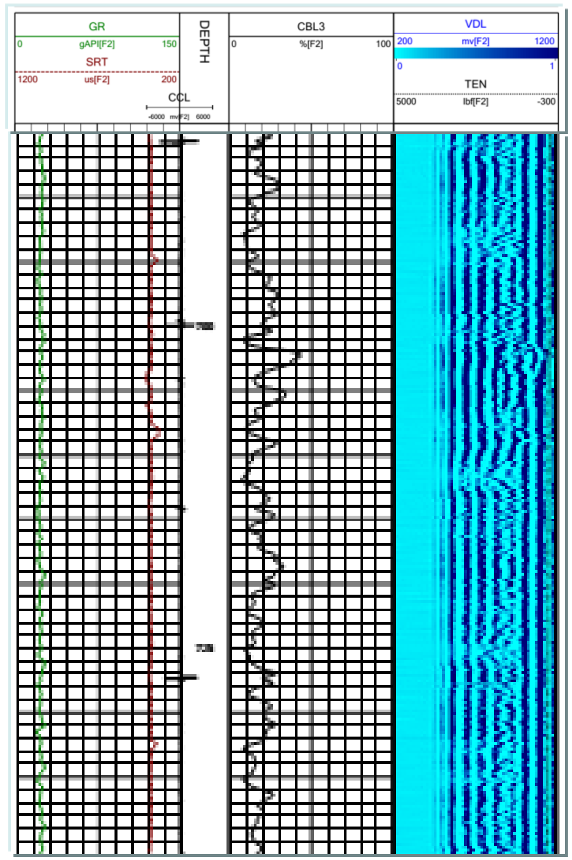

Evaluation Criterion:

- V.Good Cement CBL≤5%
- Good Cement 5%< CBL≤15%;
- Medium Cement 15%< CBL≤25%
- Poor Cement CBL>25%.

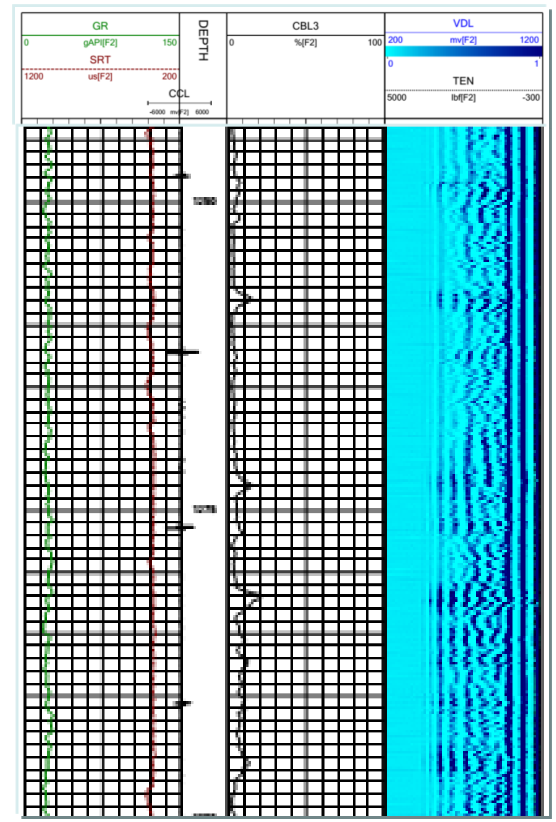
# Example for three case cement CBL ( poor – medium – good)




Poor cement



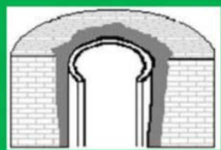

Medium to good cement

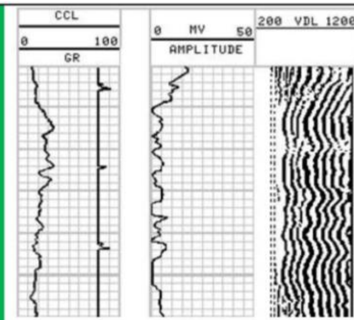



Good cement

# (CBL) Cases

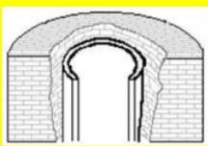
### 1) GOOD CEMENT

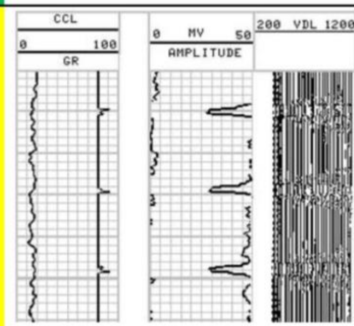





- "Amplitude" low.
- "VDL" formation signals are strong.
- Good cement. No need for squeeze

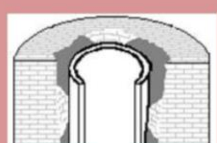
### 2) NO CEMENT

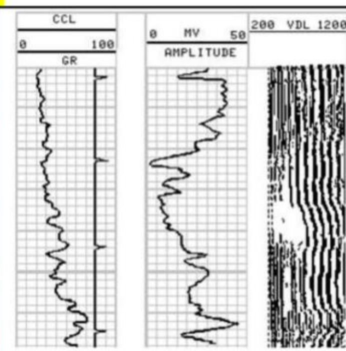





- "Amplitude" High.
- "VDL" straight. No formation signals. "V" type Chevron patterns are seen at collars.
- Squeeze cement neededı.

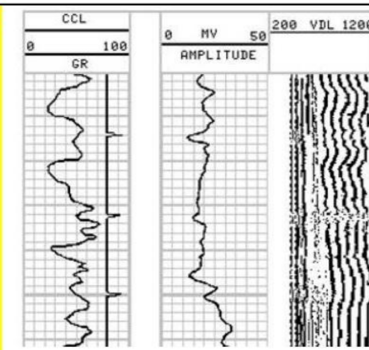
### 3) PARTIAL CEMENT





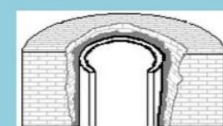

- "Amplitude" is low and moderate.
- "VDL" can shows both wiggly formation signals and straight casing signals
- Squeeze can be necessary if the channel is long enough..

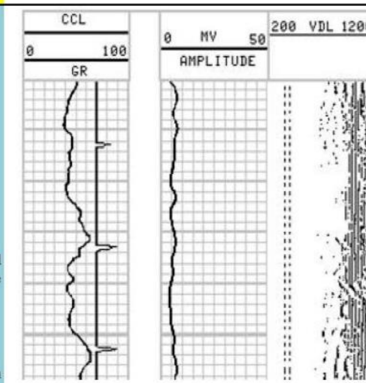
### 4) MICROANNULUS (micro gap between cement and casing)




- "Amplitude" is moderate..
- "VDL" can shows both wiggly formation signals and straight casing signals
- No need for squeeze..

### 5) CEMENT WITHOUT BOND TO FORMATION

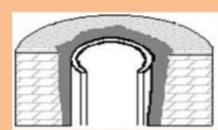


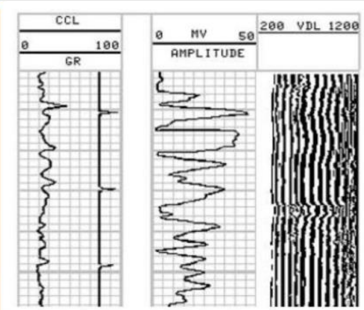



- "Amplitude" low.
- "VDL" doesn't show casing and formation signals. Thin mud signals are visible
- Squeeze needed

Note: Keep in mind that gas in formation can give the same model.

### 6) CEMENT BOND IN HARD FORMATIONS

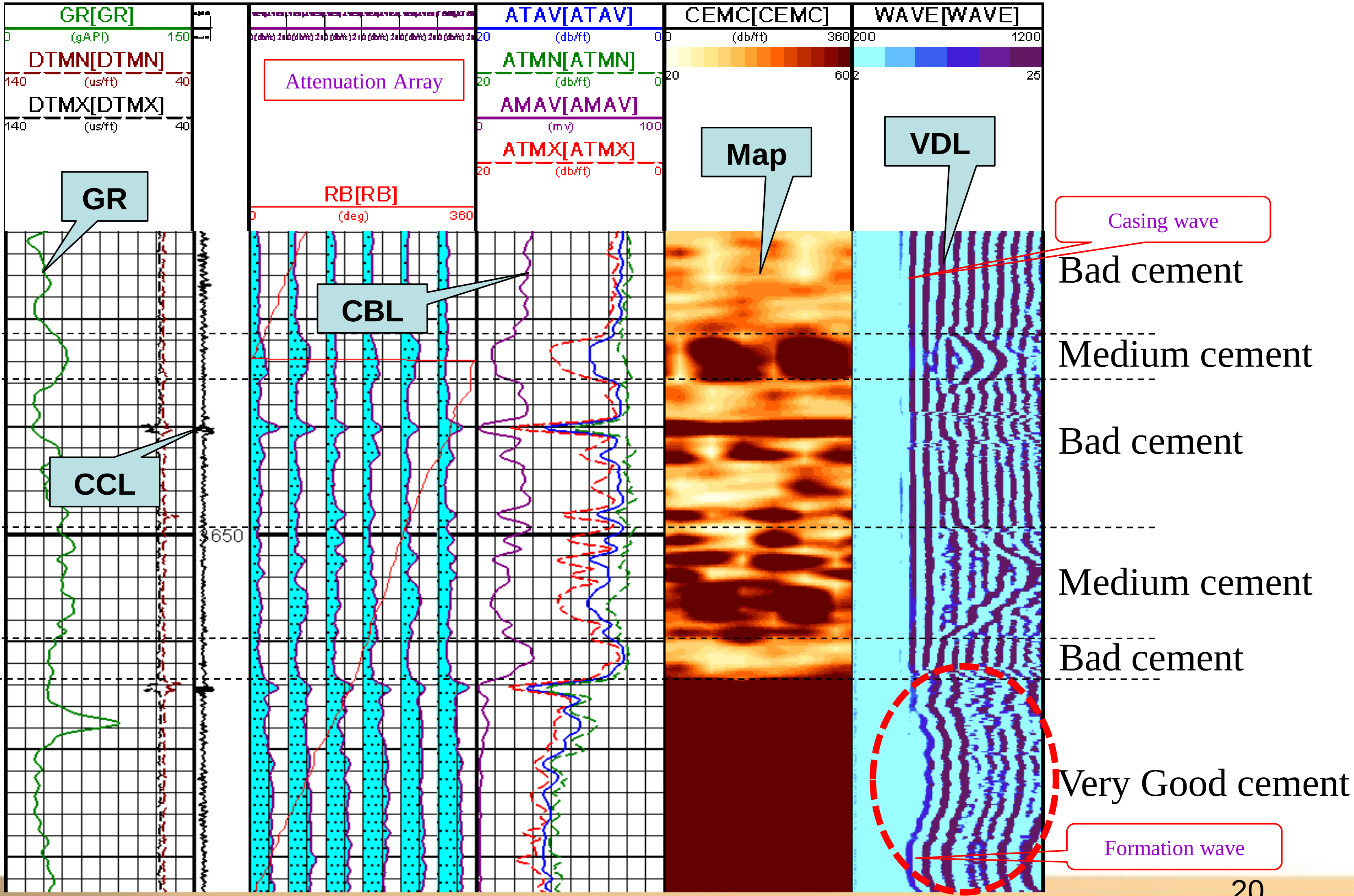




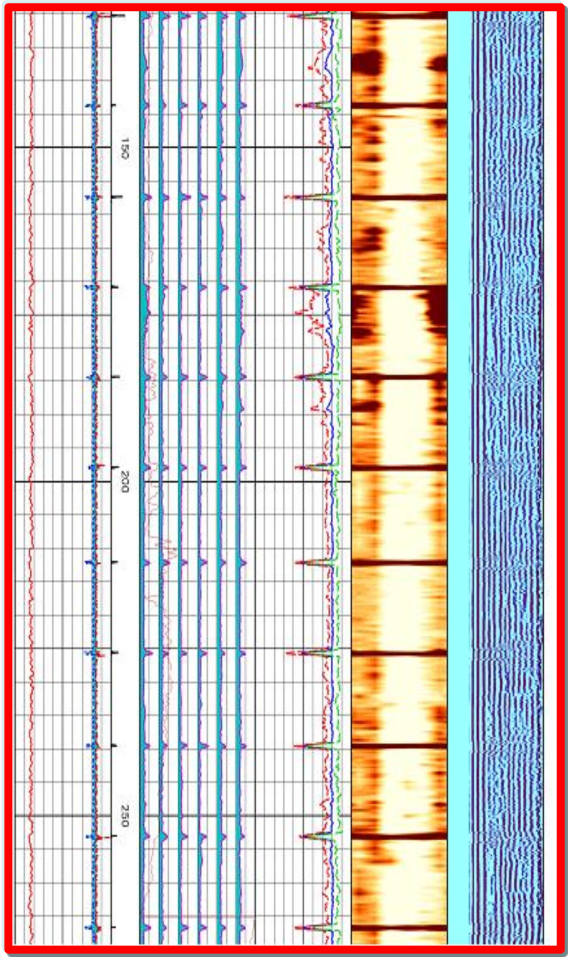

- "Amplitude changes between low and high
- Formation signals cover casing signals.
- No need for cement...

# SBT : Segmented Bond Tool

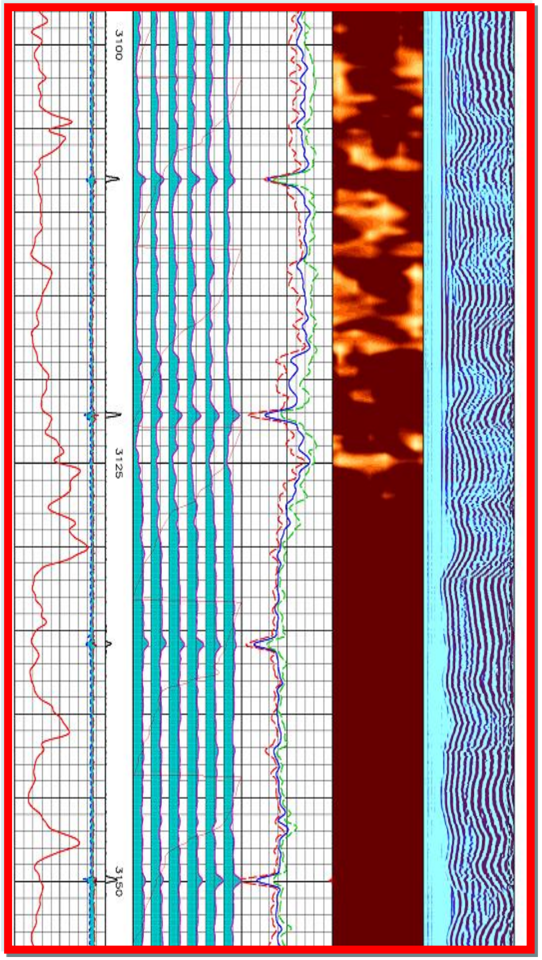
SBT 360



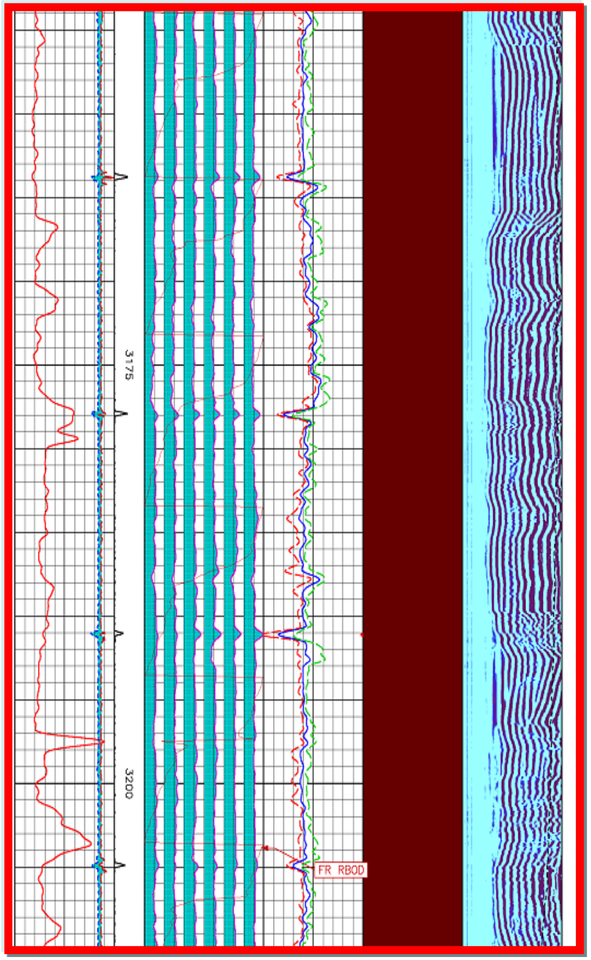
# Example for three case cement **SBT** ( poor – medium – good)




Poor cement

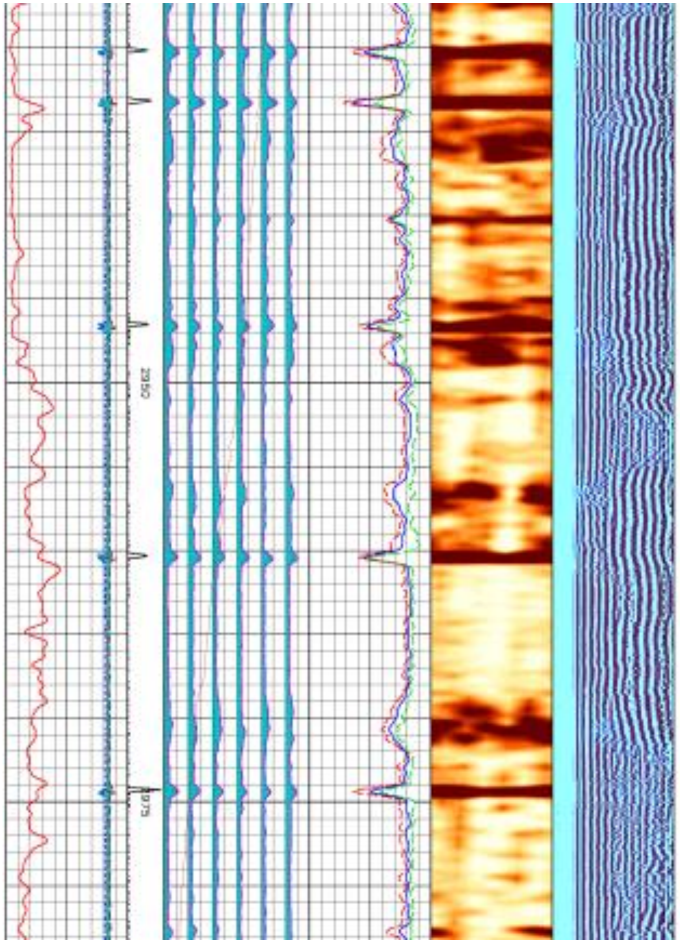



Medium to good cement

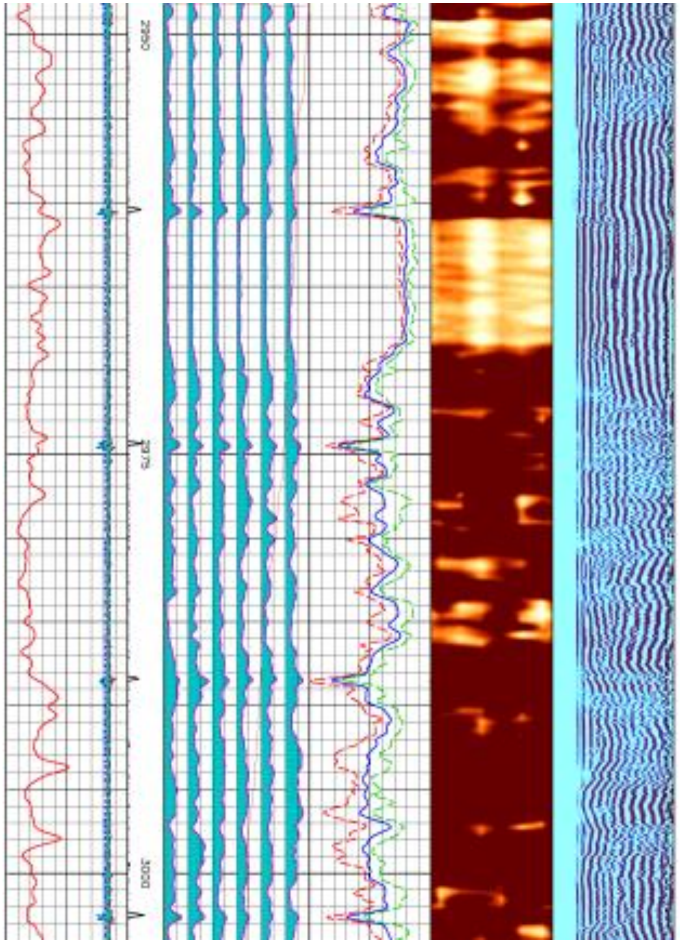



Good cement

# Example ( before and after squeeze cement )



Before Squeeze cement

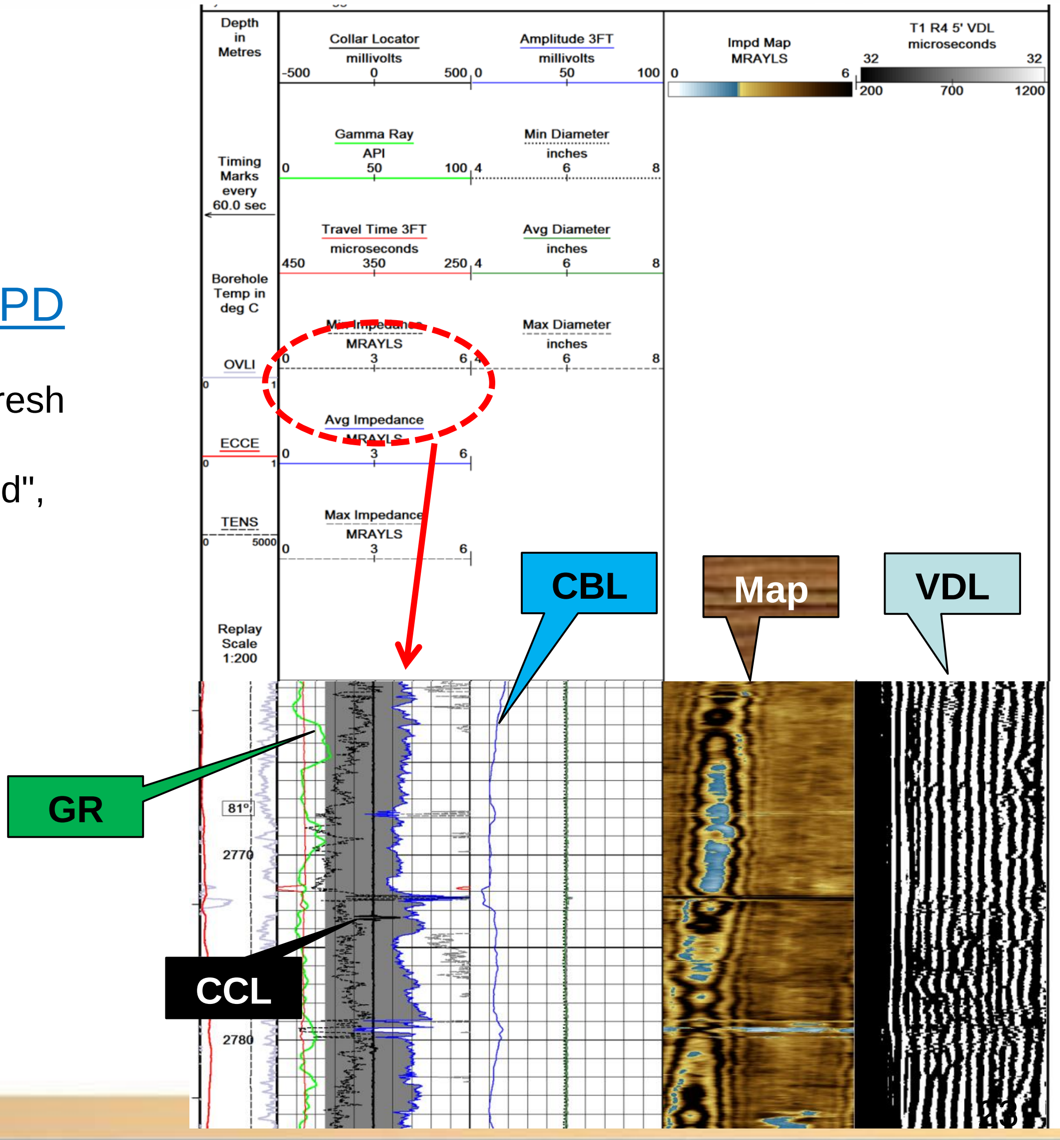


After Squeeze cement

# Ultra sonic redial scanner(URS)

## Evaluation Criteria: depend on IMPD

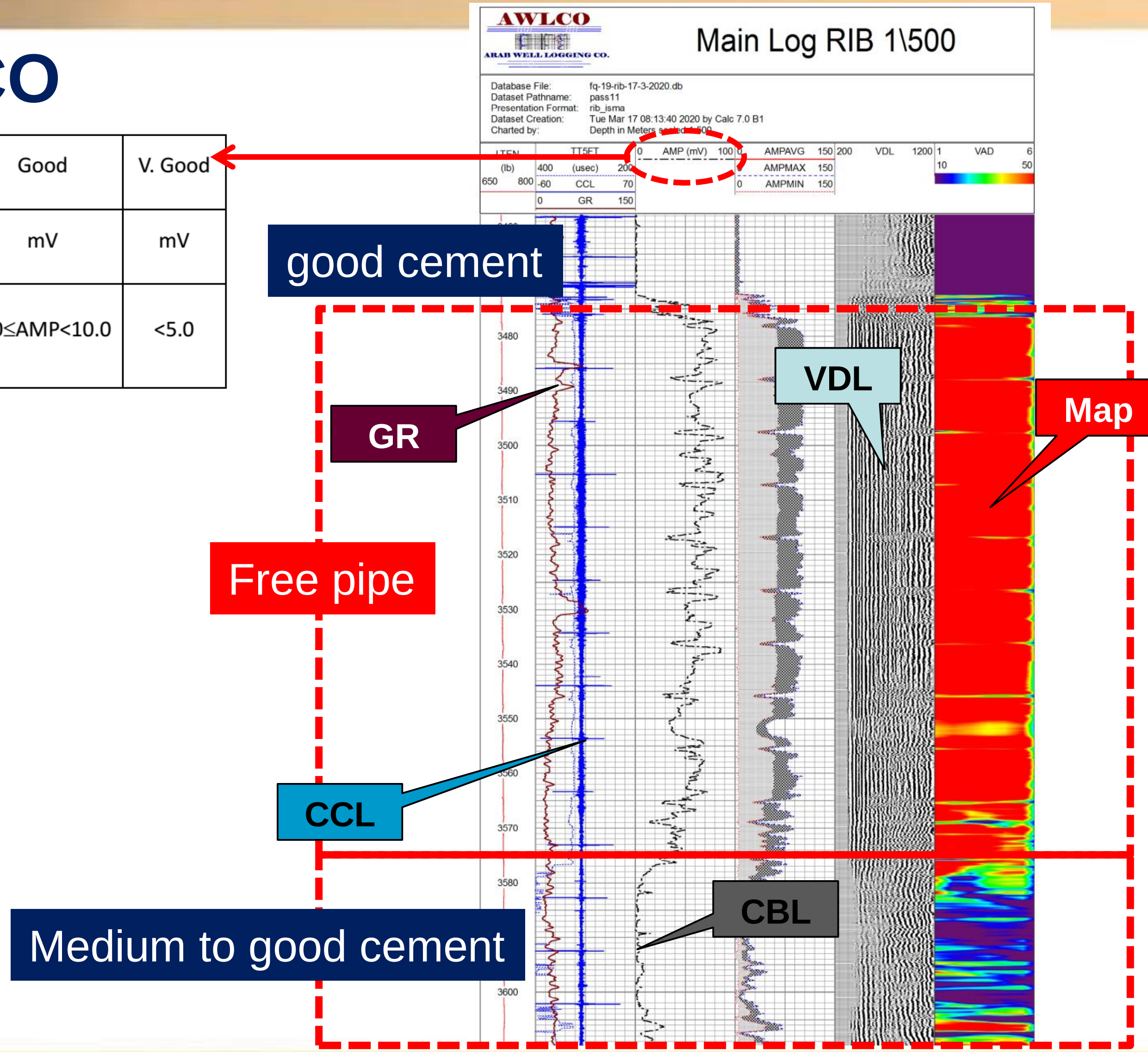
- ( IMPd<=0.38,"gas“
- ( IMPd>0.38, IMPd<=2.3),"liquid gas-Fresh Wtr",
- ( IMPd>2.3, IMPd<=2.7),"Heavy drill fluid",
- ( IMPd>2.7, IMPd<=3.85),"low IMPd",
- ( IMPd>3.8, IMPd<=5),"medium IMPd",
- ( IMPd>5),"good IMPd")



# Radius Incremented Bond

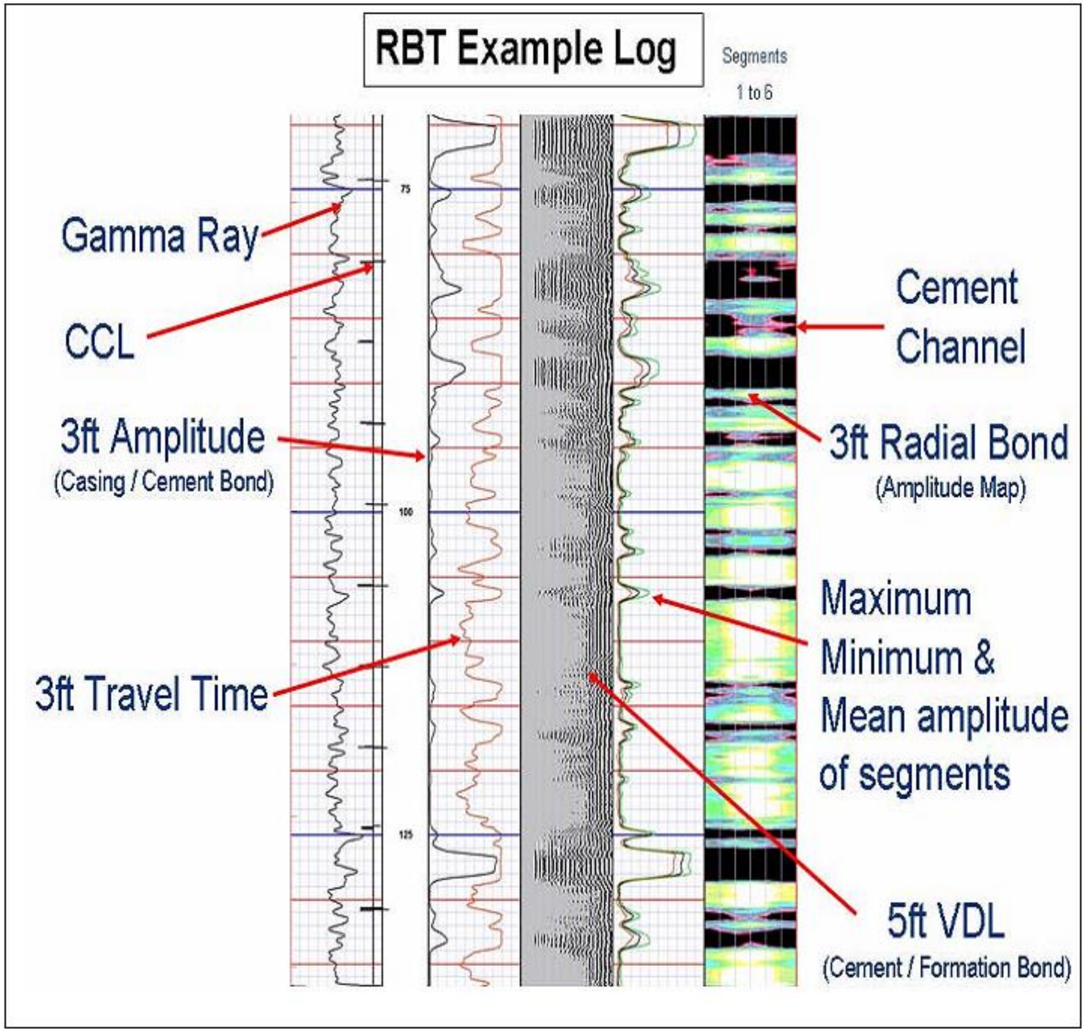
## RIB-for AWLCO

| Casing Size | | Poor | Medium | Good | V. Good |
|---|---|---|---|---|---|
| O.D. | Thickness | mV | mV | mV | mV |
| 114.3mm (4-1/2in) | 6.88mm (0.271in) | >20.0 | 10.0≤AMP<20.0 | 5.0≤AMP<10.0 | <5.0 |



# RBT (Radial Bond Tool)

For Halliburton



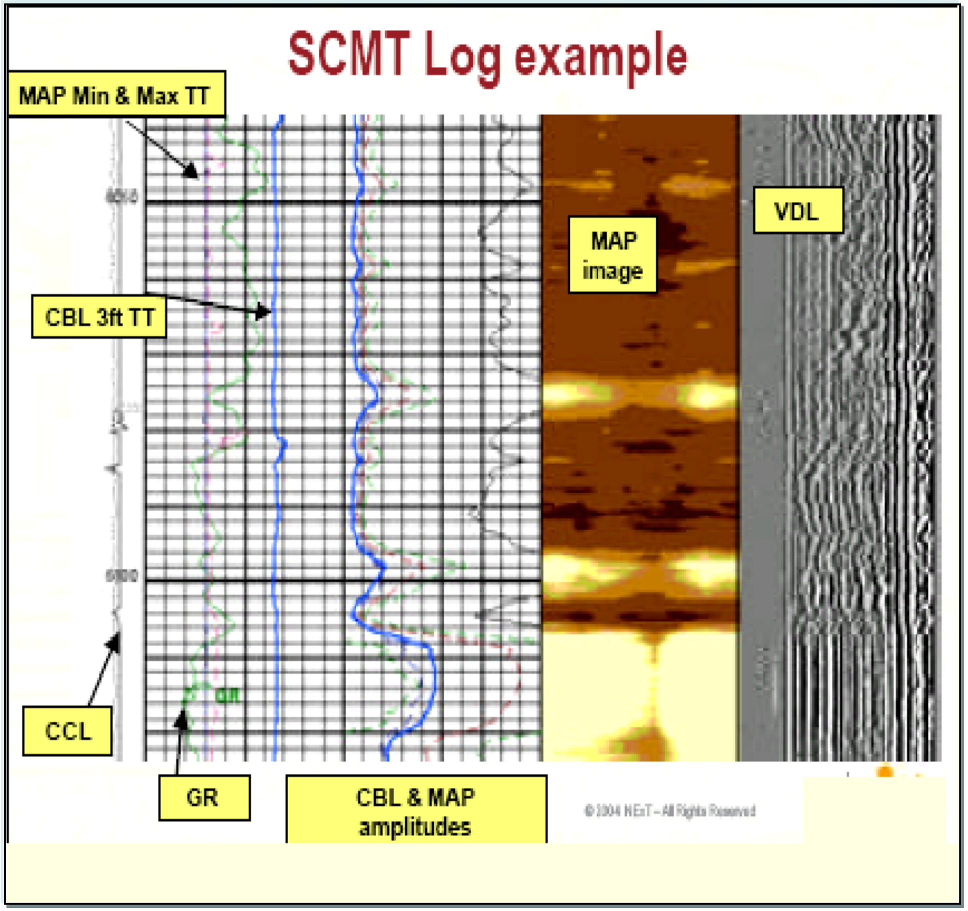
# SCMT (Slim Cement Mapping Tool)

**SCMT Applications**

„1-Cement evaluation in small completions

„2-Cement bond log and cement map below tubing completions

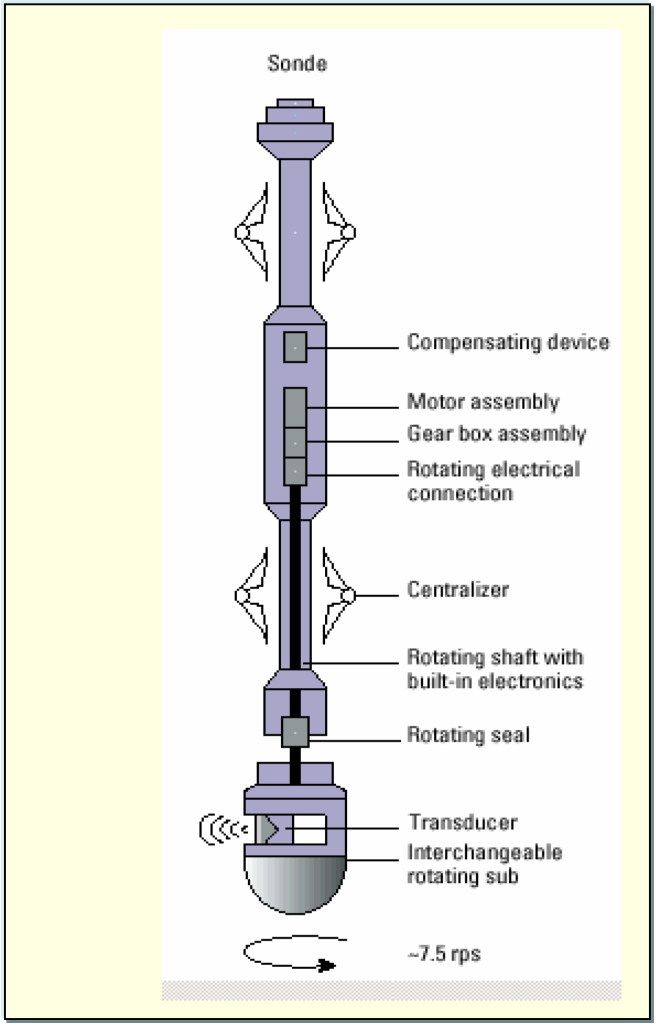
„3-Locate depths of “stuck pipe”or “stuck casing”



# (USI) Ultrasonic Image

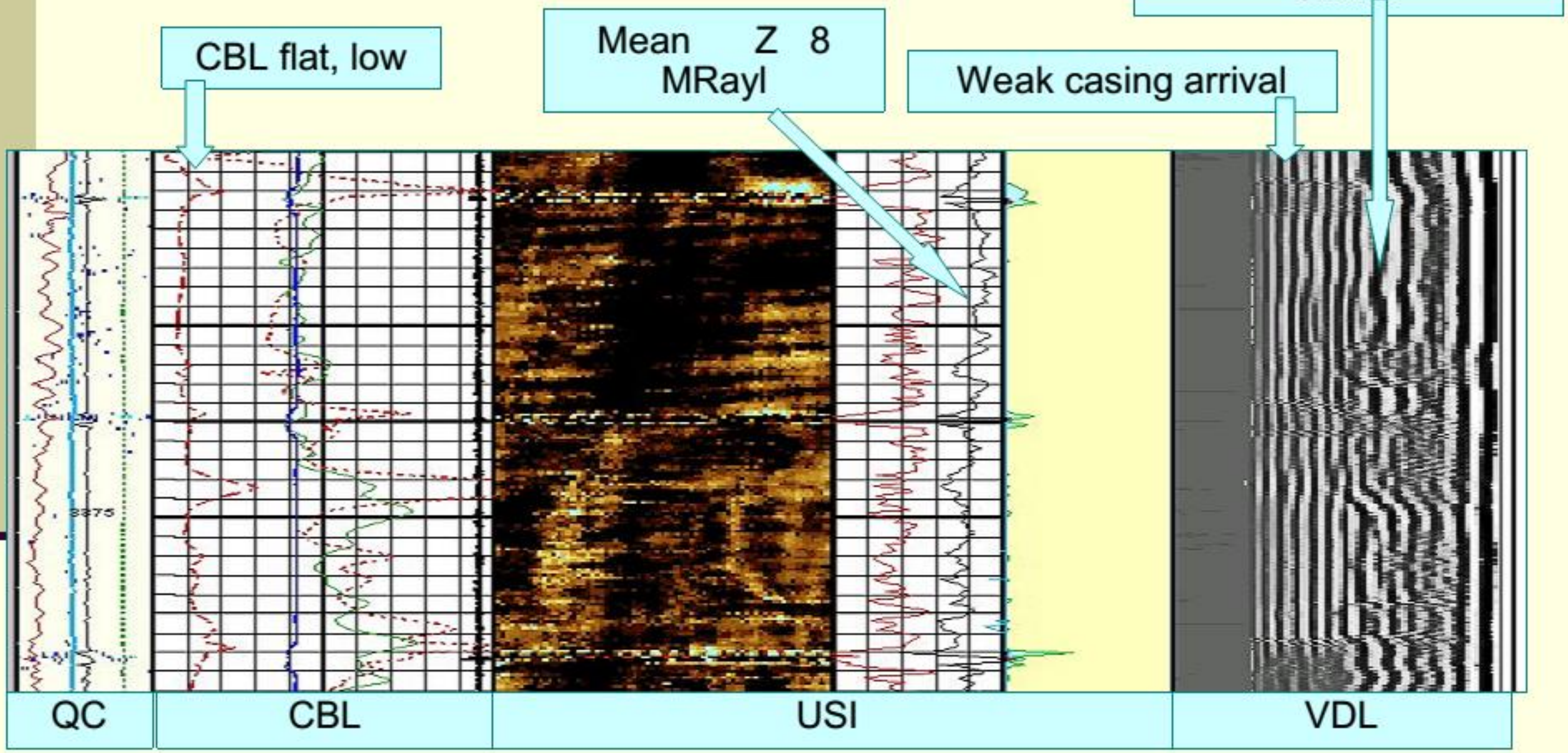
## Applications

- Determination of casing condition
- Evaluation of cement bond to casing
- Identification of channeling



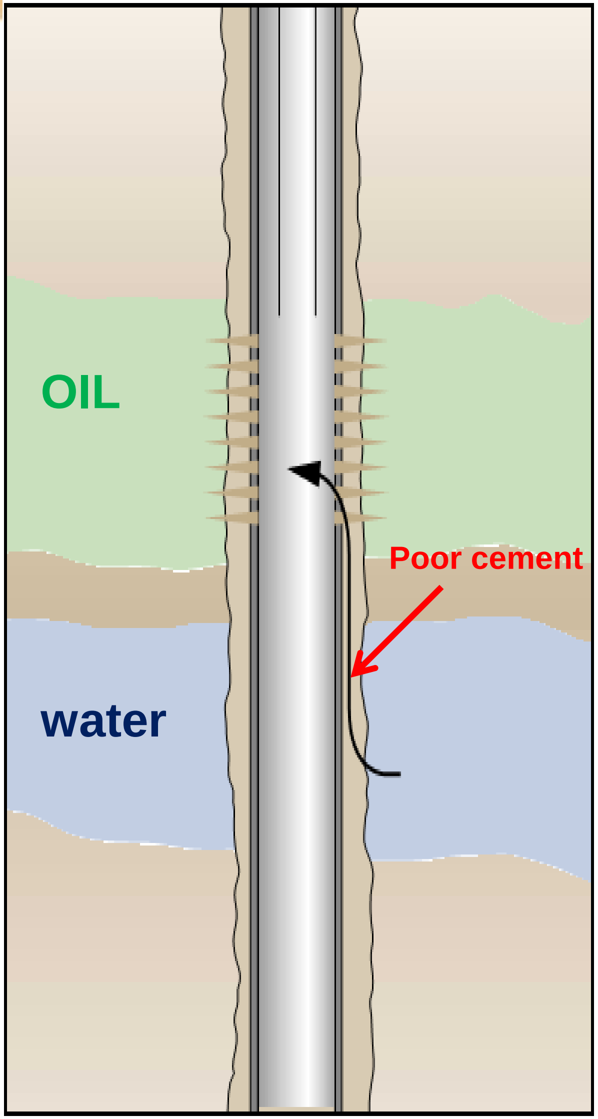
# (USI) Ultrasonic Image

- Good Cement Example



# The question ??

**Quality of cement behind casing relation with production well behavior ??**



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# Casing inspection log

Casing inspection is an important survey at all operation stages of the well. Holes in tubing or casing caused by corrosion or other damages can seriously affect production rates and fluid composition, resulting in economic loss.
Casing inspection is carried out:

- ✓ to monitor the casing/tubing integrity;
- ✓ to identify casing splits, defects, metal loss and corrosion area;
- ✓ quality control of the well intervention operations (workover).

Casing inspection log is an individual measurement, or a combination of measurements using acoustic, electrical and mechanical techniques, to evaluate the casing integrity.

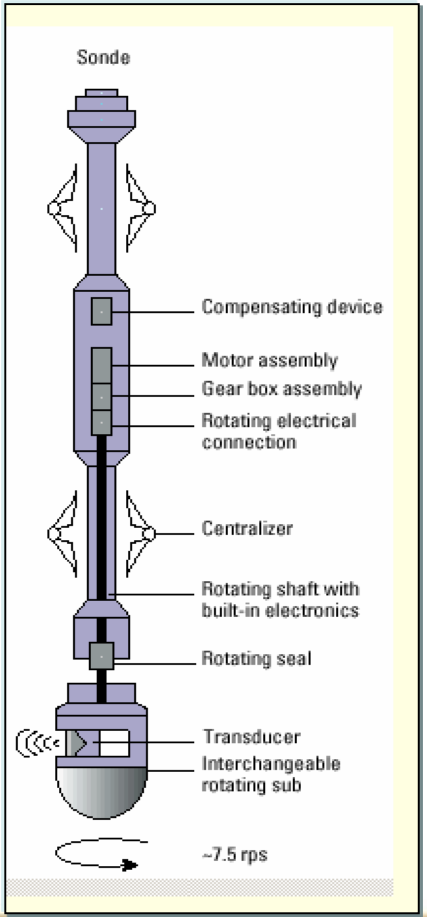
# Type of casing inspection log

**(MIT )**

Multi – Finger Imaging tool

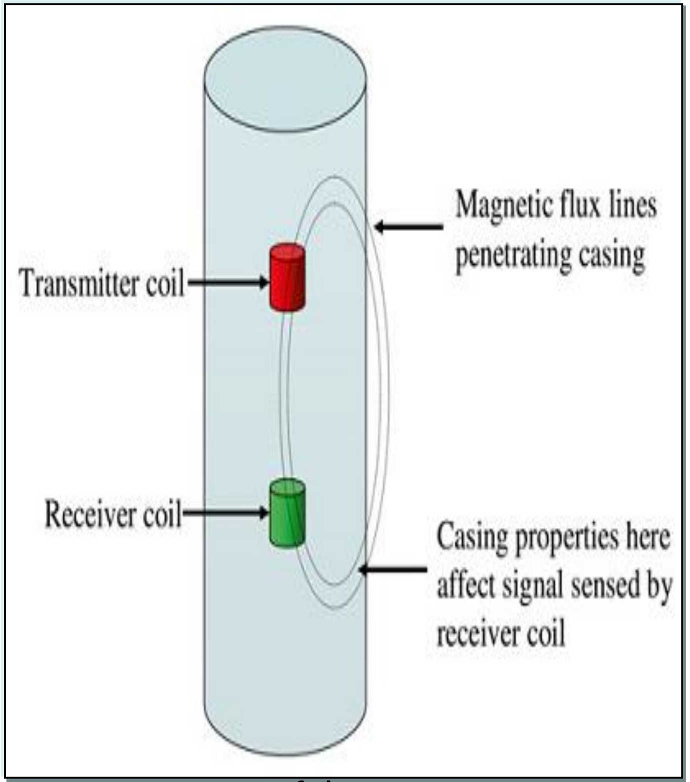

**(USI)**

Ultrasonic Image




**(ETT)**

Electromagnetic Thickness Tool




measurement of the thickness of a casing string even while the tool itself is inside tubing.

# MIT= multi – Finger imaging tool

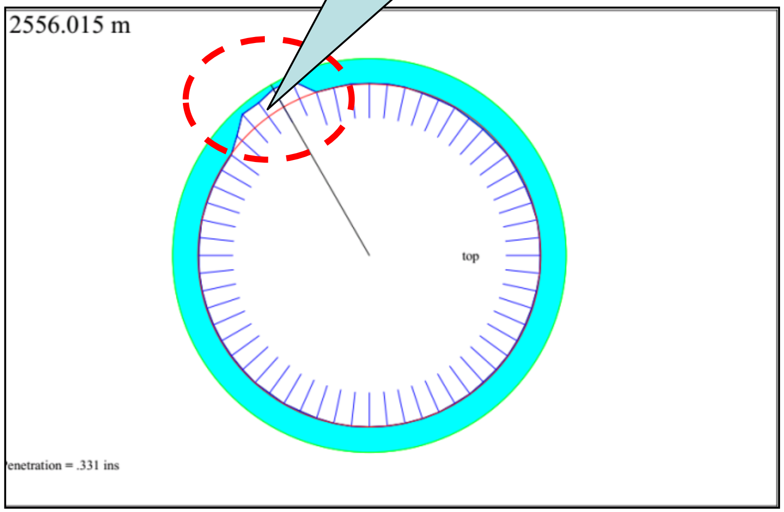
MIT= multi – Finger imaging tool
(24 , 40 ,60 ) finger

**Applications**

- Monitoring internal casing corrosion
- Identification of deformation casing

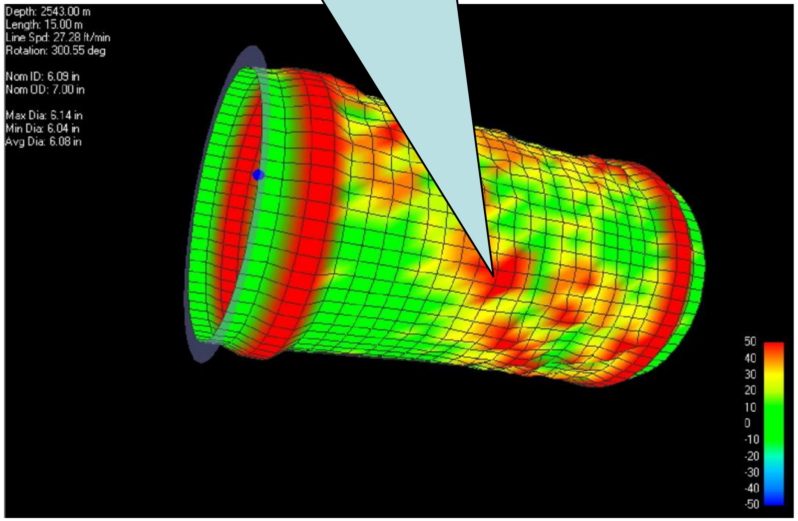
# MIT= multi – Finger imaging tool

Casing damage



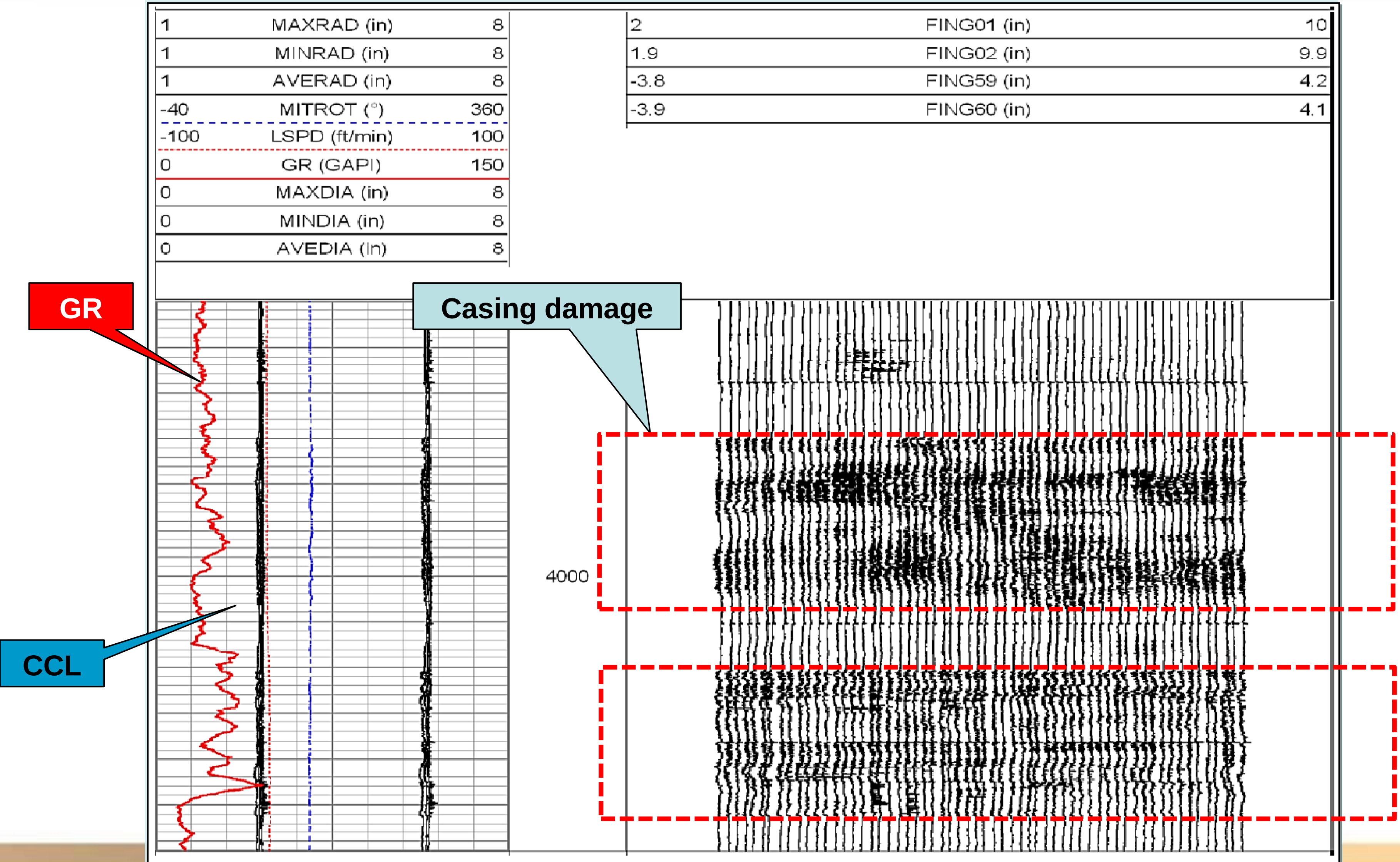

**MIT section profile**

Red Color is Casing damage , perforation , CCL

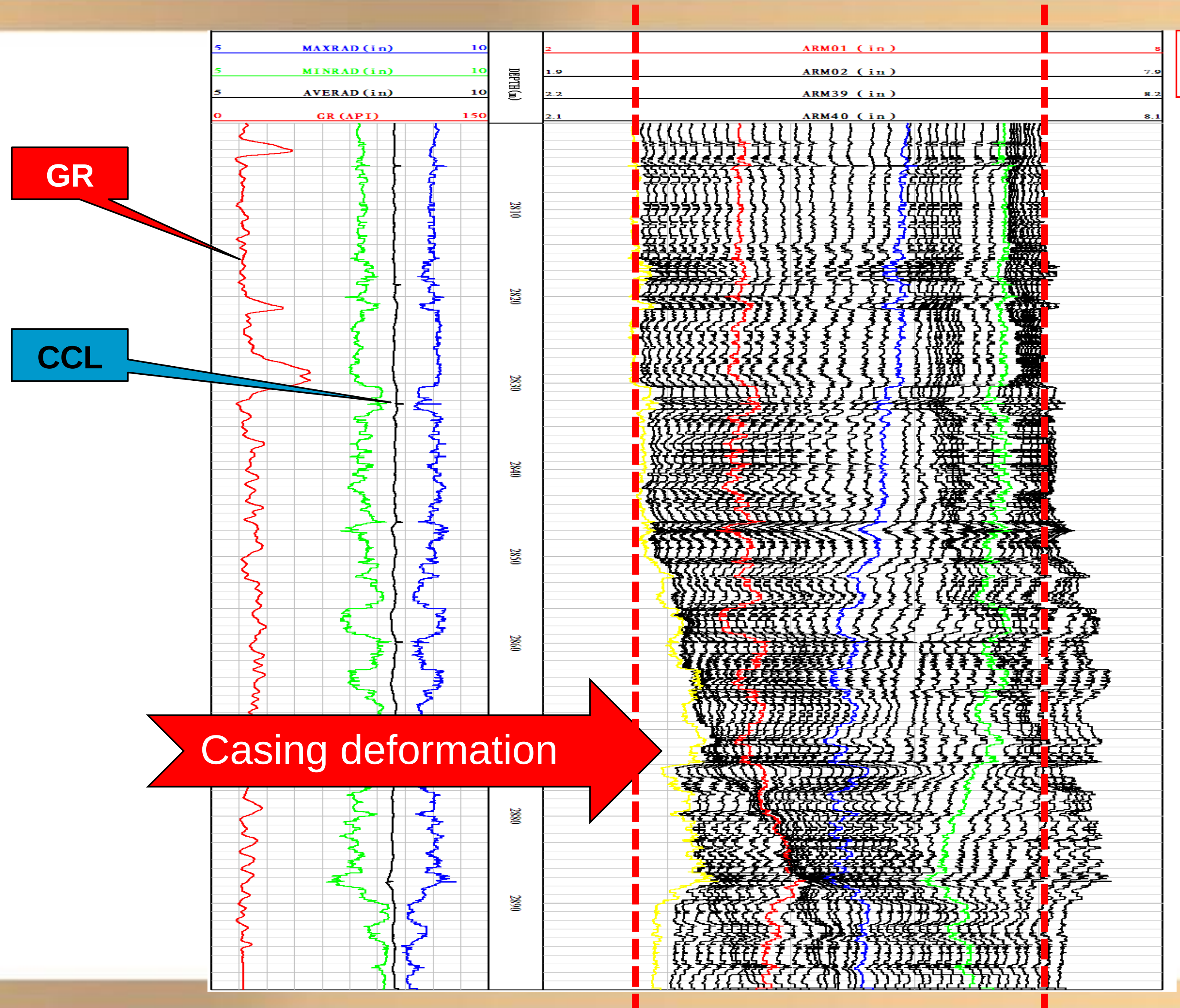



**MIT 3D-view**

# Example 1 : MIT-casing corrosion

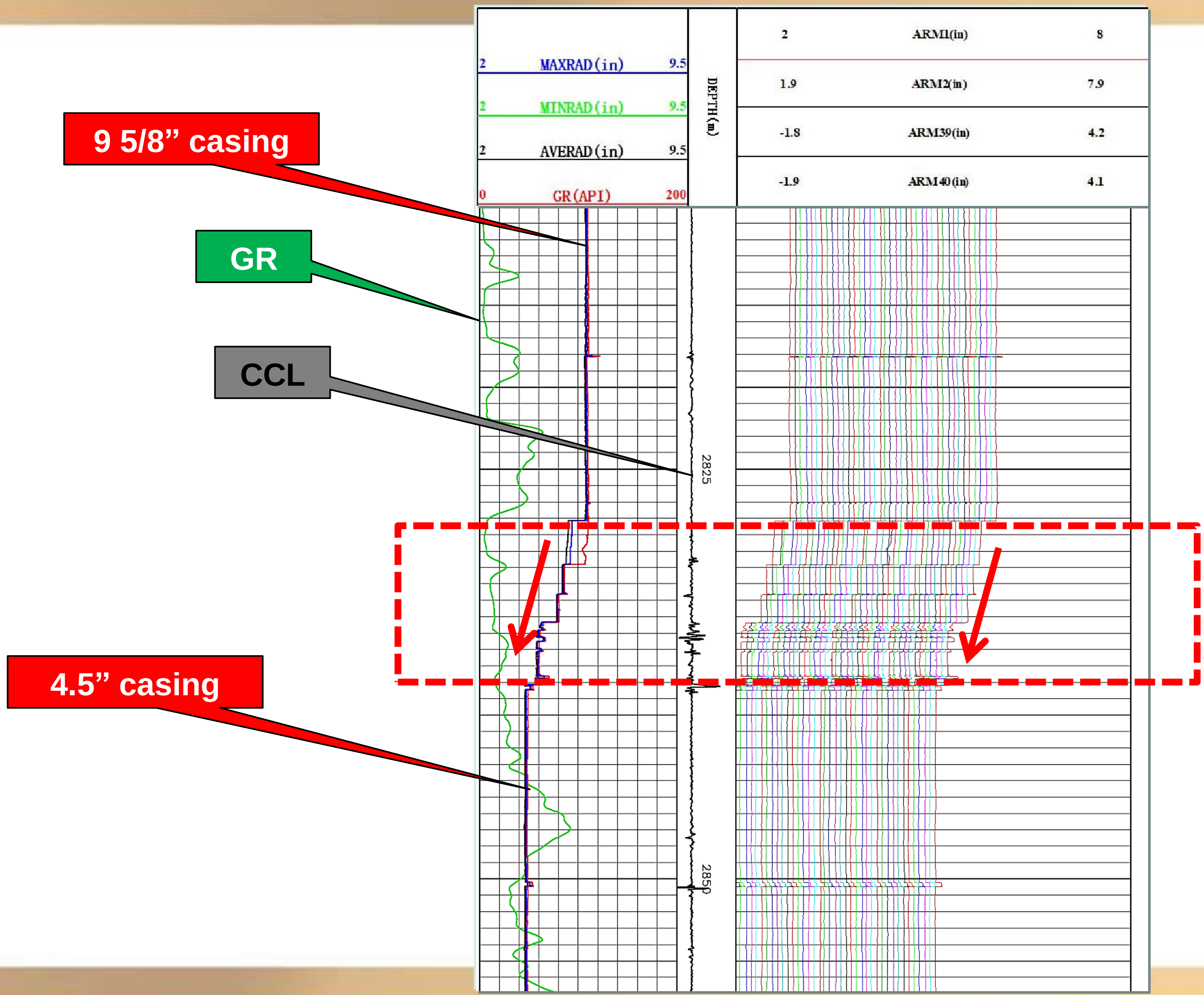


# Example 2: MIT ( 40F) ( casing deformation )




9 5/8" casing

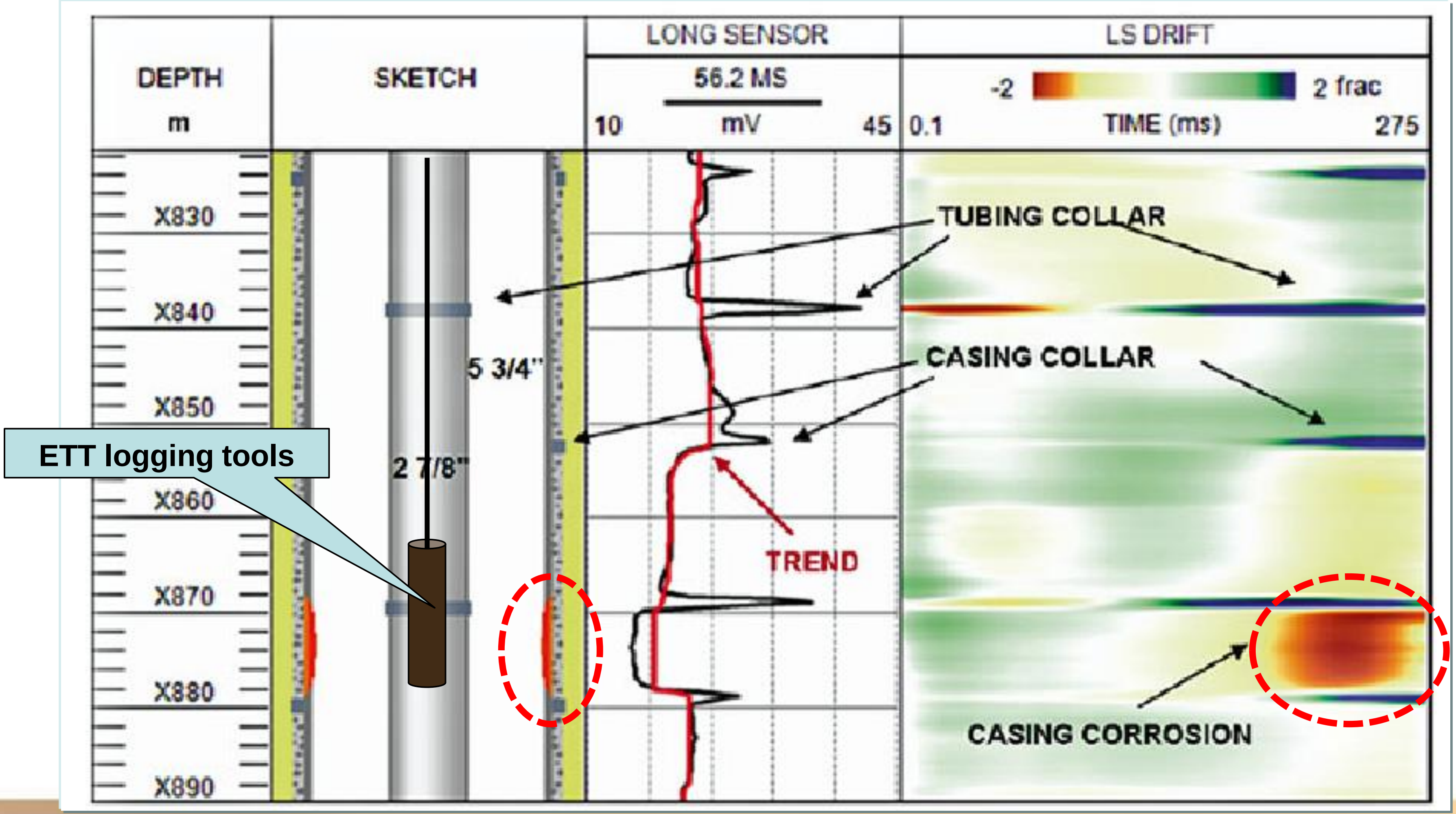
# Example 3: MIT ( 40F) ( change casing size from 7” to 4.5”)




MIT 40F show the change casing size from 7” to 4.5”

# Example 3: ETT( casing corrosion )

Electromagnetic Thickness Tool ( ETT) : Casing corrosion detected from tool inside tubing .



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# SNL Application & Limitation

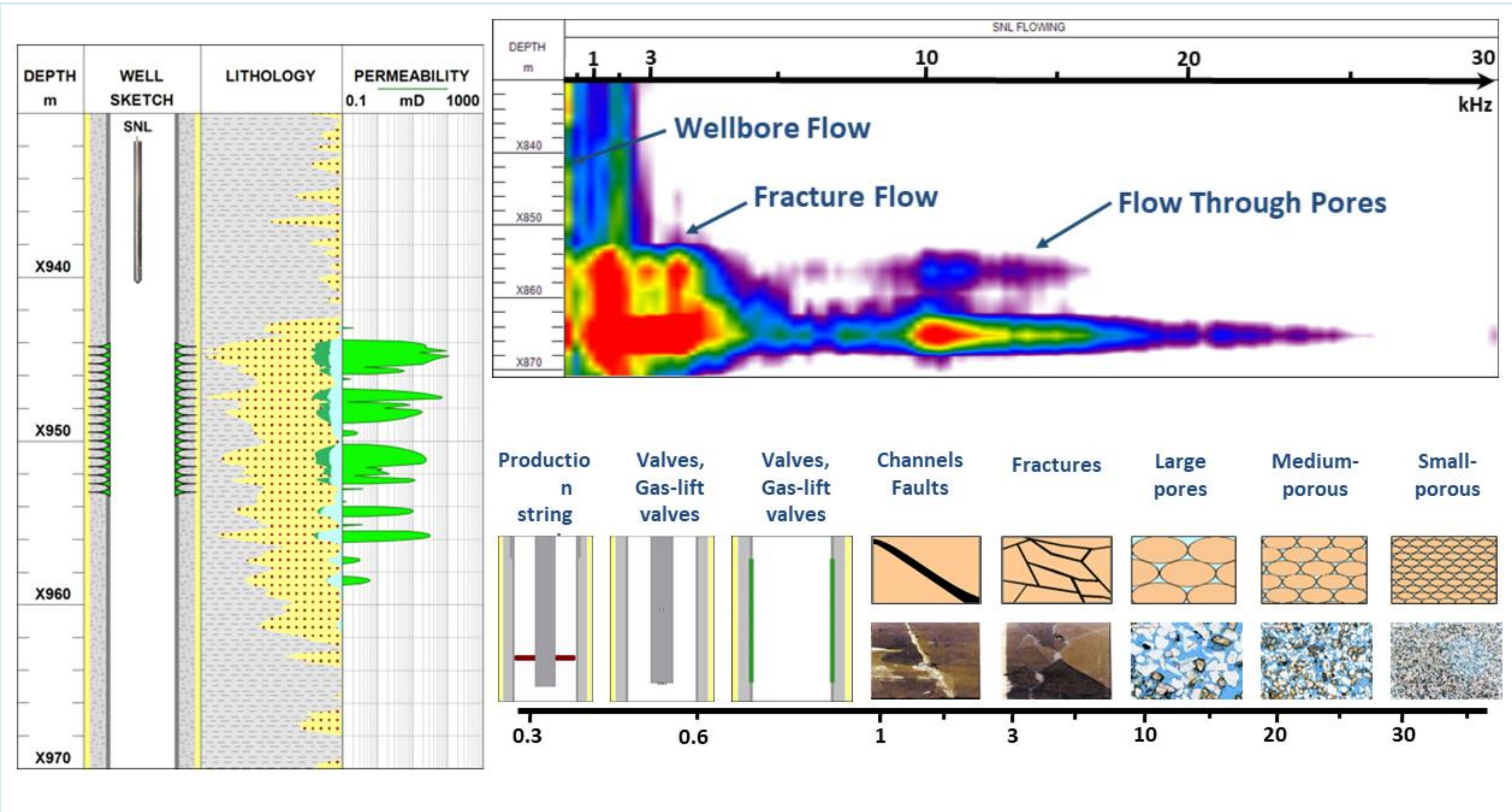
**Application for SNL**

1. Channel behind casing
2. fracture
3. Packer leak
4. Casing leak

**Limitation :**

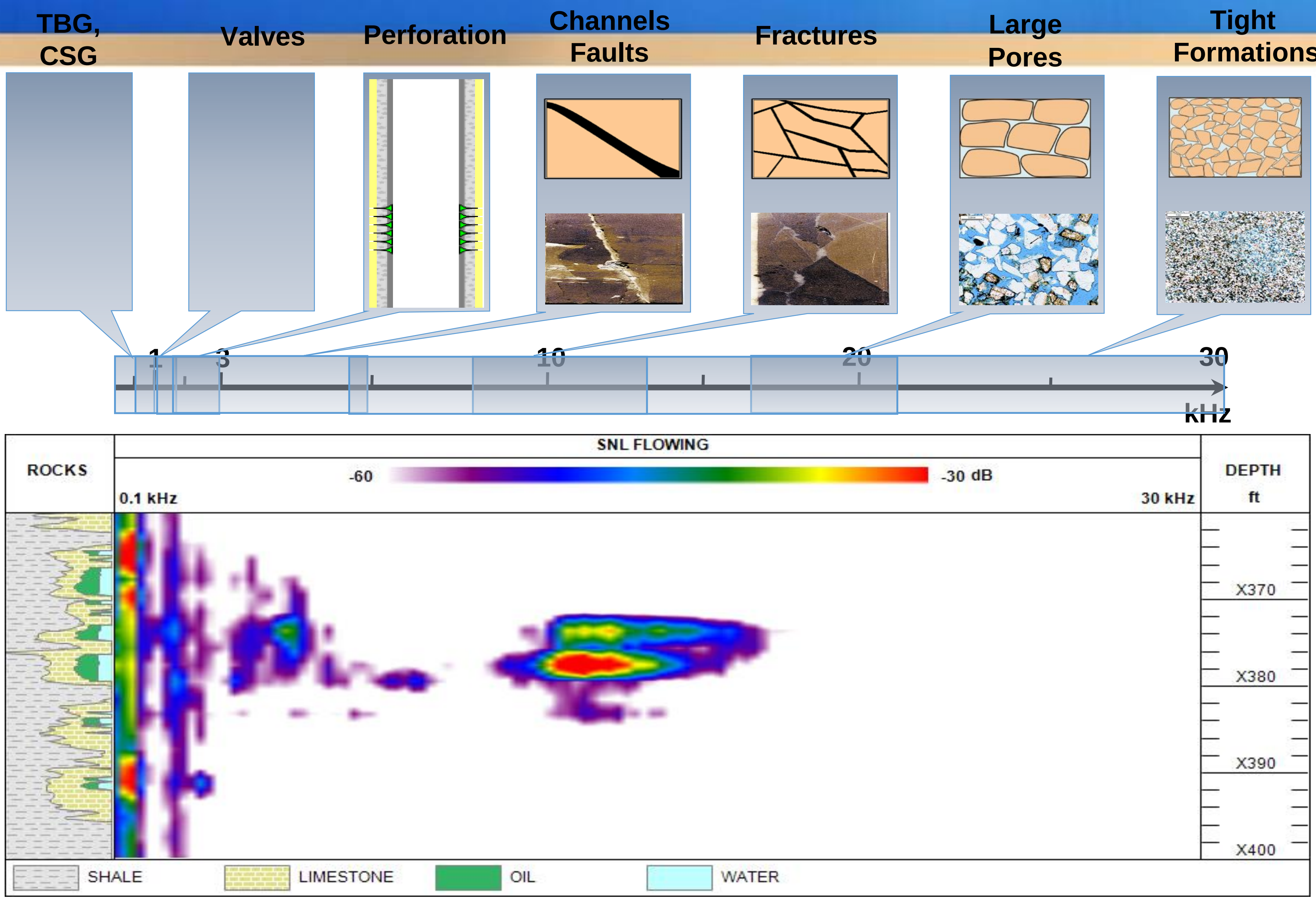
1. Run just in flowing wells
2. Should the cement bong behind casing is good

# Spectral Noise application

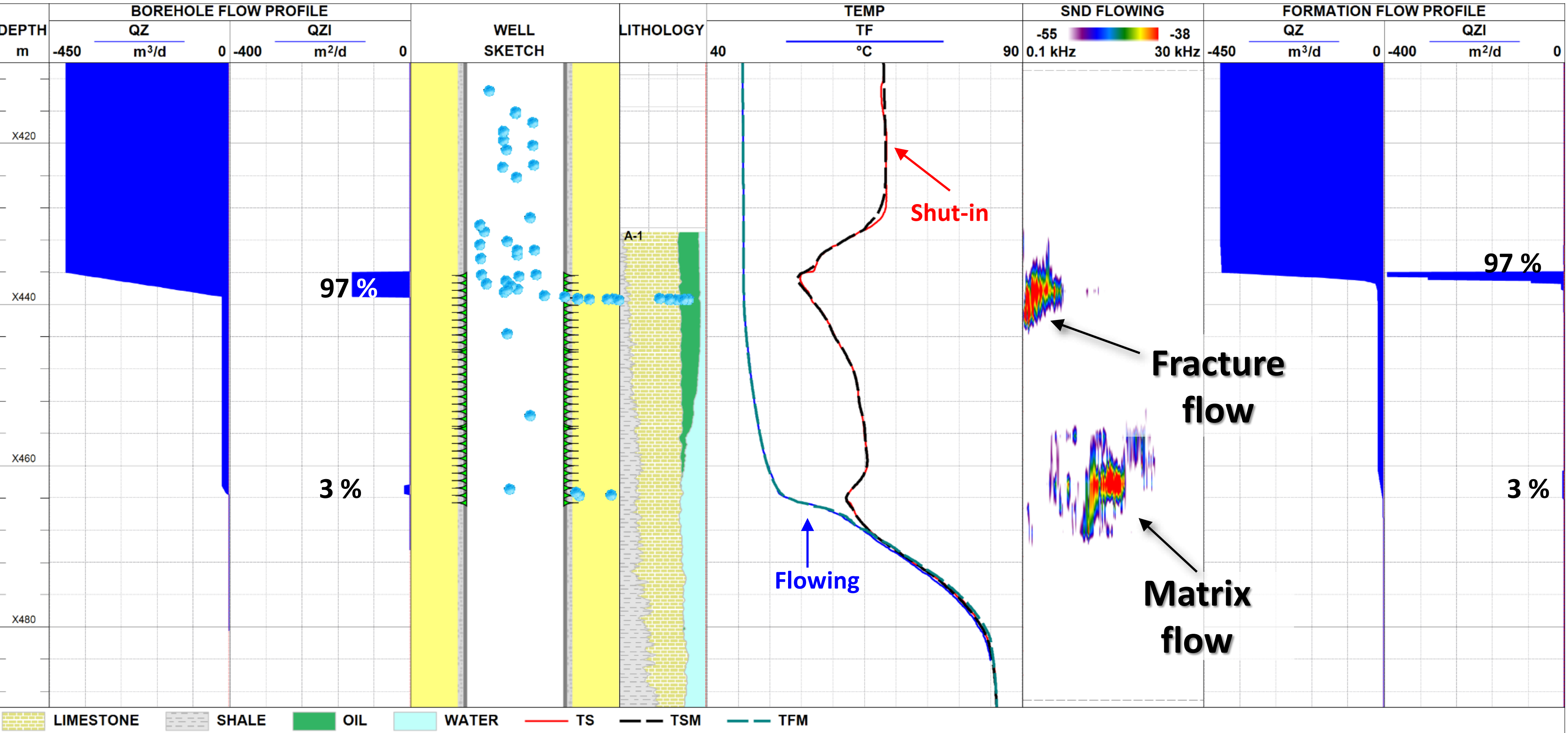



41

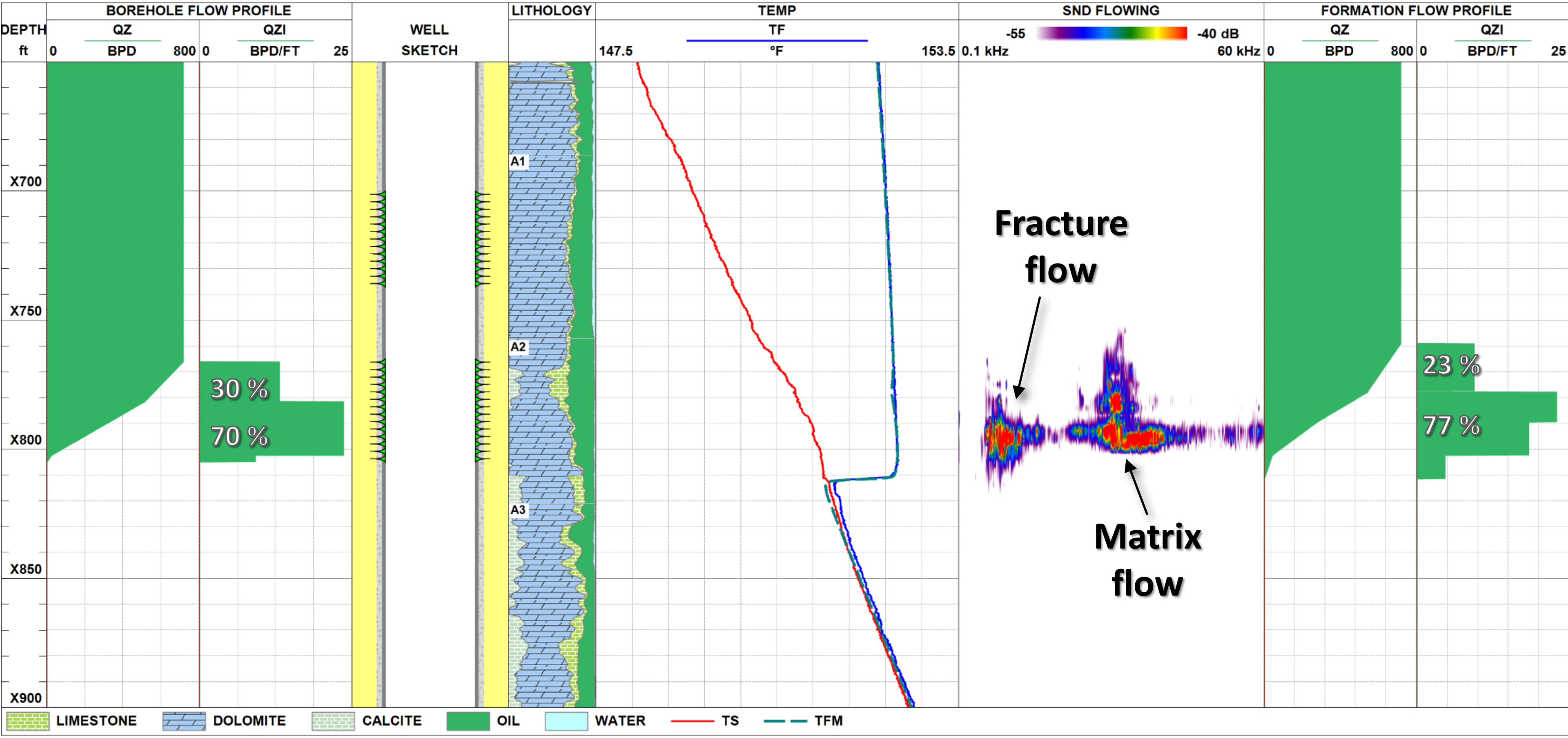
# Spectral Noise Physics



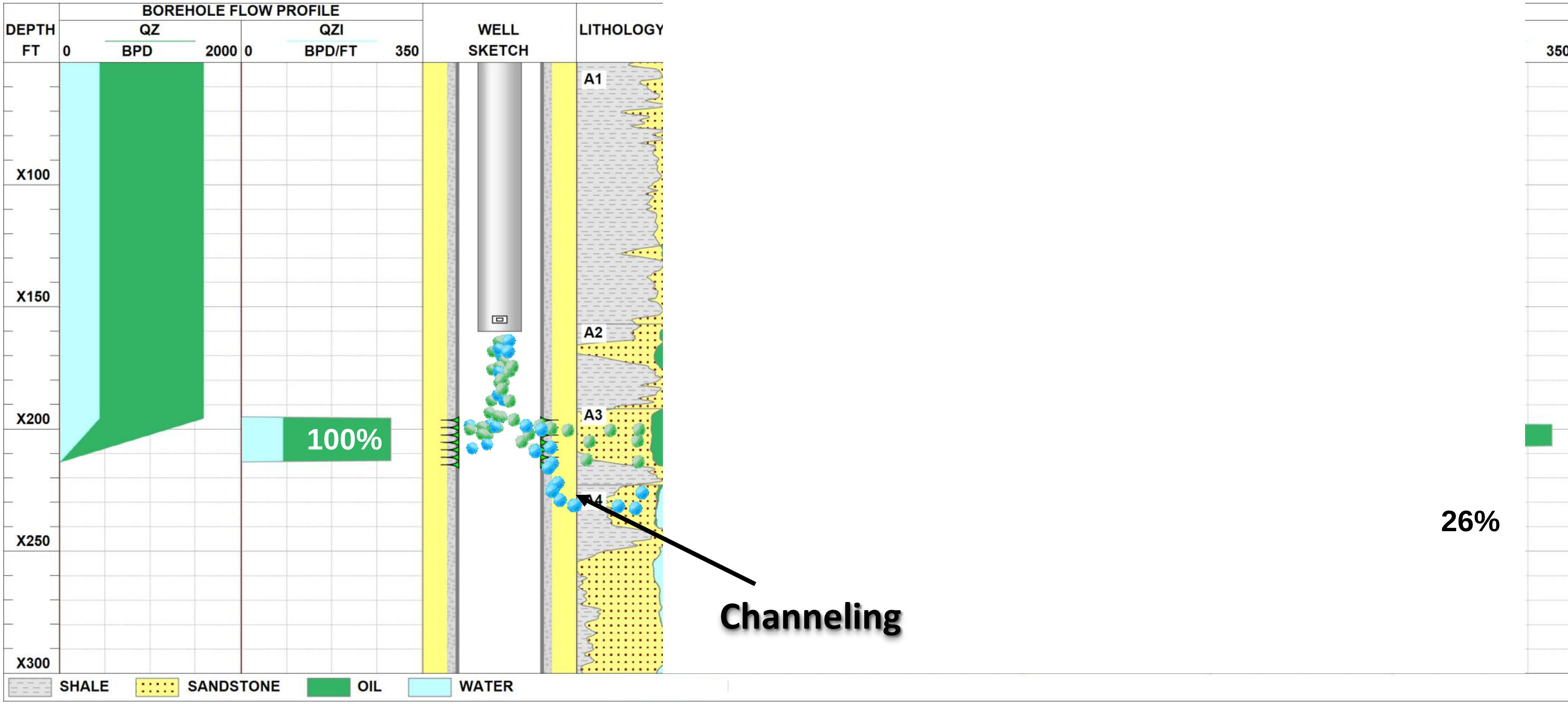
# CASE#1: Fracture and Matrix Flow in a Injector



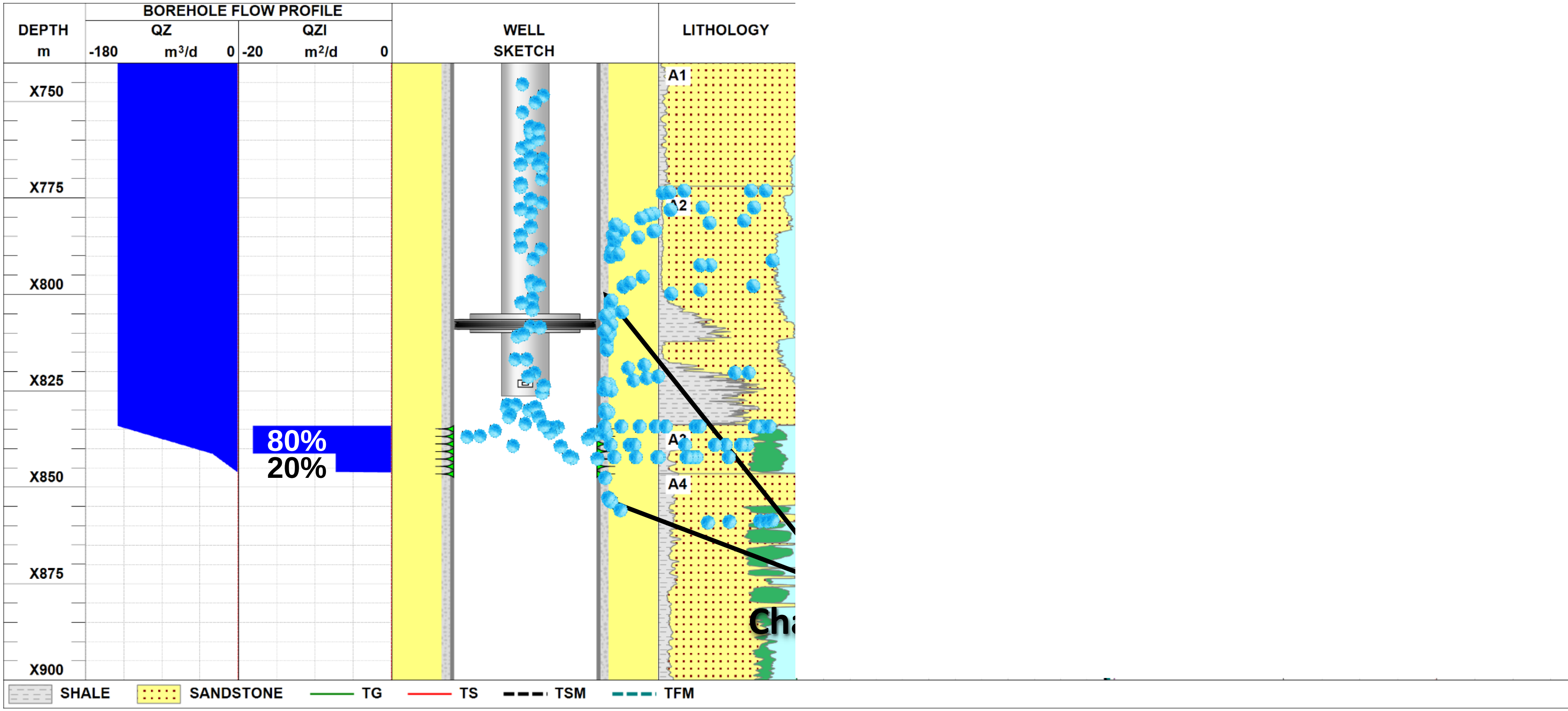
# CASE#2: Fracture and Matrix Flow in a producer



# Case#3: Behind Casing Communication in a Producer



# Case#4: Behind Casing Communication in a injector

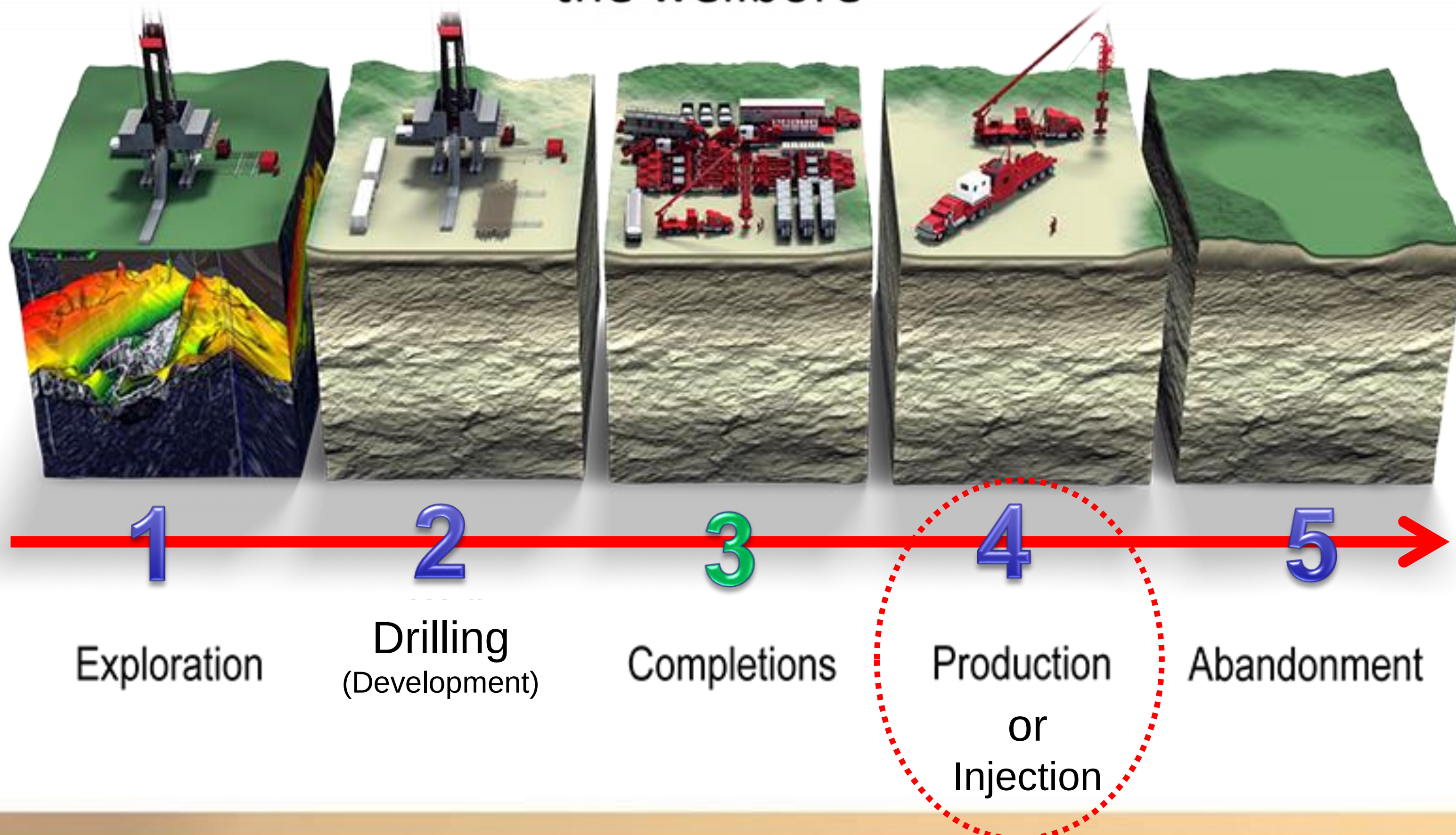


# Contents- cased hole logging

# 5-Production logging tool ( PLT)

1. Introduction to PLT
2. History Of Production Logging
3. PLT Applications
4. PLT operation
5. PLT Tools
6. data requirements for interpretation PLT

"Production Logging is the measurement of fluid parameters on a zone by zone basis to yield information about the type and movement of fluids within and near the wellbore"



# 2.History Of Production Logging

- Temperature surveys were first used in the mid 1930s. One use was the estimation of the top of the cement behind the casing

- By the late 1950s and early 1960s the basic sensor types had been developed as individual tools. The surveys required a seperate pass to obtain flowmeter, gradiomanometer, temperature and so on

- 1970 saw the sensors packaged together in one tool, meaning a more efficient single run in the hole. The individual measurements still had to be run one at a
  time. By the end of the decade advances in electronics allowed everything to be recorded in a single pass across the zone of interest. This had many advantages not least the savings in time.

  ”
- Improvements continued through the 1980s to the present day with better sensors, especially pressure gauges, and deployment methods.
  The latest tool uses completely new technology to measure a flow profile for the individual fluid phases all around the borehole.

# 3. PLT Application

1

**Evaluate completion performance**
- ✓ New wells
- ✓ Injection wells
- ✓ Re-completions

2

**Monitor reservoir performance & variations**
- ✓ Flow profile
- ✓ Well test
- ✓ Completion Efficiency

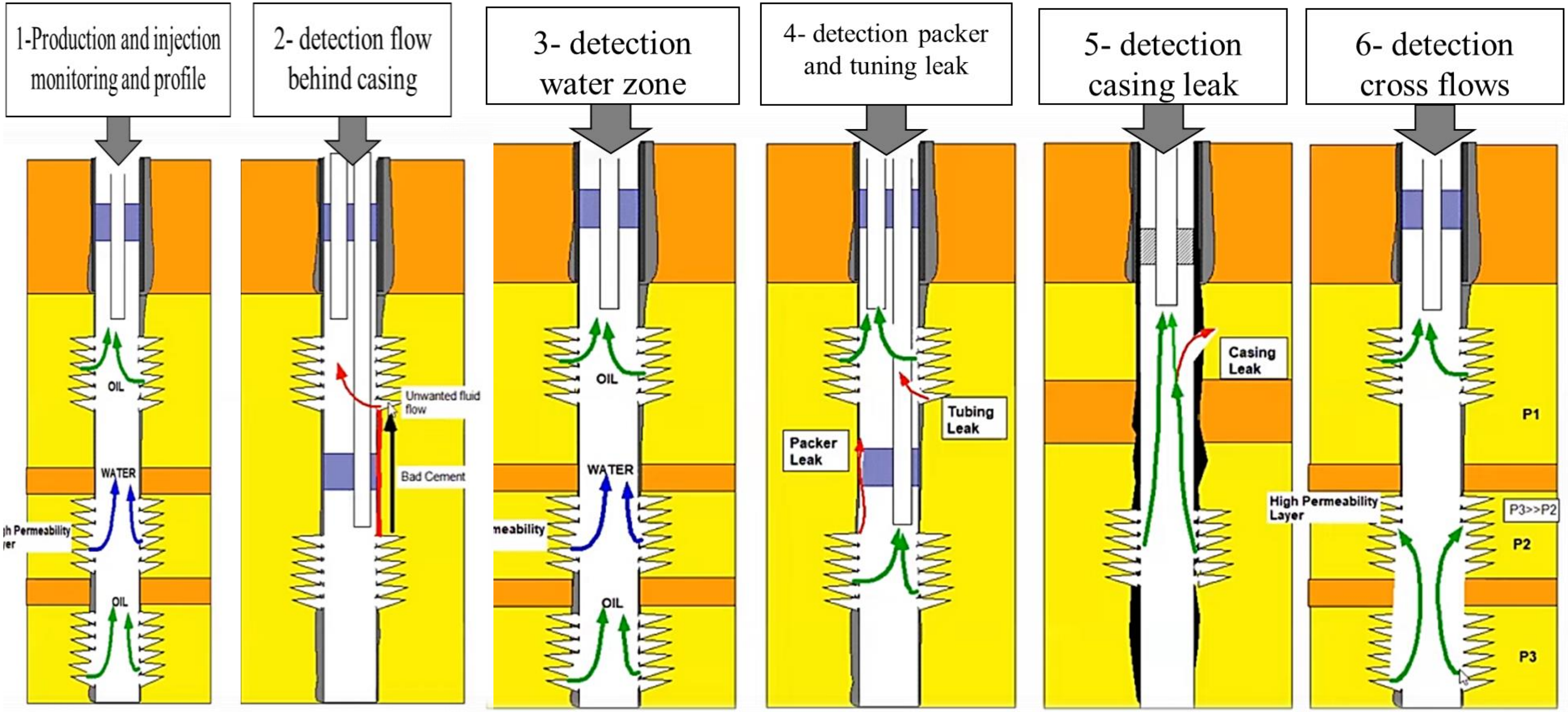
3

**Diagnose well problems**
- ✓ Water entry
- ✓ Gas entry
- ✓ Leaks and mechanical problem
- ✓ Flow behind casing

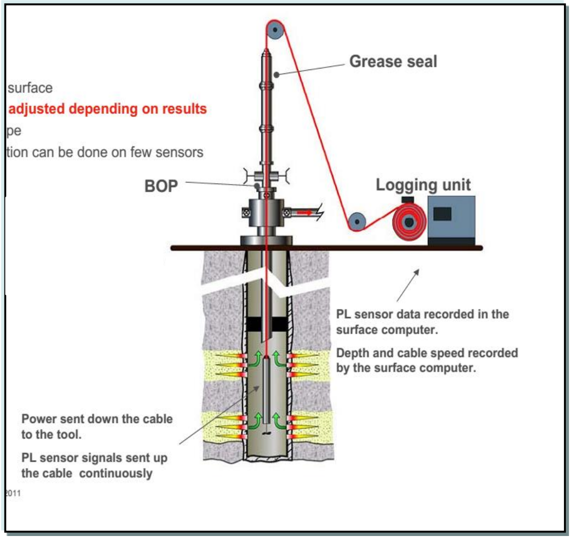
4

**Other**
- ✓ Guidance for workover
- ✓ Information for enhanced oil Recovery projects
- ✓ Identify boundaries for field development

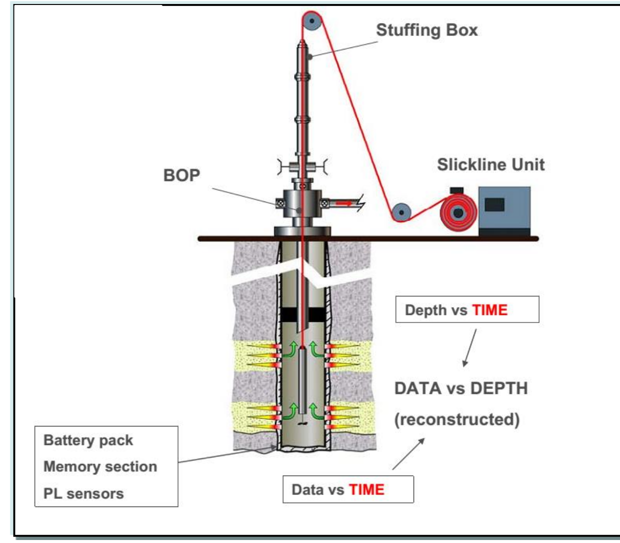
# 3.PLT Application



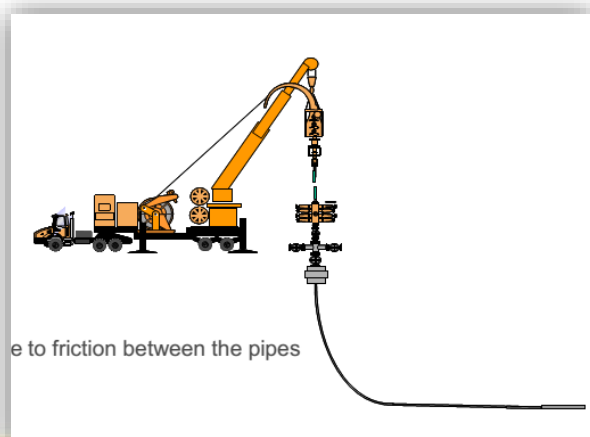
# 4.PLT- operation methods




**1-PLT operations – Electric-Line**




**2-PLT operations – Memory ( MPL)**




**3-Tractor and Coiled Tubing method**

# Pre-PLT- operation

## 1. Well Select:

- ✓ Well productivity ( low , medium , high ) ?
- ✓ Well trajectory ( vertical , deviated , horizontal ) ?
- ✓ Well type ( injector , producer ) ?
- ✓ Check the well sketch ( single completion , commingle )?
- ✓ This well produce natural flow or Artificial lift ?
- ✓ If this well produce ( ESP ) , have Y- tools or not ?
- ✓ Well situation ( sand , asphalt ) ?

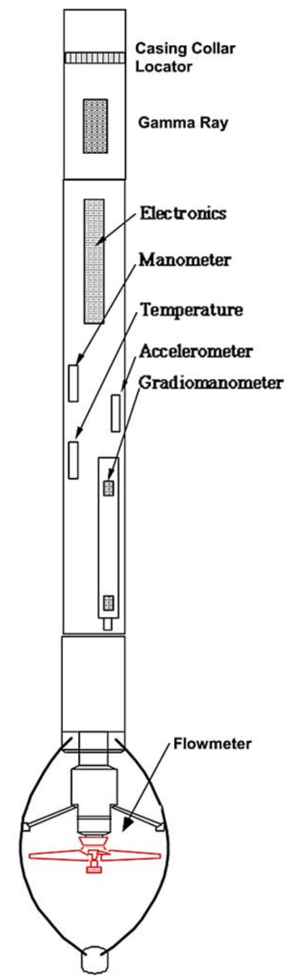
# Pre-PLT- operation

- **2.In well site before run PLT :**

- Take fluid sample from well head and send to lab to check the water )
- Put the well to test separator to check the production at the same day will run PLT
- Keep the well head pressure and chock size constant before and after PLT operation , to compare the results .

# 5.PLT- Tools

1. GR
2. CCL
3. Caliper
4. Centralizers
5. Flow-meter ( spinner)
6. Temperature
7. Pressure
8. Density
9. Capacitance



# 5.PLT- Tools

**Producer Well**

1. GR
2. CCL
3. Caliper
4. Centralizers
5. Flow-meter ( spinner)
6. Temperature
7. Pressure
8. Density
9. Capacitance

**Injection Well**

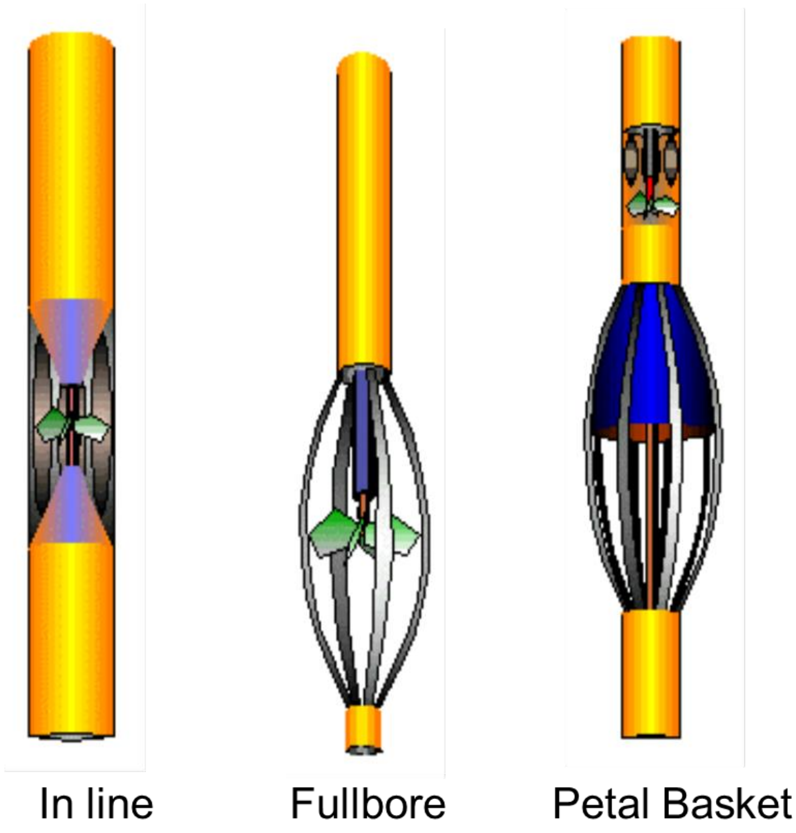
1. GR
2. CCL
3. Caliper
4. Centralizers
5. Flow-meter ( spinner)
6. Temperature
7. Pressure

# 5.PLT- Tools

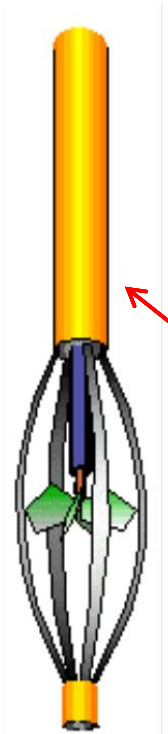
- **Gamma- Ray**
  - Usually, the depth matching is done thanks to the GR log
    - Needs to load the open hole GR
  - Could give good indications of water source if scales are radioactives
  - With gravel pack, Frac-Pack, the natural radioactivity is not more visible.
- **CCL**
  - CCL could help in depth matching if particular completion elements can be identified
  - Perforations may sometimes
- **Caliper**
  - Caliper diameter is measured thanks to 2 perpendicular arms
  - Diameter is mandatory to compute flow rate
  - Even with an accurate completion sketch, caliper data has to be examined
    - Scales could be observed thanks to the caliper
- **Centralizers**
  - To keep the tool in the middle of the wellbore is important to get a representative data (downhole recirculation)

# PLT Tools – Flow-meter ( Spinner )

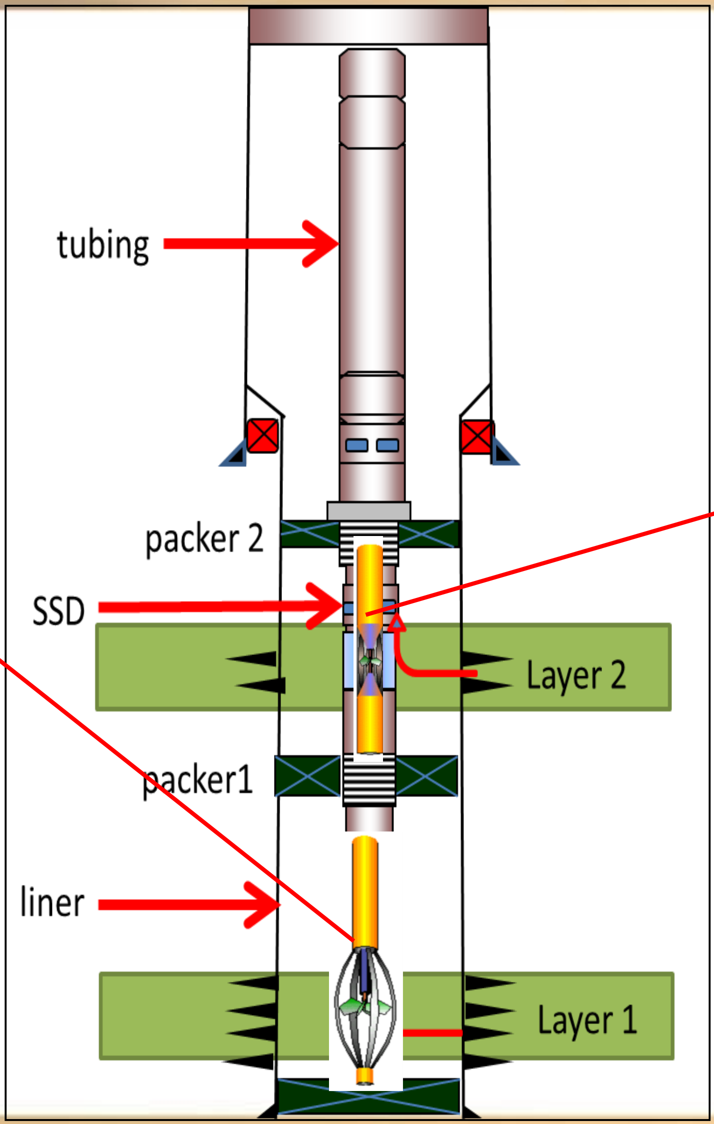
- **In line Flowmeters**
  - small spinner
  - good for high flowrates
  - Mainly used as backup spinner
- **Full bore Flowmeters**
  - maximum spinner blade size
  - best for wide range of flowrates
  - For injection wells could be replaced by turbine
- **Petal Basket**
  - stationary measurement
  - good for low flowrates
  - May affect flow regime

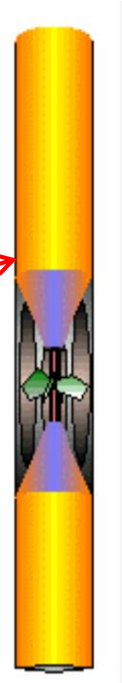


# PLT Tools – Flow-meter ( Spinner )



Full-bore spinner



In line spinner

# PLT Tools – Flow-meter type

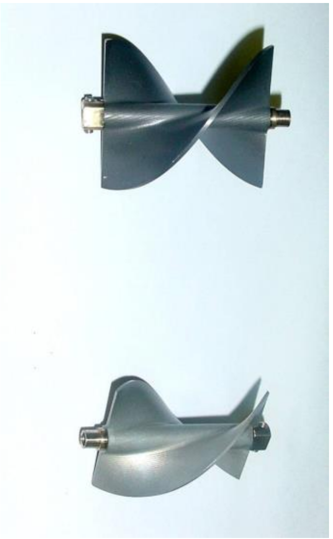
Fullbore Spinner 3-arm

Fullbore Spinner 6-arm

Continuous Spinner

In-line Spinner

Diverter Flowmeter



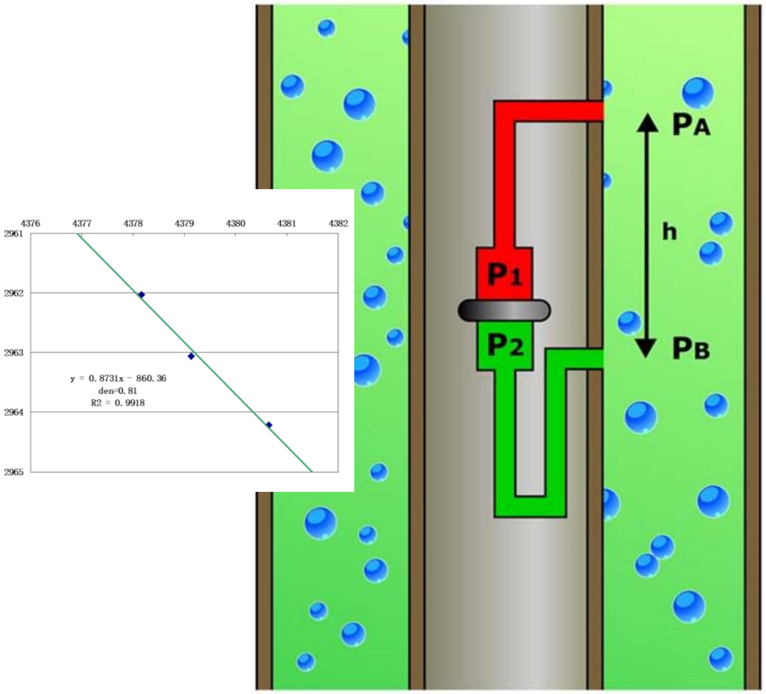
Turbine Spinner

# PLT Tools – Temperature tools

- Temperature is one of the most useful “auxiliary” measurements made in production logging.
- Temperature is very important as it is a good liquid **indicator in gas wells**
- The temperature can be more sensitive to small flows than the flowmeters
- Combined with pressure it helps compute the PVT parameters.
- The response time is very important more than the resolution itself (especially for quantitative temperature analysis)
- In addition, it will detect very small fluid entries:
    - The derivative of temperature wrt depth (dT/dZ) can be used to clarify fluid entries in complex environments.
    - Gas entries, for example, are characterized by a sharp reduction in temperature.
- It is the only tool in the string that “sees” behind casing, hence it can be used to **detect channeling**.

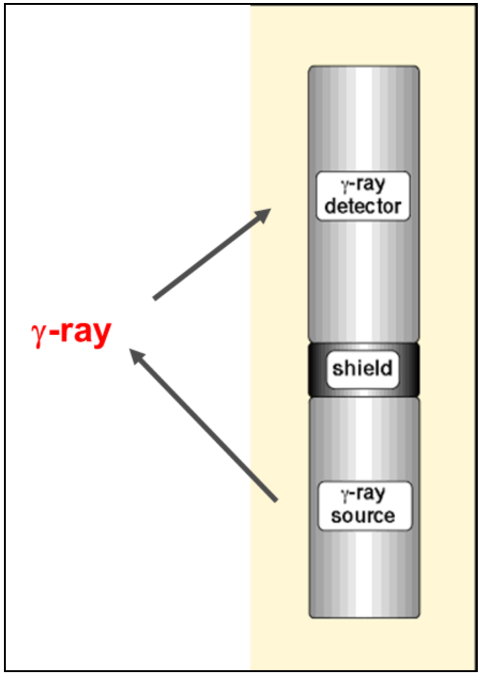
# PLT Tools - Density

**Density is used to determine liquid source entry**




**Gradiomanometer**

Tool measure the difference in pressure between two points




**Nuclear fluid density tool**

Gamma ray absorption

# PLT Tools – Fluid Hold up tools

- **The purpose of this tool** is to determine the mixture hold up and determine the relative **proportions of the phases present**
- Two main way to measure it
  - Single sensor in the “middle” of the wellbore
    - Capacitance/Impedance tools
  - Imaging tools that allow you to have a complete view of the borehole with several probes : Multi array tool
    - Two main manufacturers are
      - Sondex :
        - » Multi Capacitance (CAT)
        - » Multi Resistivity (RAT)
      - Schlumberger : 4 probes
        - » Multi Resistivity (flowview)
        - » Optical probes (GHOST)

# PLT Tools - Capacitance

- **This tool use the difference between the dielectric constant of water and that of oil or gas**
- A simple way to find the dielectric constant of a fluid is to use the fluid as the dielectric between the plates of a capacitor
- Hence the tool measures frequency… counts /sec

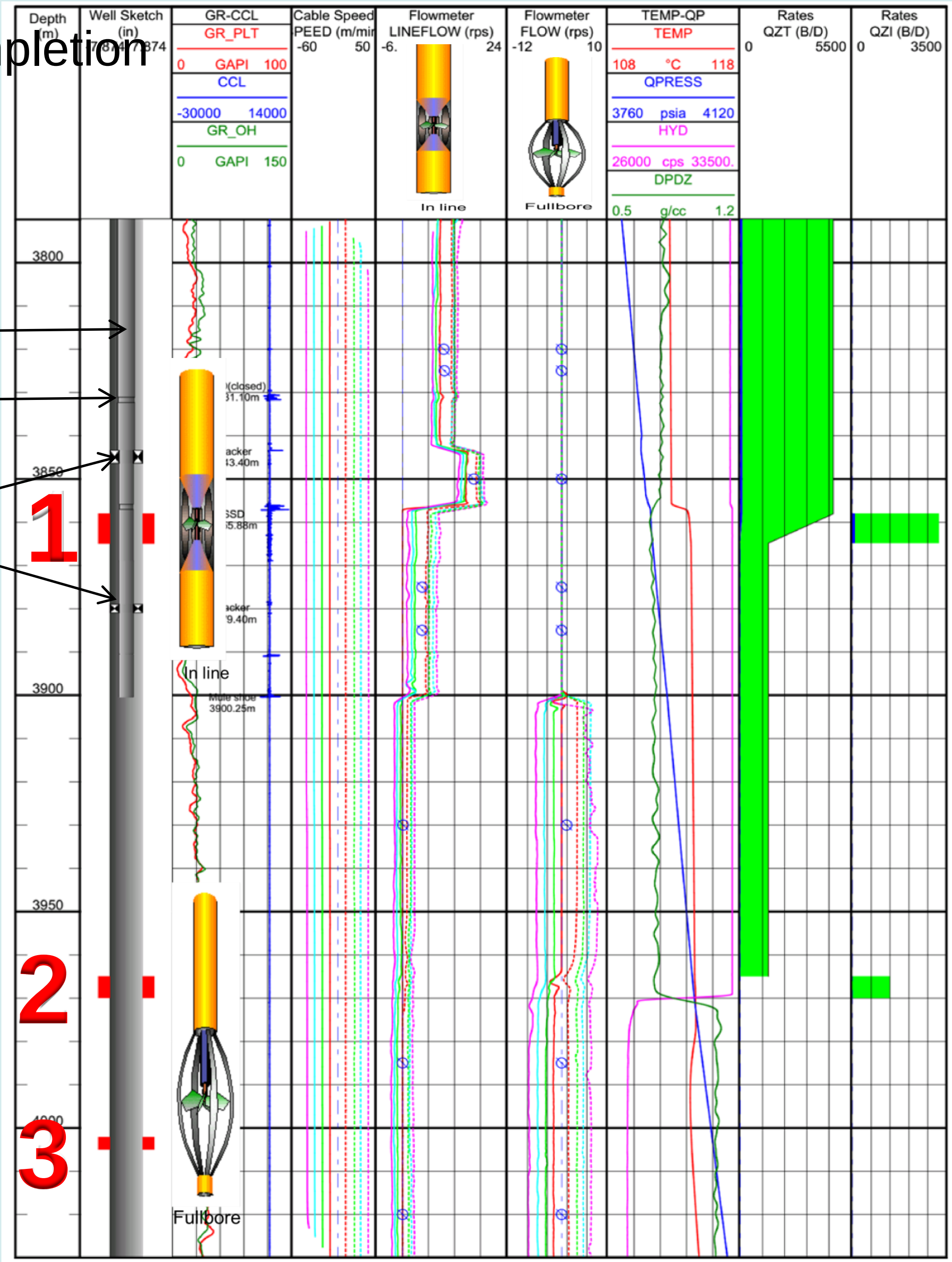
# Case1 : PLT – commingle completion

PLT - flowing

tubing

casing

packers




| Water | Oil | Total Fluid | Water Cut |
|---|---|---|---|
| B/D | B/D | B/D | % |
| 98.8 | 2299.5 | 2398.3 | 4.1 |
| 0.0 | 1026.4 | 1026.4 | 0.0 |
| 0.0 | 0.0 | 0.0 | 0.0 |
| 98.8 | 3325.9 | 3424.7 | 2.9 |

# Case 2 : PLT – well producing Liquid & Liquid Channeling

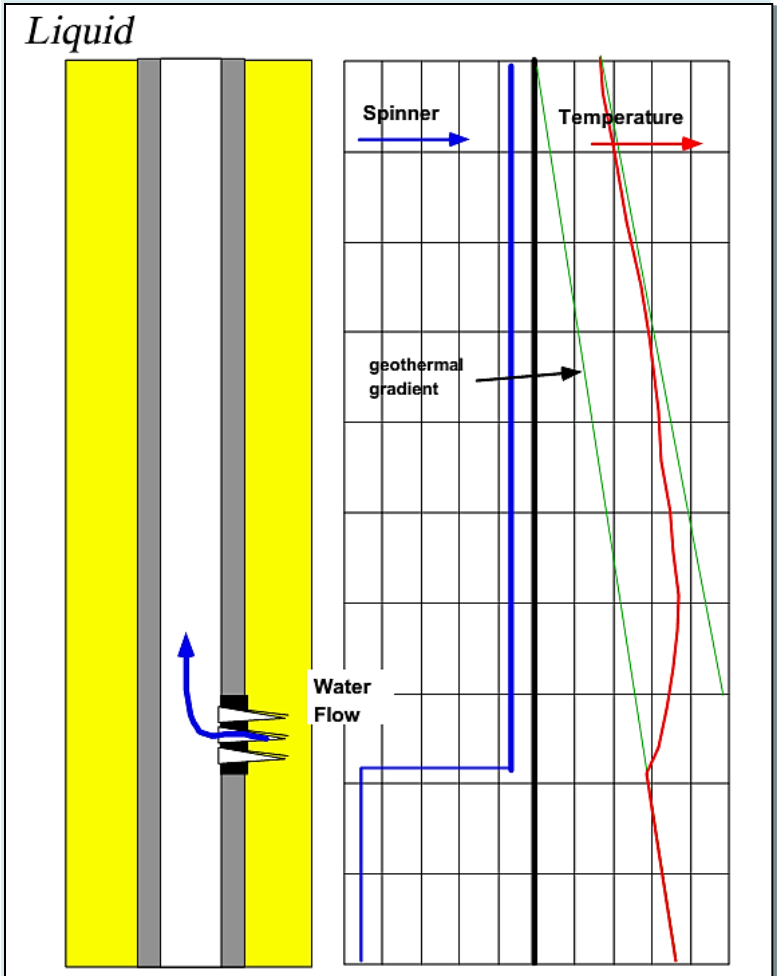



Fig. G4: Well producing liquid.

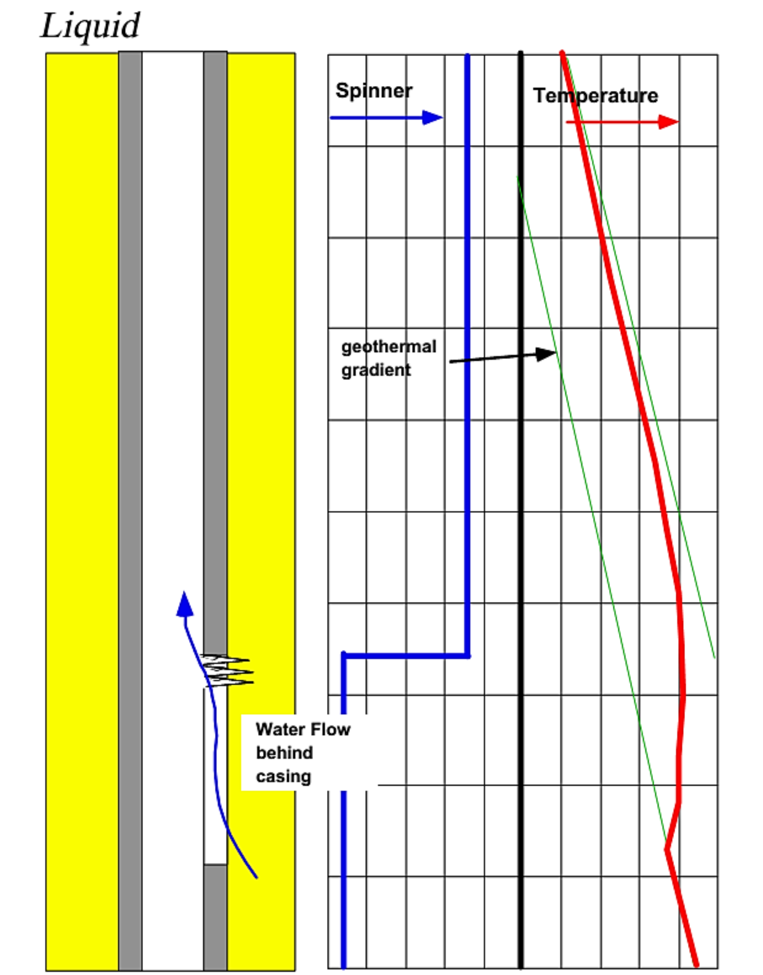



Fig. G6: Liquid Channeling.

# Case 3 : PLT – well producing gas & gas Channeling

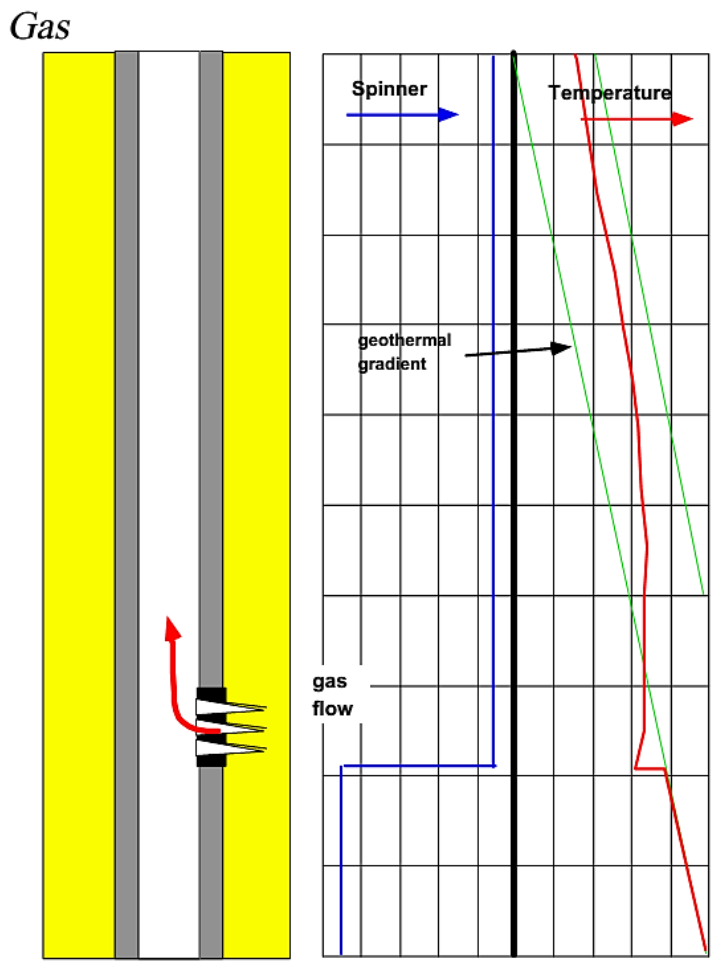



Fig. G5: Well producing Gas.

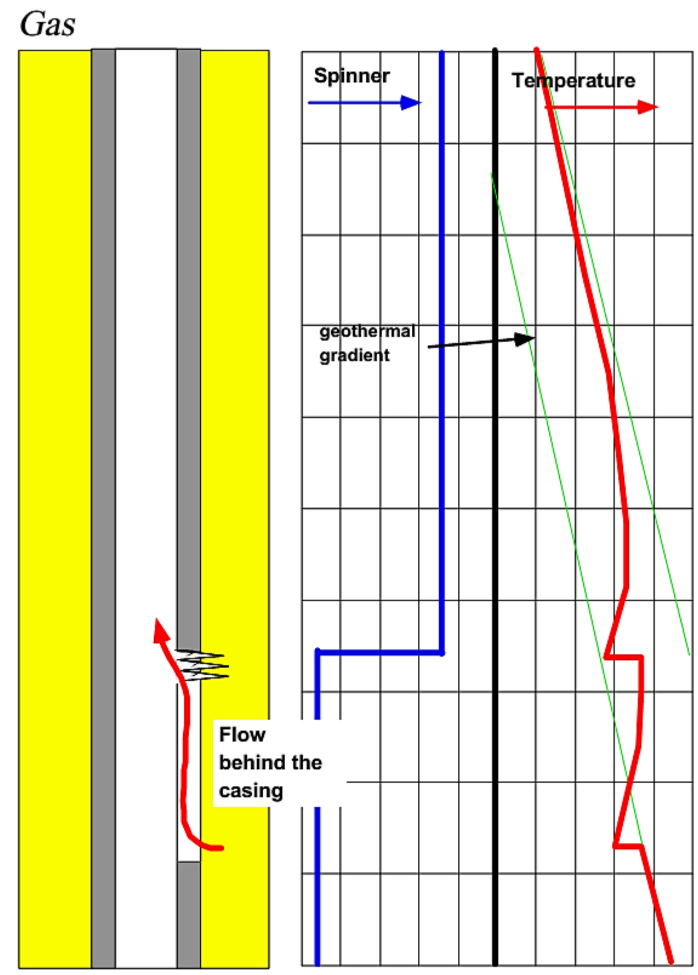



Fig. G7: Gas Channeling.

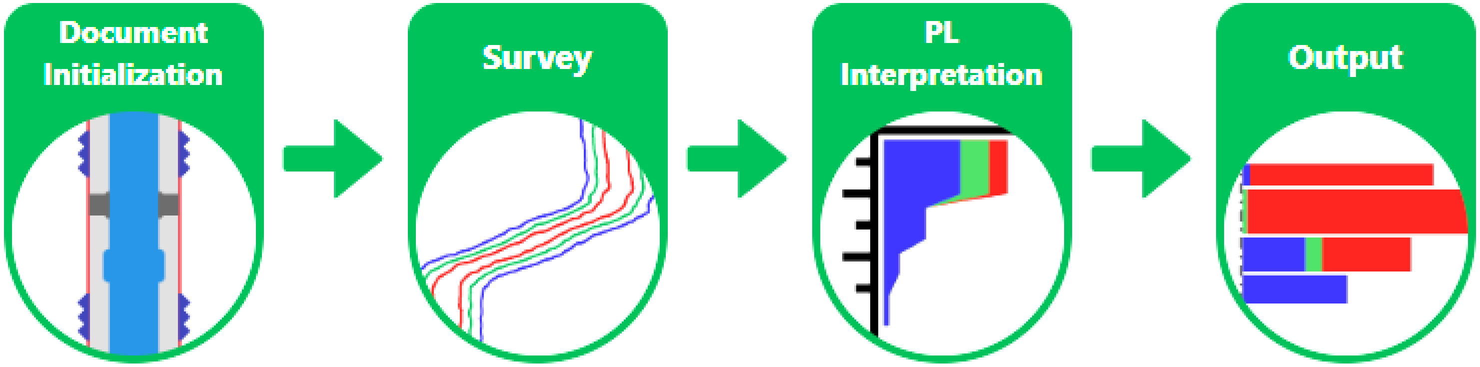
# 6.PLT interpretation data requirements

Emeraude software use for Production Logging interpretation from KAPPA company.

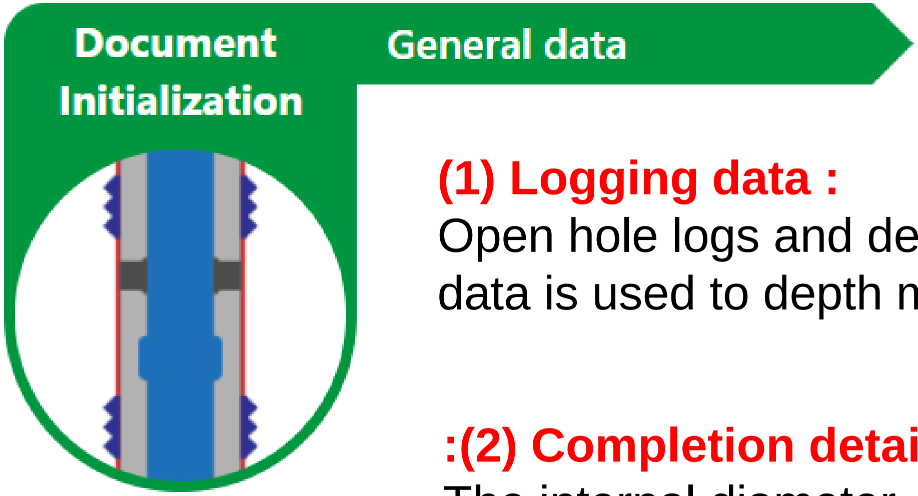
.

# PLT interpretation data requirements

## Emeraude workflow



# PLT interpretation data requirements

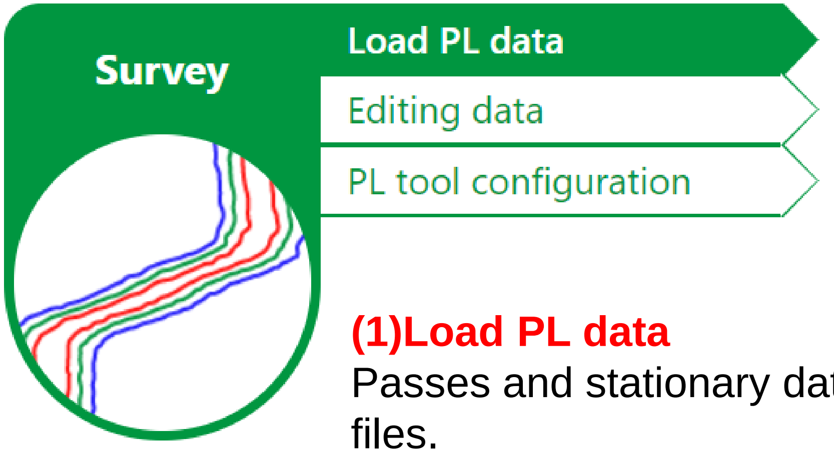



**(1) Logging data :**
Open hole logs and deviation surveys are loaded. This data is used to depth match the PLT data

**:(2) Completion details**
The internal diameter, depth of the perforations and reservoir zones, markers, pipe roughness and deviation are loaded in the completion details.

**:(3) Well Sketch**
It is possible to create a completion diagram of the well, by selecting completion items (casing, tubing, cement, etc.)

# PLT interpretation data requirements




**(1)Load PL data**

Passes and stationary data are loaded from LIS, LAS and ASCII files.

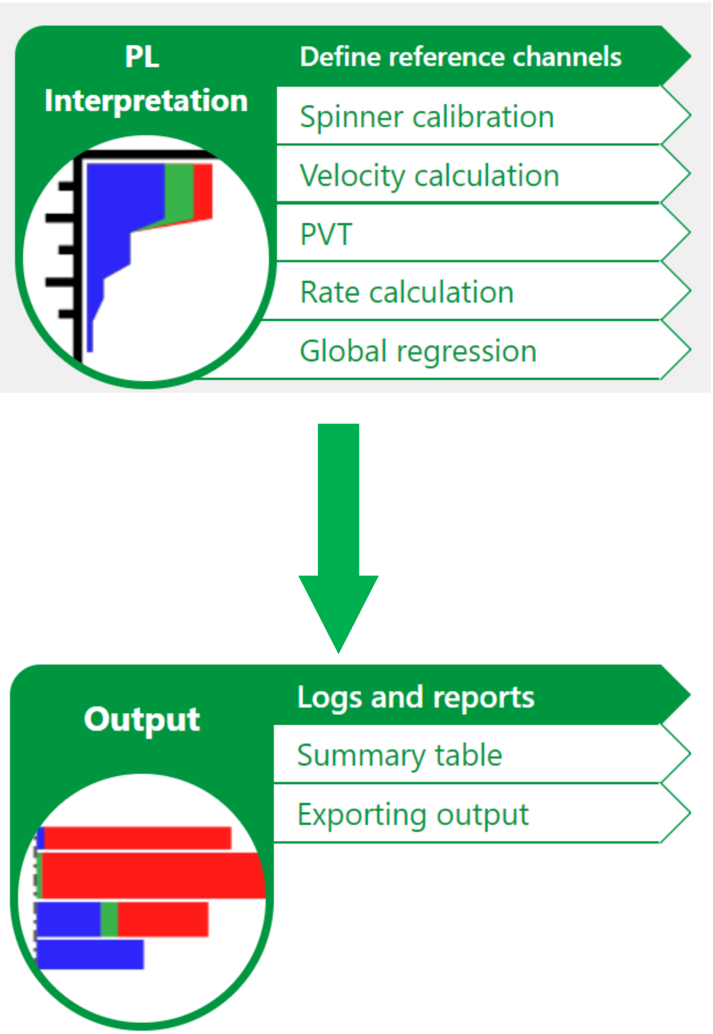
**(2)Editing data**

The raw PL data normally requires editing before an interpretation can be performed. Emeraude contains a broad range of editing options: lateral average, depth stretch, shift, delete data and fill, hide data, merging, splicing, derivative, sampling, user formula module, etc…

**(3)PL tool configuration**

In Emeraude, the user must specify the type of **density tool** that is used, so the proper corrections are applied in the calculation scheme. **The spinner** blade diameter must be entered to compute the velocity profile correction factor. A built-in list of c**apacitance** tools is included for the different vendors, with their respective calibration charts.

# PLT interpretation data requirements

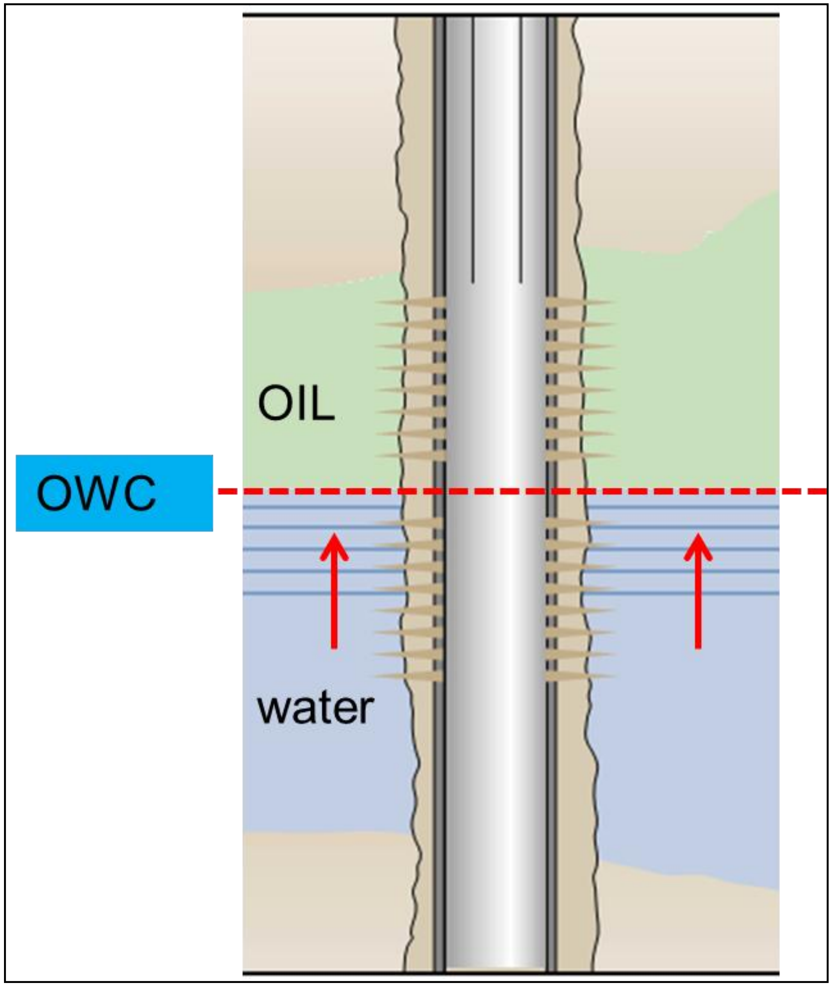


# Contents- cased hole logging

1. Introduction to cased hole logging
2. Cement Logs
3. Casing inspection log
4. Spectral Noise Tool  ( SNL)
5. Production logging tool ( PLT)
6. **Reservoir saturation tool**

# Saturation logging-Applications

1. Formation evaluation behind casing.
2. Water saturation in old wells.
3. Water saturation in new wells where modern open hole logs have not been run.
4. Formation oil volume from C/O ratio, independent of formation water salinity .
5. Lithology from C/O ratio,.

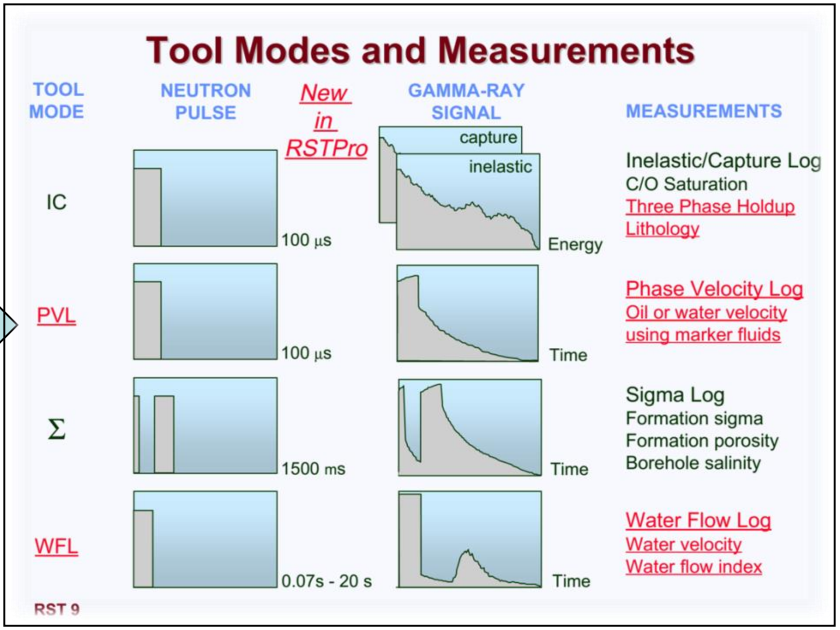


# Saturation log types

Many types almost use neutron as a source . And some tools use two modes such as ( SIGMA , C/O)

- Thermal Decay Time (TDT)

  Reservoir Saturation Tool ( RST)
- Reservoir Saturation Tool ( RST-pro)
- Reservoir Monitor Tool (RMT)
- Pulsed Neutron ( PNX)
- Pulse Neutron Neutron ( PNN)




**Note : Limitation in salinity and porosity**

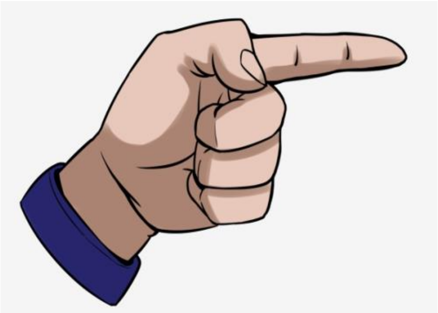
# Saturation log Modes

| Measurement Matrix | | Modes type | | | |
|---|---|---|---|---|---|
| Company | Tool I.D | Sigma Logging | C/O Logging | Water Flow | Inelastic gamma ( gas ) |
| Baker | RPM | √ | √ | √ | √ |
| Halliburton | RMT | √ | √ | √ | √ |
| Halliburton | TMD | √ | | √ | √ |
| Hotwell | PNN | √ | | | |
| Schlumberger | RST | √ | √ | √ | √ |
| Weatherford | CRE | √ | √ | √ | √ |

# Saturation log detector type

## Pulsed-Neutron Sensor

| Specifications | | | | | |
|---|---|---|---|---|---|
| Company | Tool I.D | O.D ( inch ) | Detector Type | Spacing* | Max Temp ( F ) |
| Baker | RPM | 1.6875 | NaI-gamma | Near,Far,Long | 350F |
| Halliburton | RMT | 2.125 | BGO-gamma | Near, Far | 300F |
| Halliburton | TMD | 1.6875 | NaI-gamma | Near, Far | 325F |
| Hotwell | PNN | 1.6875 | He-neutron | Near, Far | 300F |
| Schlumberger | RST | 2.50&1.6875 | GSO-gamma | Near, Far | 300F |
| Weatherford | CRE | 1.6875 | LaBr3-gamma | 4 Spacings | 325F |
| *Typical Near spacing 12 to 15 inches, Typical Far spacing18 to 25 inches, Typical Long spacing 30 to 36 inches. | | | | | |



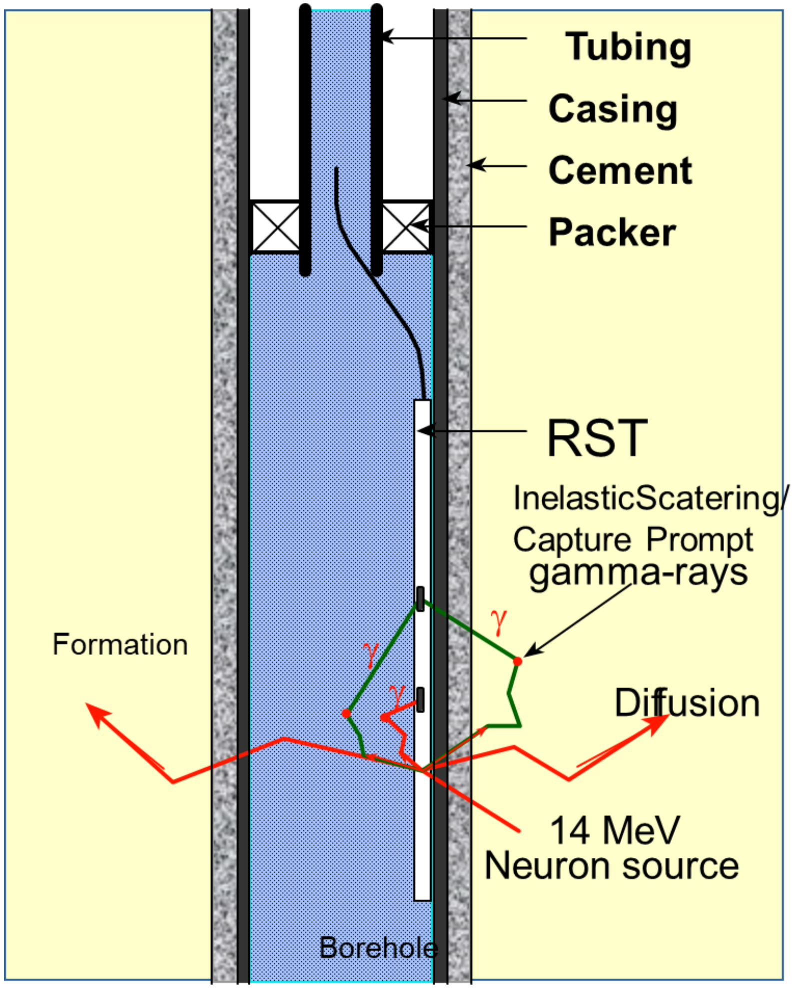
Reservoir Saturation Tool

# SIGMA

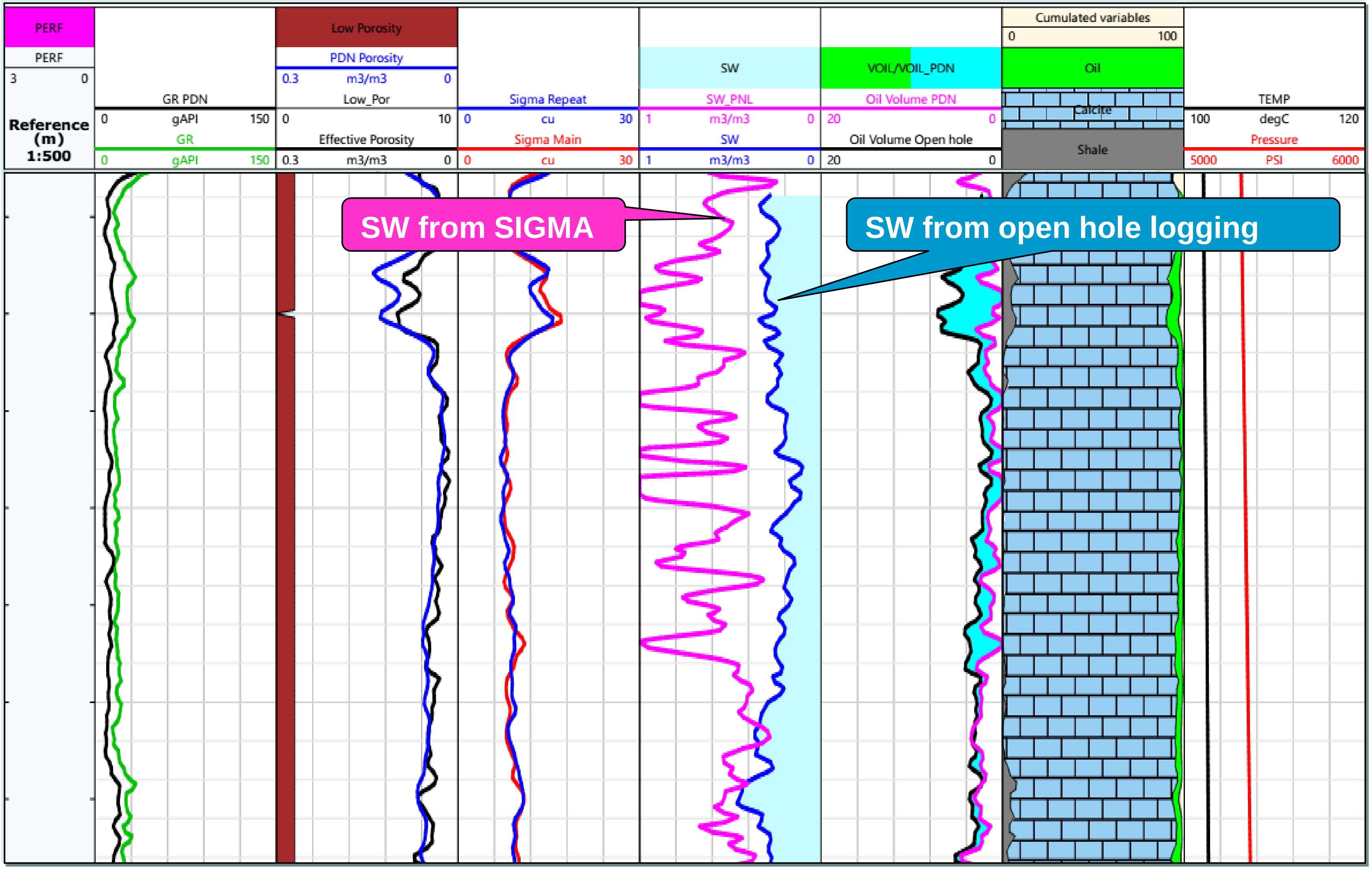
# Saturation log -Basic Theory

- Tool generates neutrons
- Neutrons interact with:
  - tool,
  - borehole fluids,
  - formation
- We measure GRs

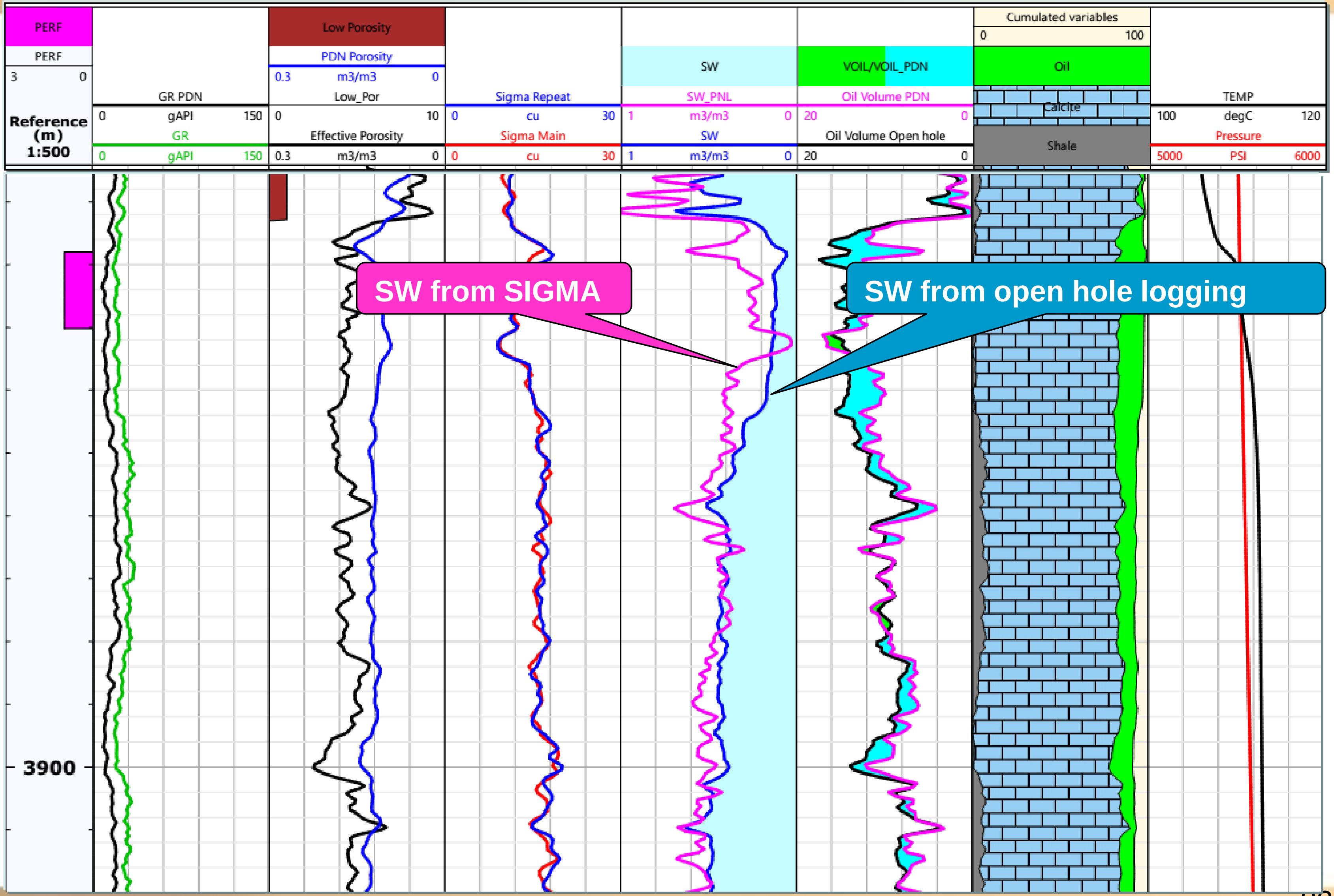
We want to know Sw !



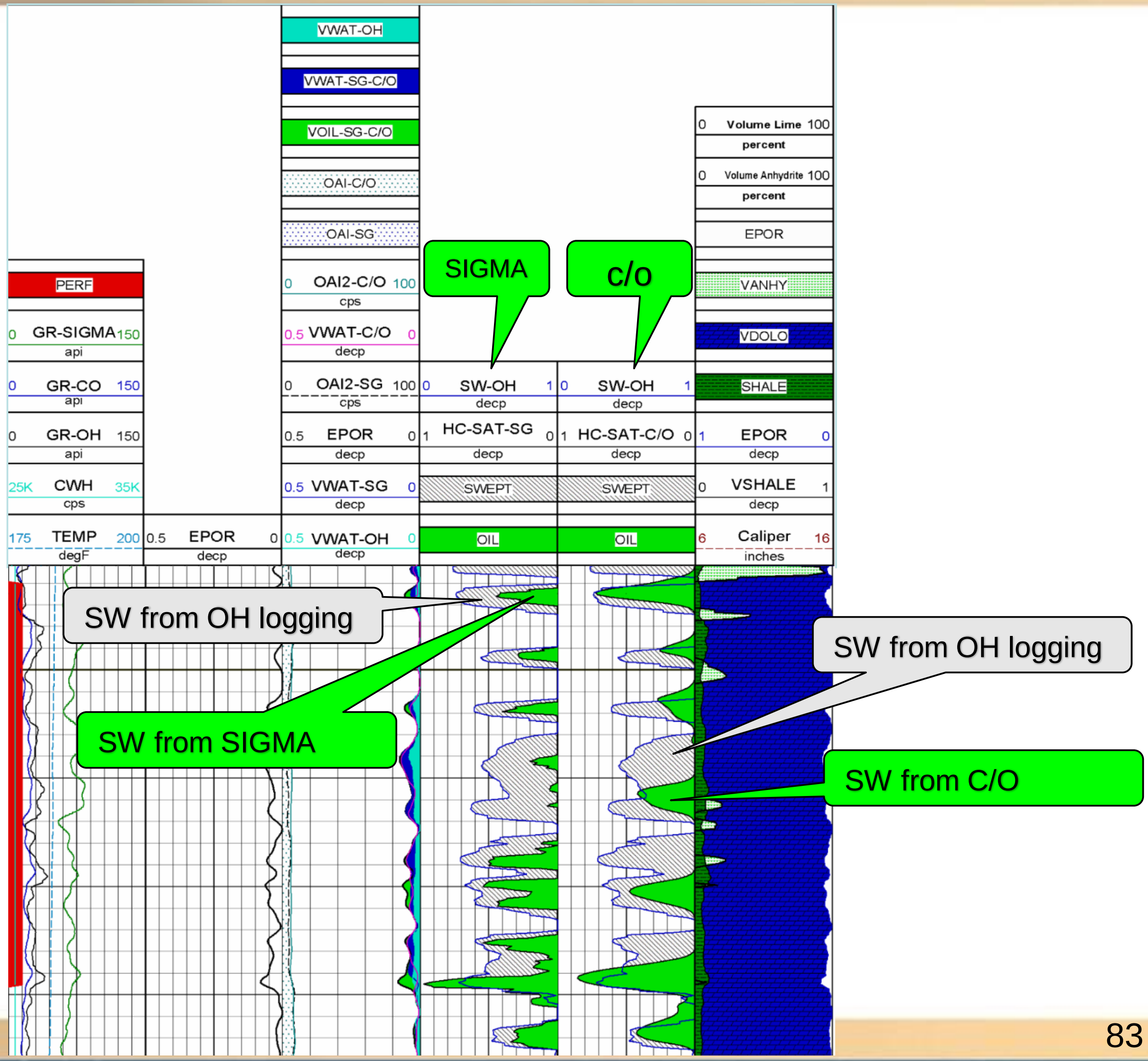
# CASE 1 : SIGMA -porosity less than 10

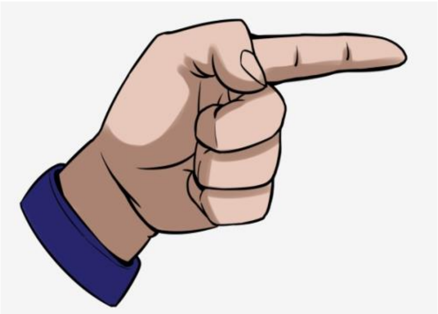


# CASE 2 : SIGMA -porosity more than 10



# CASE 3 : SIGMA –and C/O--- RMTi ( Halliburton)





Reservoir Saturation Tool

# RST-pro

# RST Outline

- Introduction
- Basic Theory
- Sigma / TDT
- IC mode (Inelastic/Capture)
- WFL Mode (Water Flow Log)
- PVL mode (Phase Velocity Log)

TPHL mode (Three Phase Holdup Log )

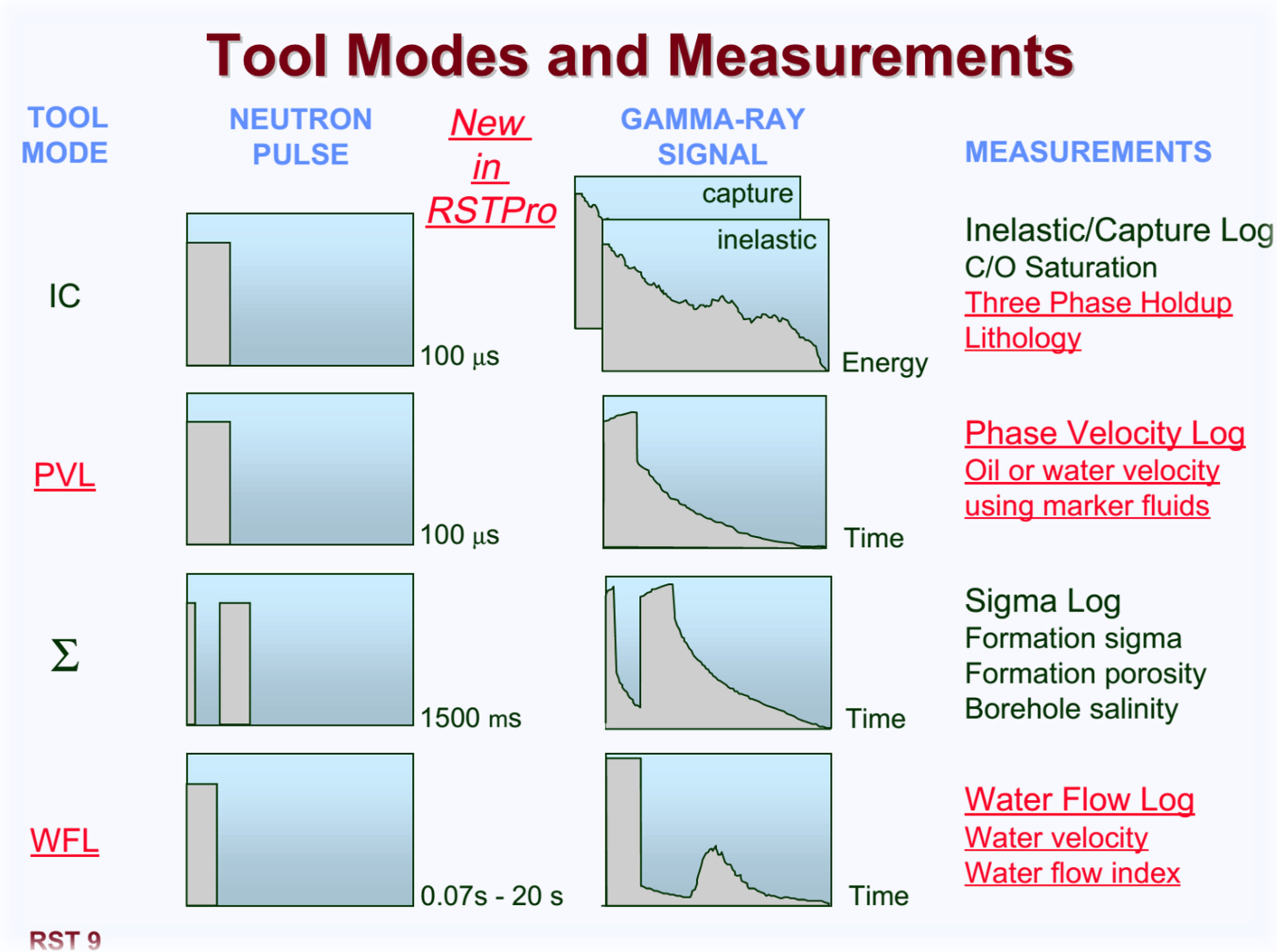
# RST Introduction

- RST is a nuclear tool with different logging modes
- Essentially it can provide three types of measurements:
  - Reservoir saturation
    - from Inelastic Capture (C/O) or Sigma measurements.
  - Lithology and elemental yields
    - from analysis of inelastic capture gamma ray spectra.
  - Borehole fluid dynamics from :
  - WFL (Water Flow Log)
  - PVL (Phase Velocity Log)
  - TPHL(Three Phase Holdup Log)

# RST Applications

1. Formation evaluation behind casing
2. Sigma, porosity, and C/O measurement in one trip in the wellbore
3. Water saturation evaluation in old wells where modern open hole logs have not been run
4. Measurement of water velocity inside casing, irrespective of wellbore angle (production logging)
5. Measurement of near-wellbore water velocity outside the casing (remedial applications)
6. Formation oil volume from C/O ratio, independent of formation water salinity
7. Capture yields (H, Cl, Ca, Si, Fe, S, Gd, and Mg)
8. Inelastic yields (C, O, Si, Ca, and Fe)
9. Borehole salinity

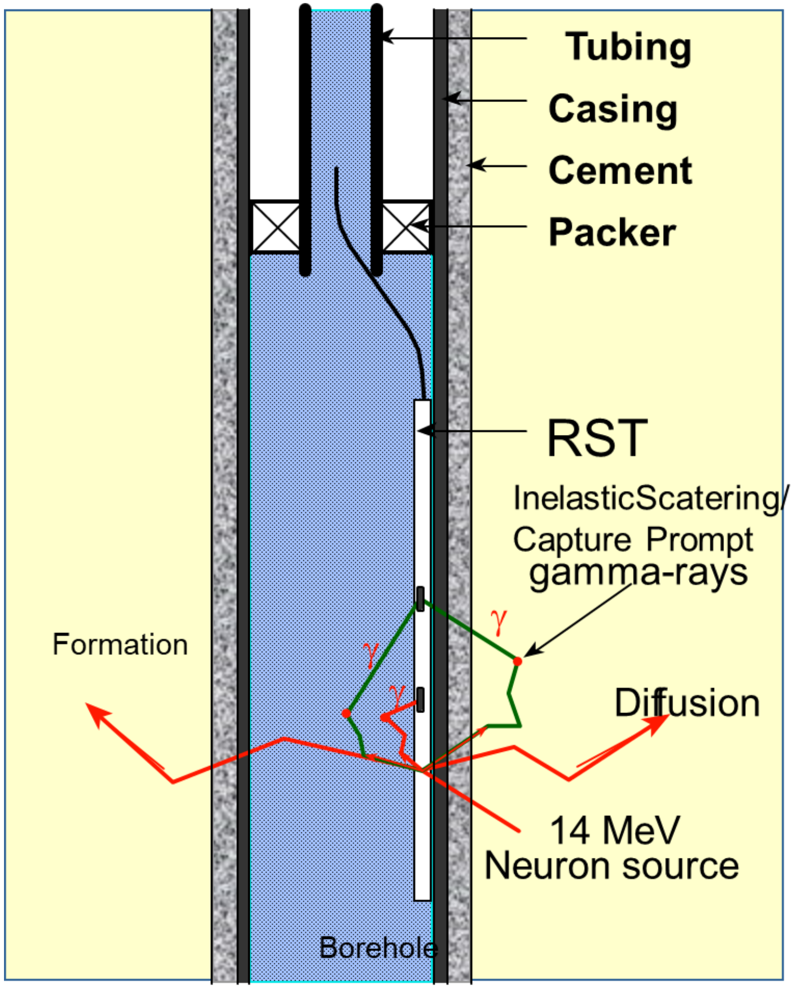
# Tool Modes and Measurements



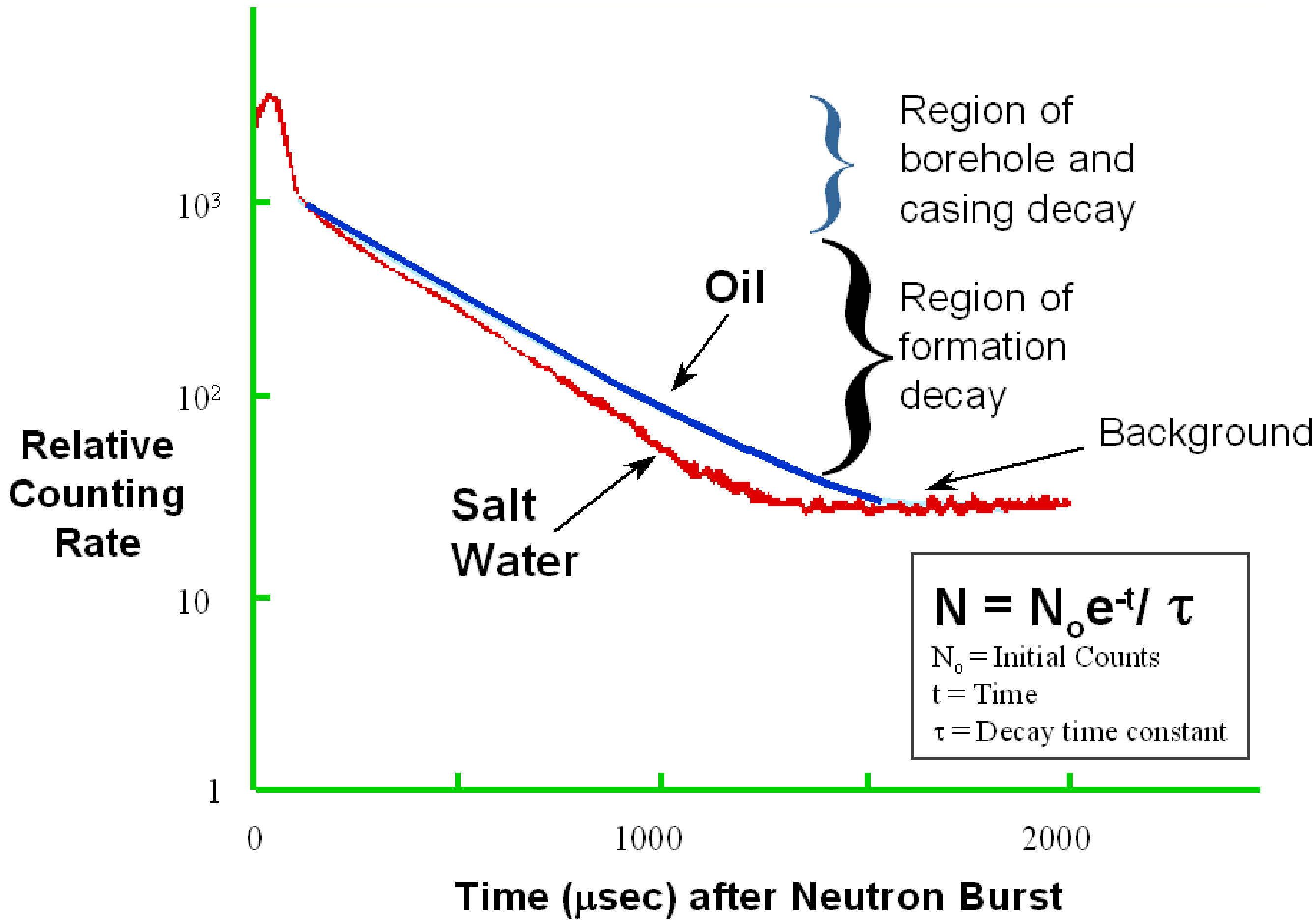
# Basic Theory

- Tool generates neutrons
- Neutrons interact with:
  - tool,
  - borehole fluids,
  - formation
- We measure GRs

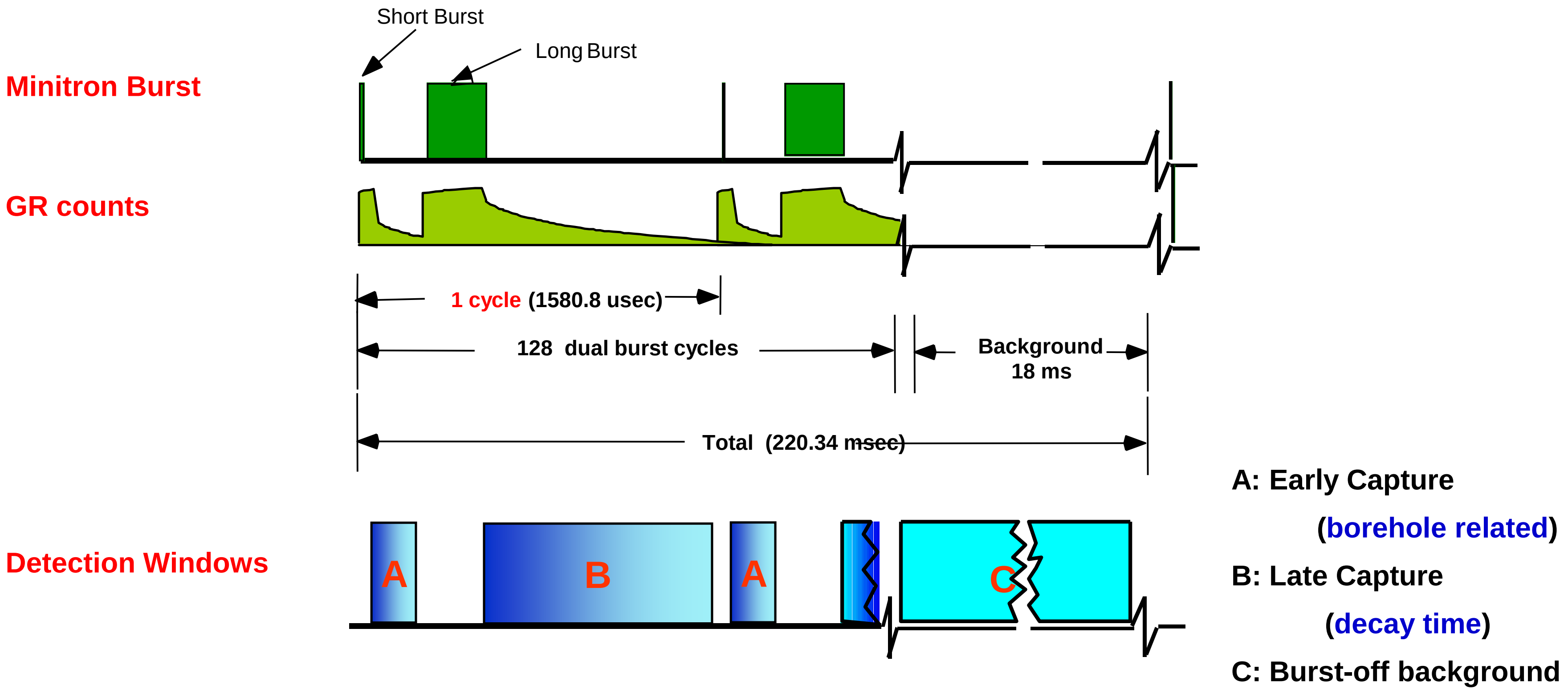
We want to know Sw !



# Sigma principle



# Sigma Acquisition




- GR **counts** detected from capture of thermal neutrons
- From exponential thermal neutron decay rate ➔ Sigma

# Why do we measuring Sigma

- **Elements have a Capture Cross section property: Sigma : $\Sigma$**

| | |
|---|---|
| Gas | 0 - 12 |
| Oil | 18 - 20 |
| Water | 22 (fresh) - 130 (saline) |
| Shale | 35 - 55 |
| Matrix | 8 - 12 |

- **What do we log?**

$$\begin{aligned}\Sigma_{log} = \; & (\Sigma_{water} * \phi S_w) && \textbf{Water} \\ & + (\Sigma_{oil} * \phi(1-S_w)) && \textbf{Oil} \\ & + (\Sigma_{matrix} * (1-\phi-V_{shale})) && \textbf{Matrix} \\ & + (\Sigma_{shale} * V_{shale}) && \textbf{Shale}\end{aligned}$$

# Sw calculations

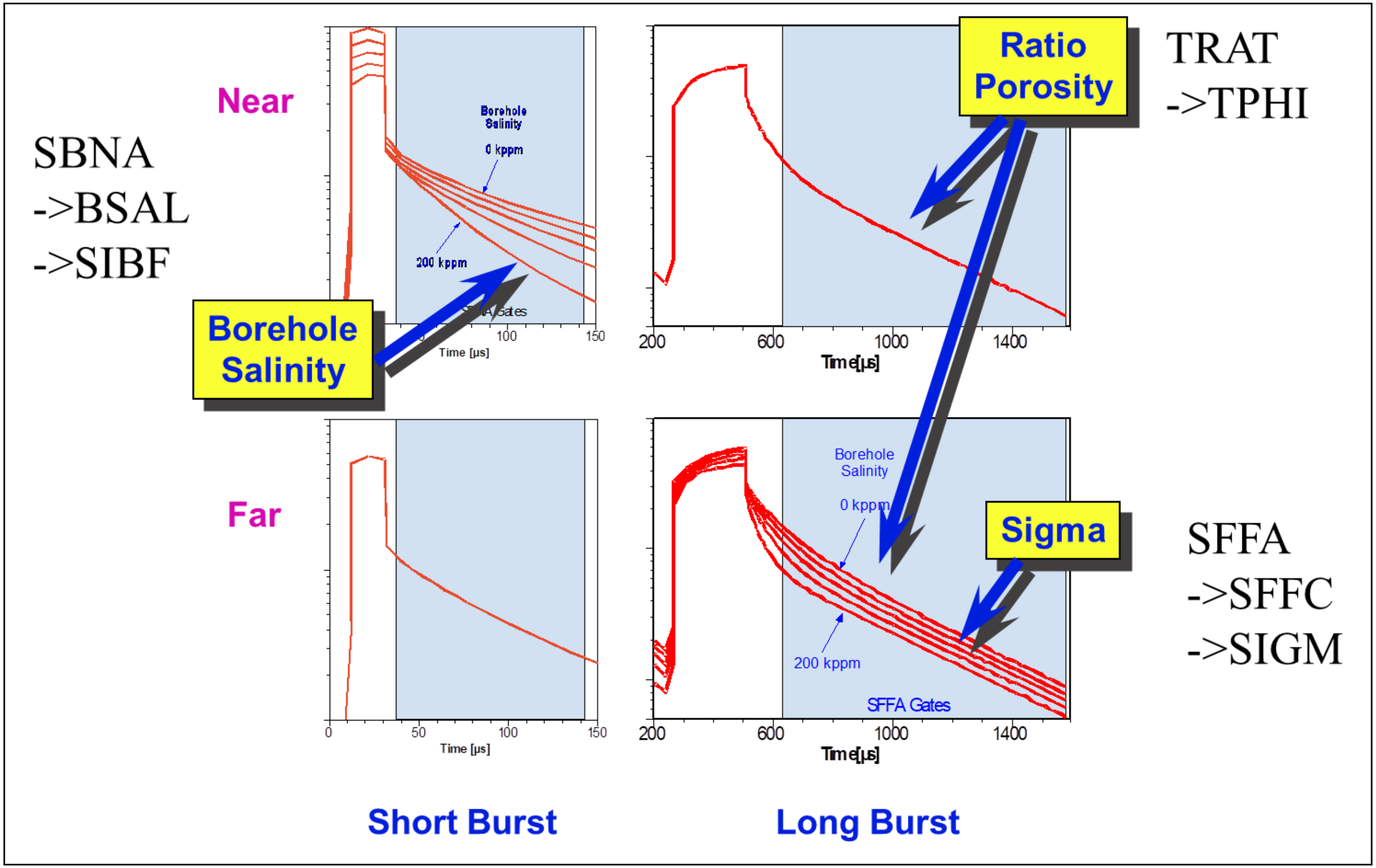
- Stand Alone
  - *If other data is known*

$$S_w = \frac{(\Sigma_{LOG} - \Sigma_{ma}) - \phi(\Sigma_h - \Sigma_{ma}) - V_{sh}(\Sigma_{sh} - \Sigma_{ma})}{\phi(\Sigma_w - \Sigma_h)} \quad \text{……}Eq\ 1$$

- Time Lapse Technique
  - *If another* $\Sigma$ *log exits……*

$$\Delta S_w = (\Sigma_{log} - \Sigma_{base}) / (\phi(\Sigma_{water} - \Sigma_{oil}))$$

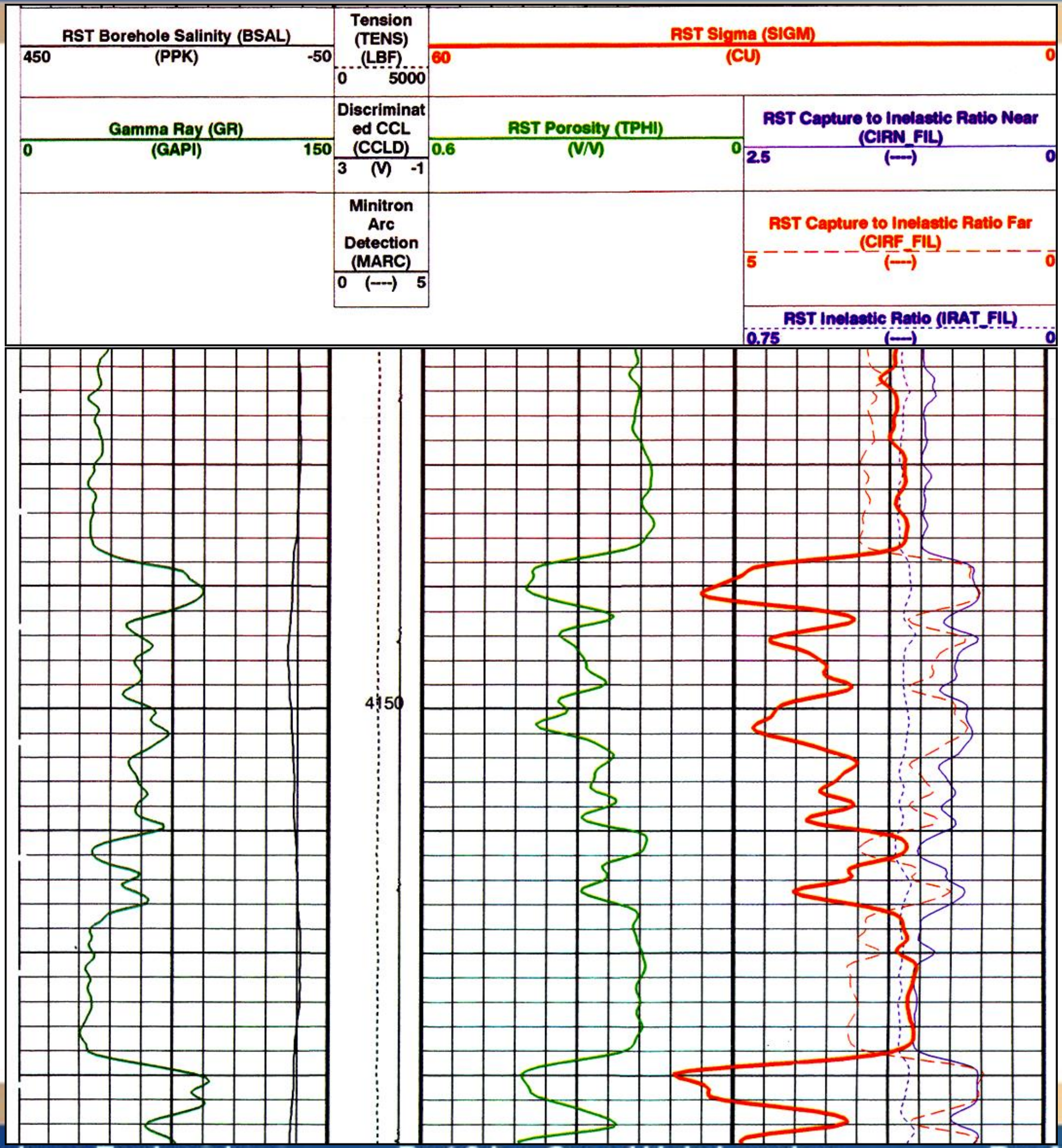
# RST apparent quantities



# Sigma Mode Applications

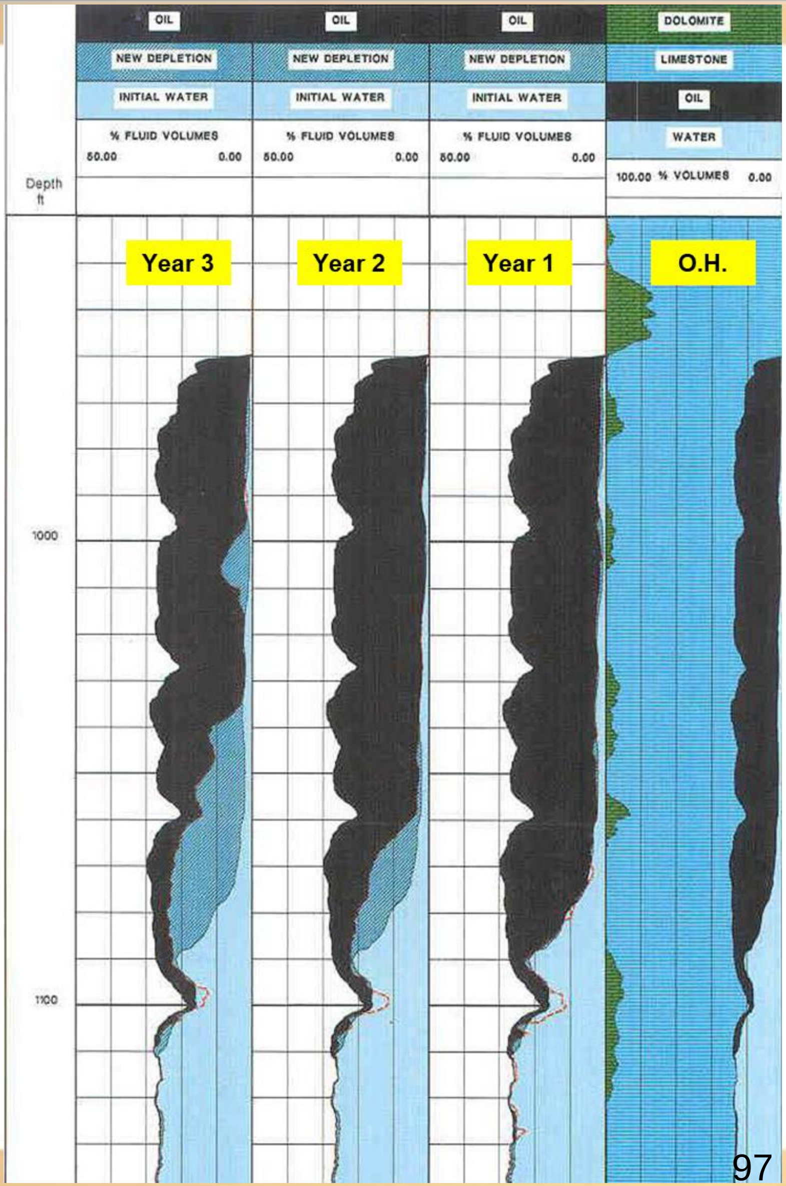
- **Stand-alone Sw when formation water is saline**
  - More ~ **35,000 ppm** (NaCl equivalent) required
  - Estimate today Sw using time lapse technique
- **Monitoring Porosity through casing**
  - TPHI is the best characterized *slim-hole neutron* porosity
- **Production logging applications**
  - Gas-Oil & Water-Oil contacts (GOC & WOC)
  - Gas well monitoring
  - Borehole salinity monitoring (BSAL)
- **Helps on C/O interpretation**
  - eg. Input of Porosity is required

# Sigma Log Example



# Monitoring Contacts

- Three logs were run over several years.
- They show the rise in Water / Oil contact (WOC).

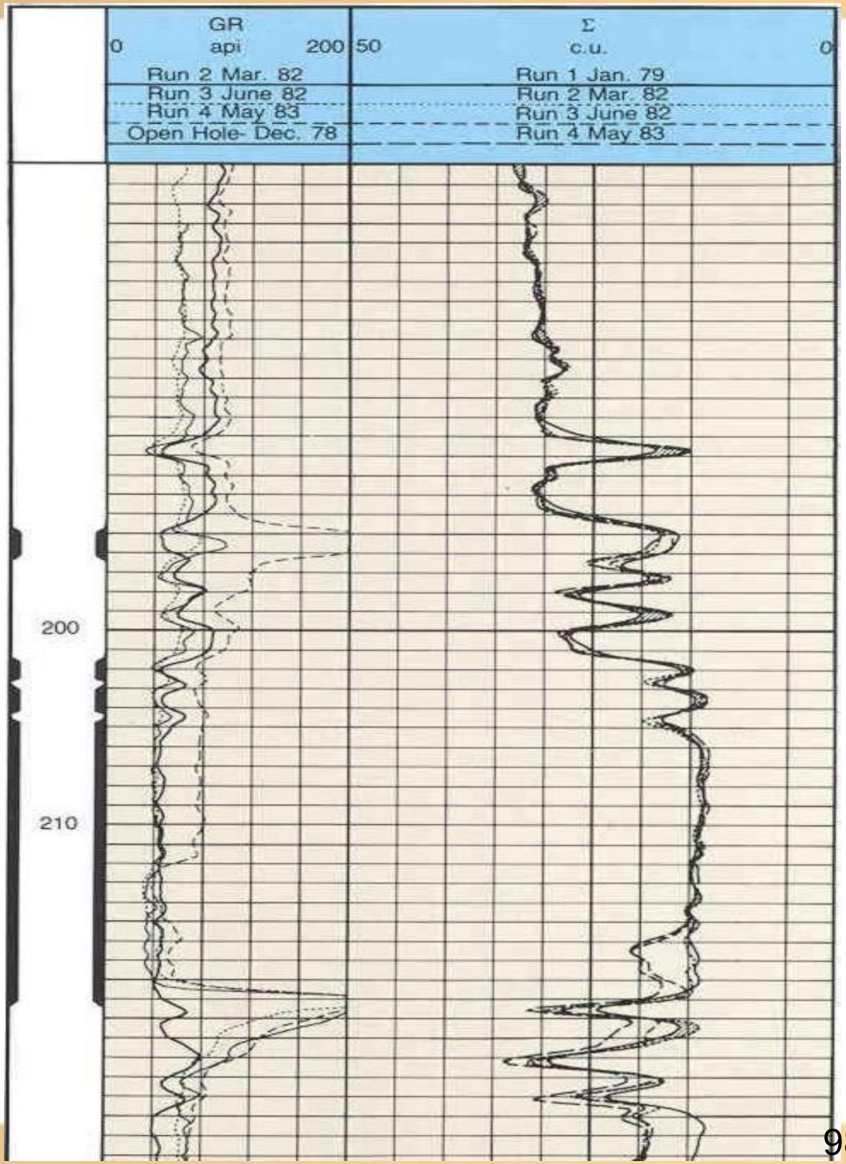


# Time lapse technique

- Multiple logging runs over X-year time
- If $\Sigma_w$, $\Sigma_h$ and $\phi$ are known, change in $S_w$ can be estimated

Time lapse

$$\Delta Sw = \frac{\Delta\Sigma}{\phi\,(\Sigma w - \Sigma h)}$$



# RST over TDT-P

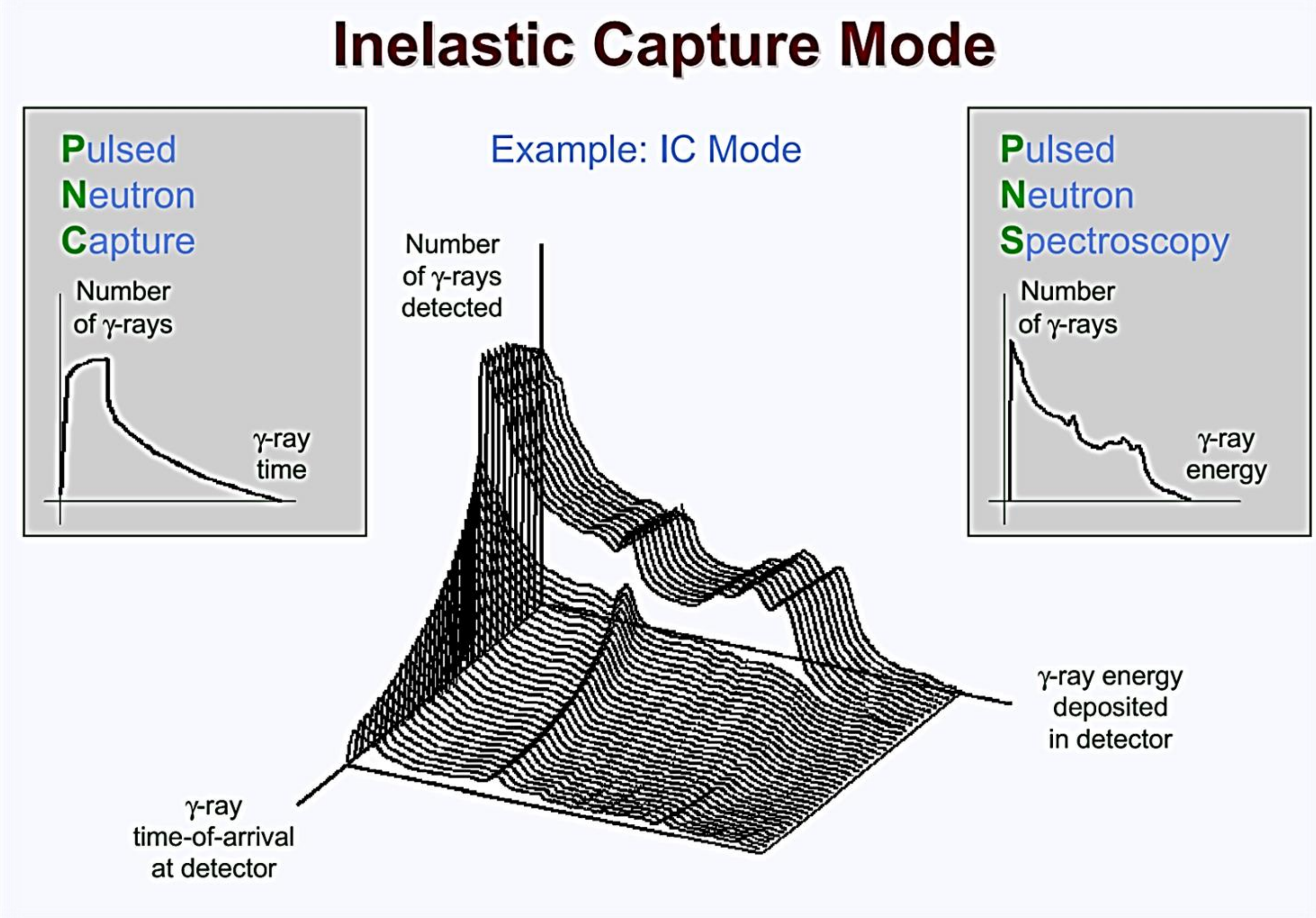
- **No water salinity limitations**
  - RST can be run also in **IC** mode (not only Sigma)
    => Injection fluids, unknown salinities ,etc
- Improved Sigma readings
  - due to bigger database characterization (4000 points)
- Faster Sigma logging
- Faster WFL stations
- Improved minitron efficiency & reliability
- CPLT & PSP combinable ===> New applications !

# IC mode applications

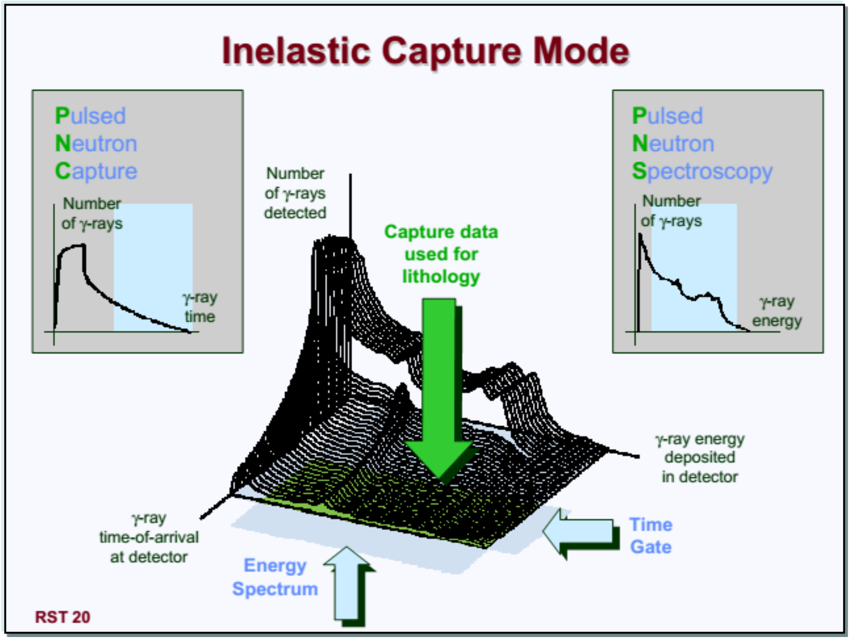
- Sw can be determined from Sigma readings, UNLESS:
  - F Formation water salinity is <u>less</u> than 35,000 ppm
    - – not enough contrast between Oil & Water sigma
  - F Variable or <u>unknown</u> formation water salinity
  - F Water injection fields
    - – Although WSAL may be high, the result mixture is unknown or not the same from base log ➔ *Time lapse technique* can NOT be used

- Water-Oil contact (WOC) when low salinity
  - – In Low porosity reservoirs, required speed for a quantitative IC results is not practical, but still the contact can be determined from C/O ratios

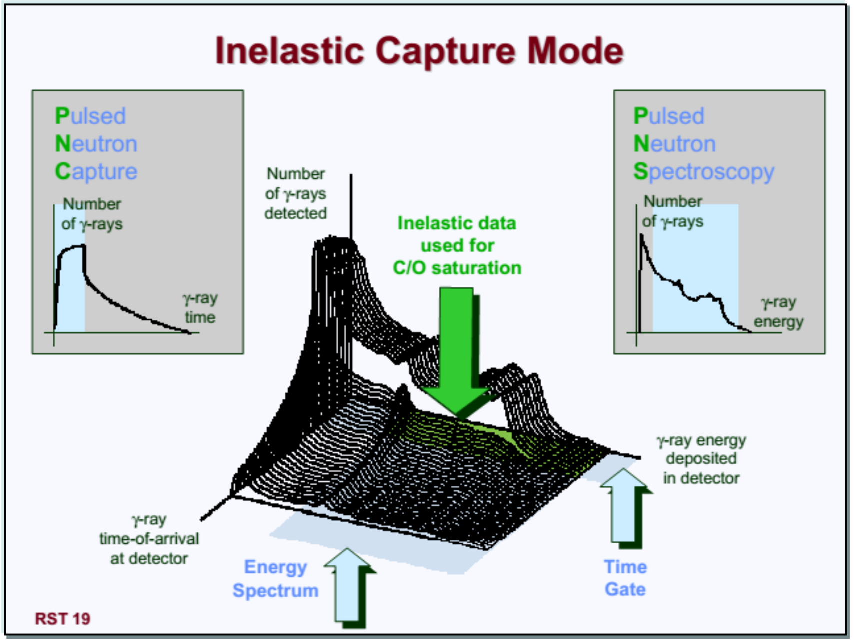
# IC mode applications



# IC mode for determined lithology & saturation

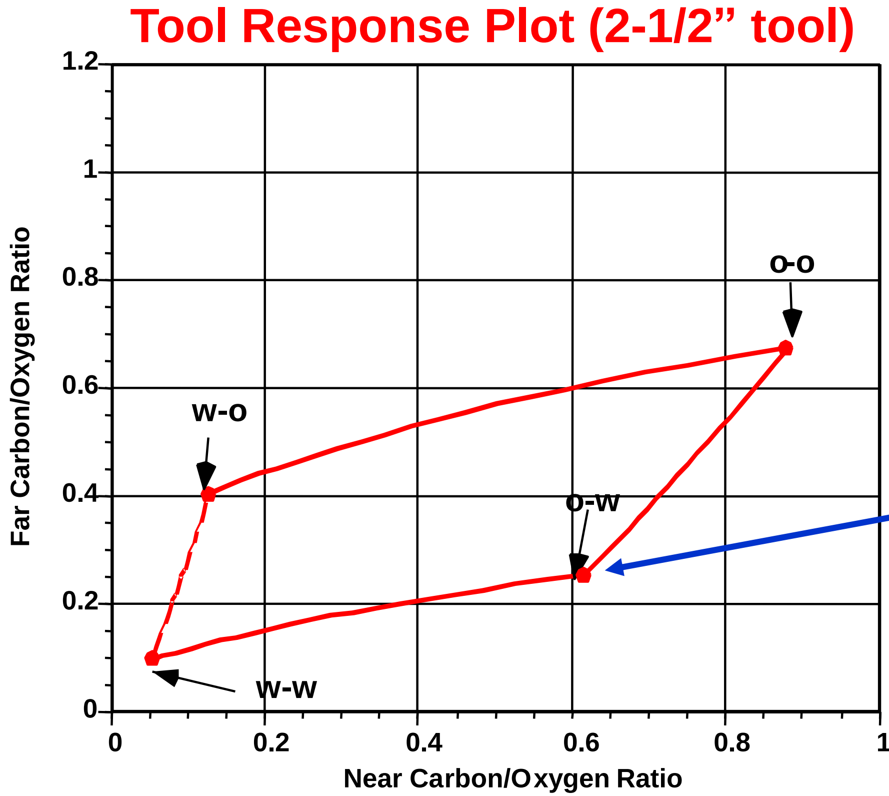



IC mode for determined lithology




IC mode for determined saturation

# Near & Far C/O ratios




| | | |
|---|---|---|
| w-w: | water in borehole | water in formation |
| o-w: | oil in borehole | water in formation |
| o-o: | oil in borehole | oil in formation |
| w-o: | water in borehole | oil in formation |

– This point is the tool response when:
  - **Oil** in the borehole
  - **Water** in the formation

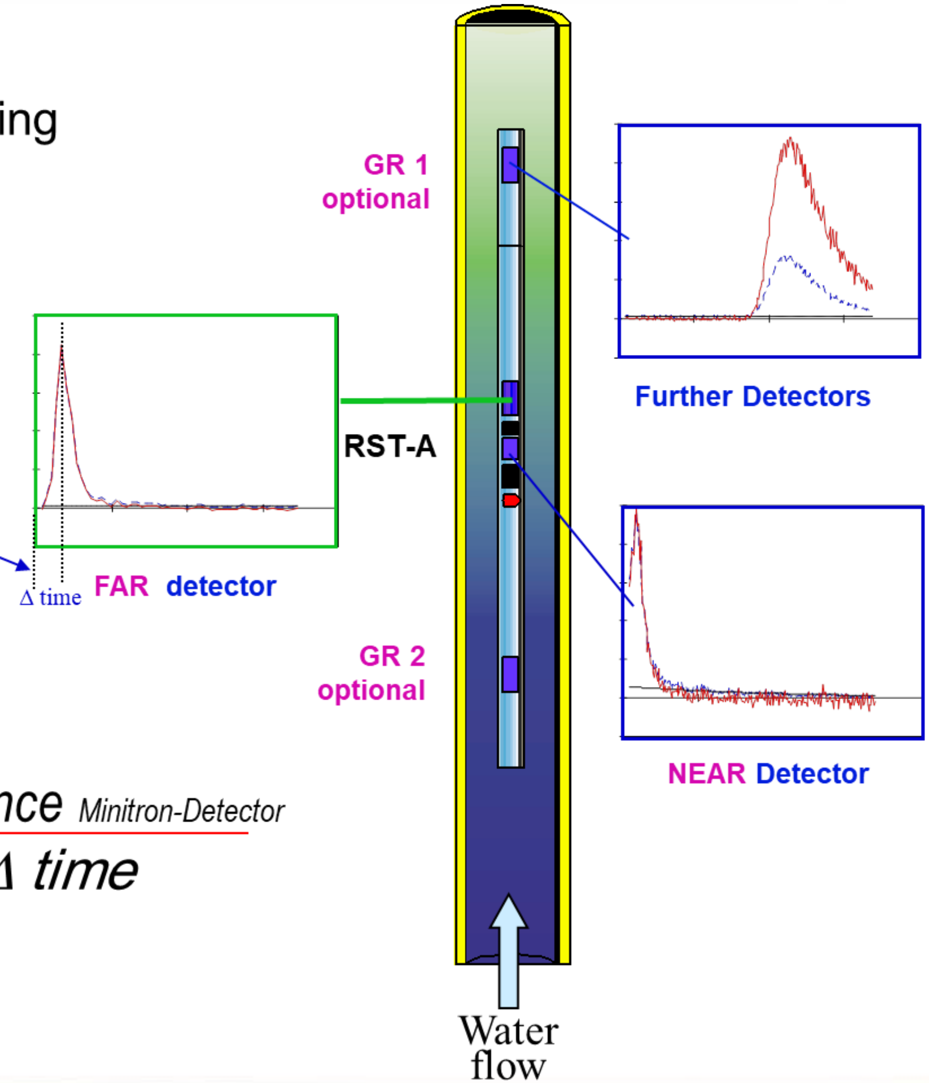
# Water Flow Logging

Applications

- Water flow inside / behind the casing
- Water speed detection (ie.horizontal wells)
- Up & Down flow detection
- Qualitative Flow contributions of zones

# Water Flow Logging - method

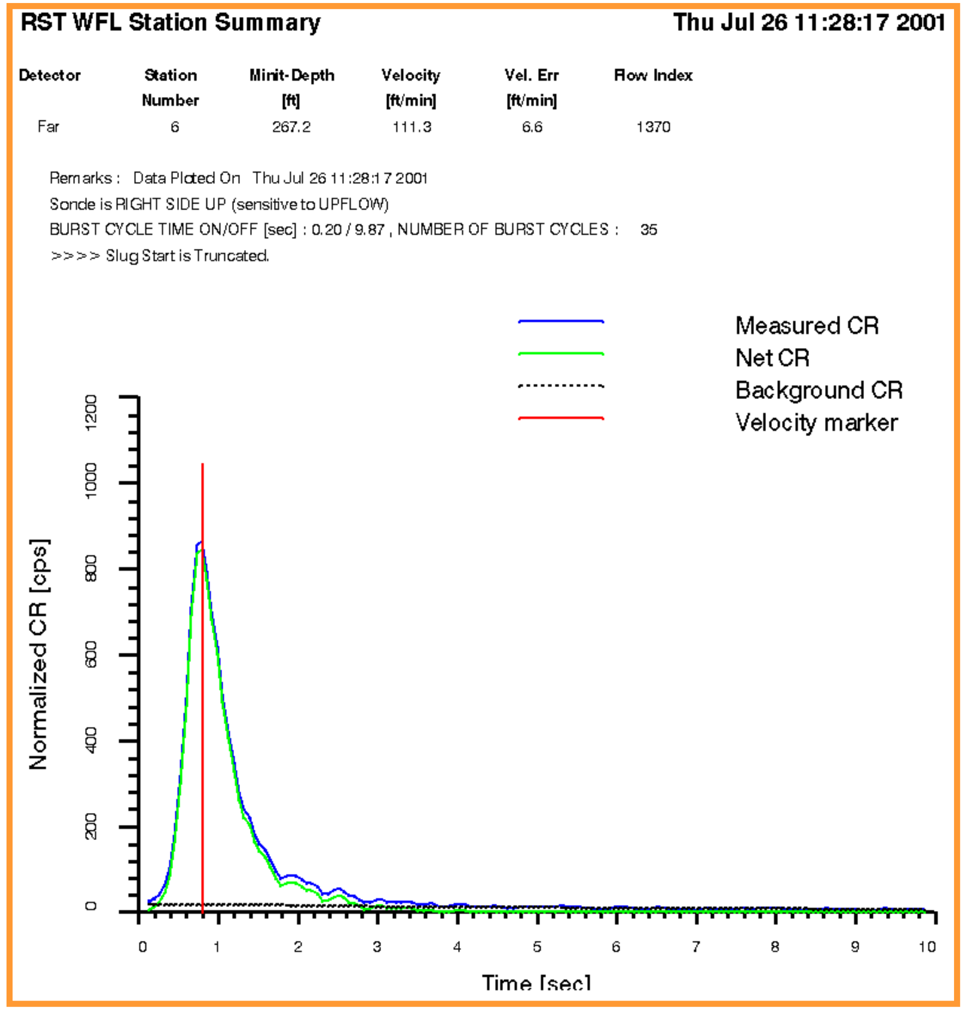
- Tool is static & Water is moving
- Neutrons activates Oxygen from water ($H_2O$)
- Activated "cloud" is seen by detector at Δ time




$$WATER_{\ velocity} = \frac{Distance_{\ Minitron\text{-}Detector}}{\Delta\ time}$$

# Water Flow Logging -Station report

- Text file is recorded with “plot” picture of ALL detectors
- PDS Station report is generated for the detector **selected** in WFL panel
- **Net GR counts = Measured – Background**
- **Velocity Marker**
  - Computed peak after decay correction
- Flow index
  - is not corrected for pipe size so it is relative and will change with pipe diameter
- More information
  - Tool orientation
  - Cycle timing & # cycles acquired
  - Slug quality



# Phase Velocity Logging

Applications

- Phase speed on horizontal wells
- Part of flagship provides full interpretation

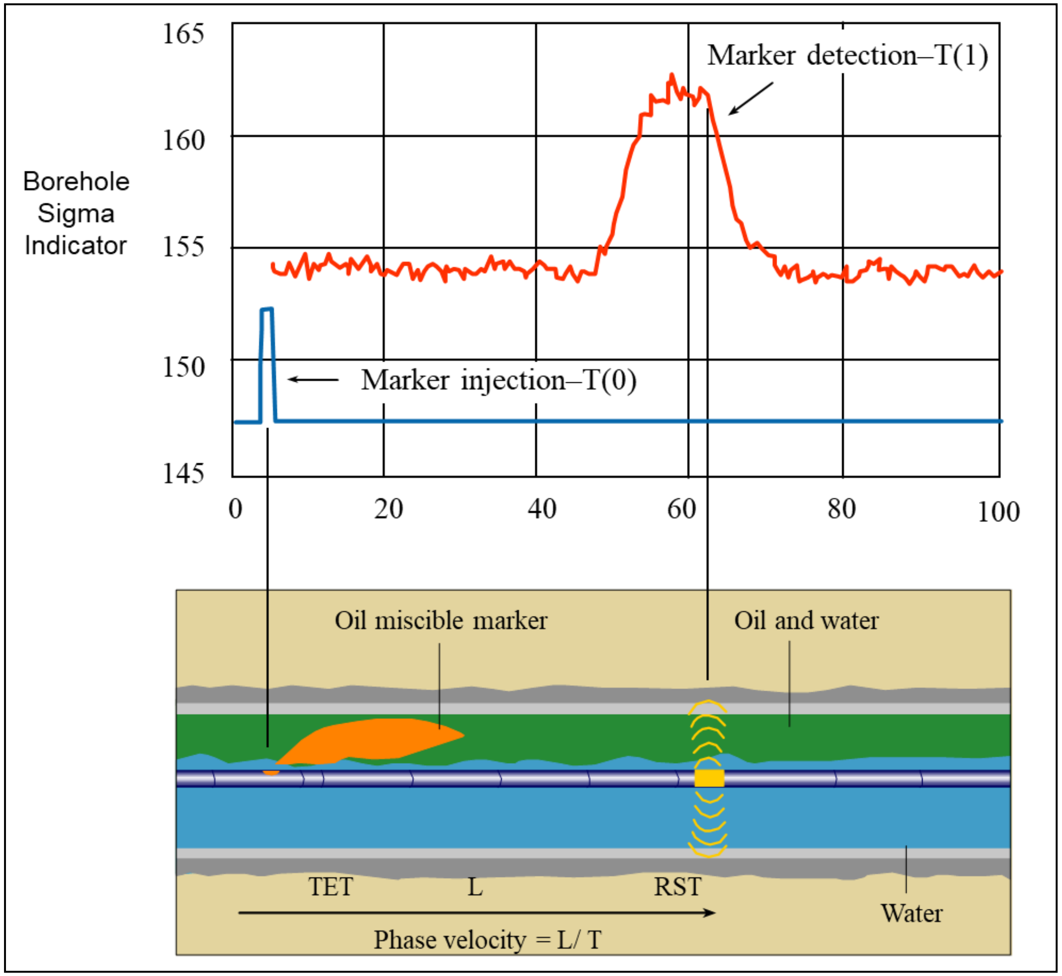
# PVL : Phase Velocity Logging Method

Marker fluid

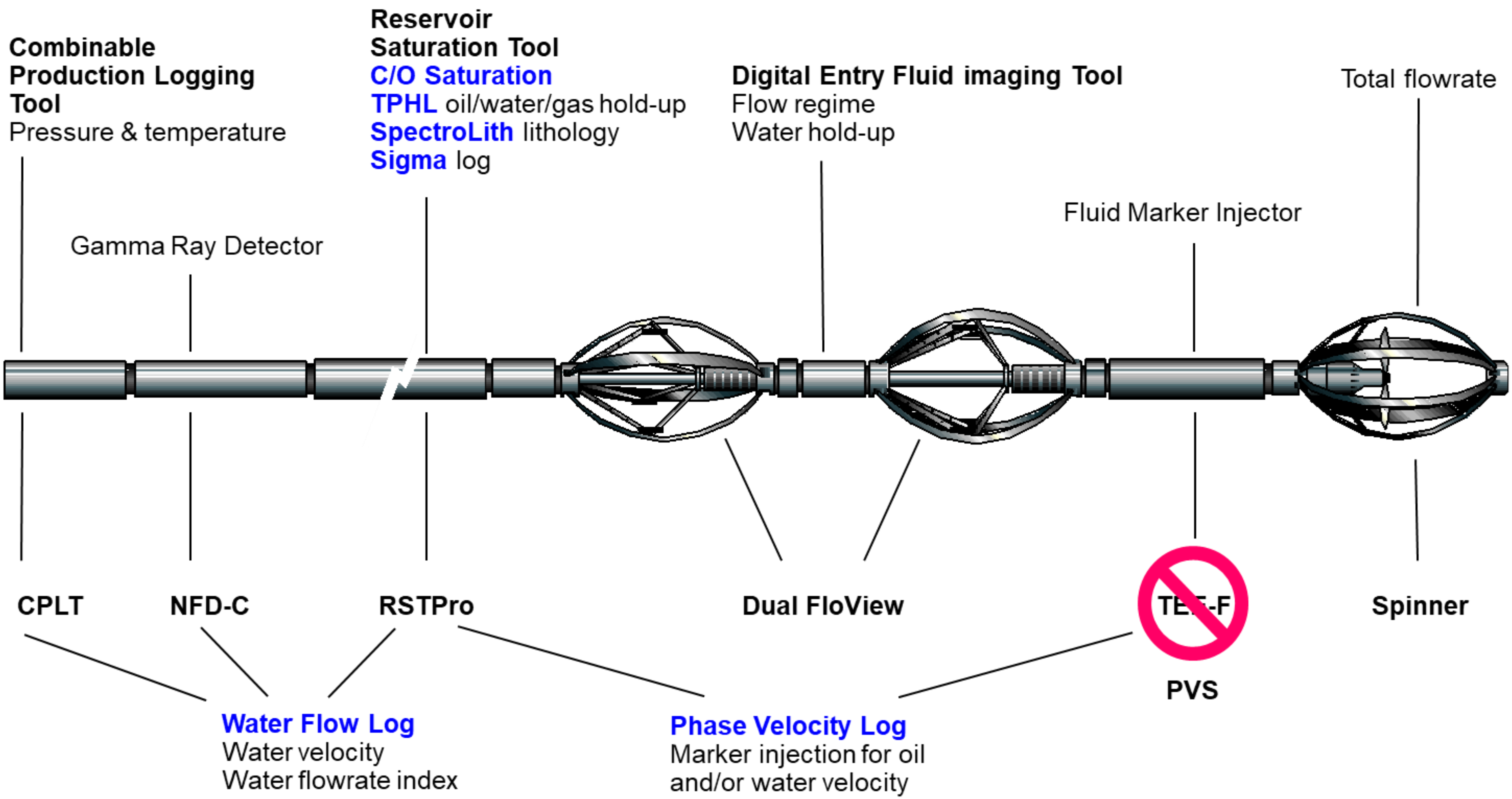
- High neutron absorption
- Non-radioactive, non-toxic
  Water : Gadolinium chloride ($GdCl_3$)
- Oil: New organo-metallic compound

Processing chain

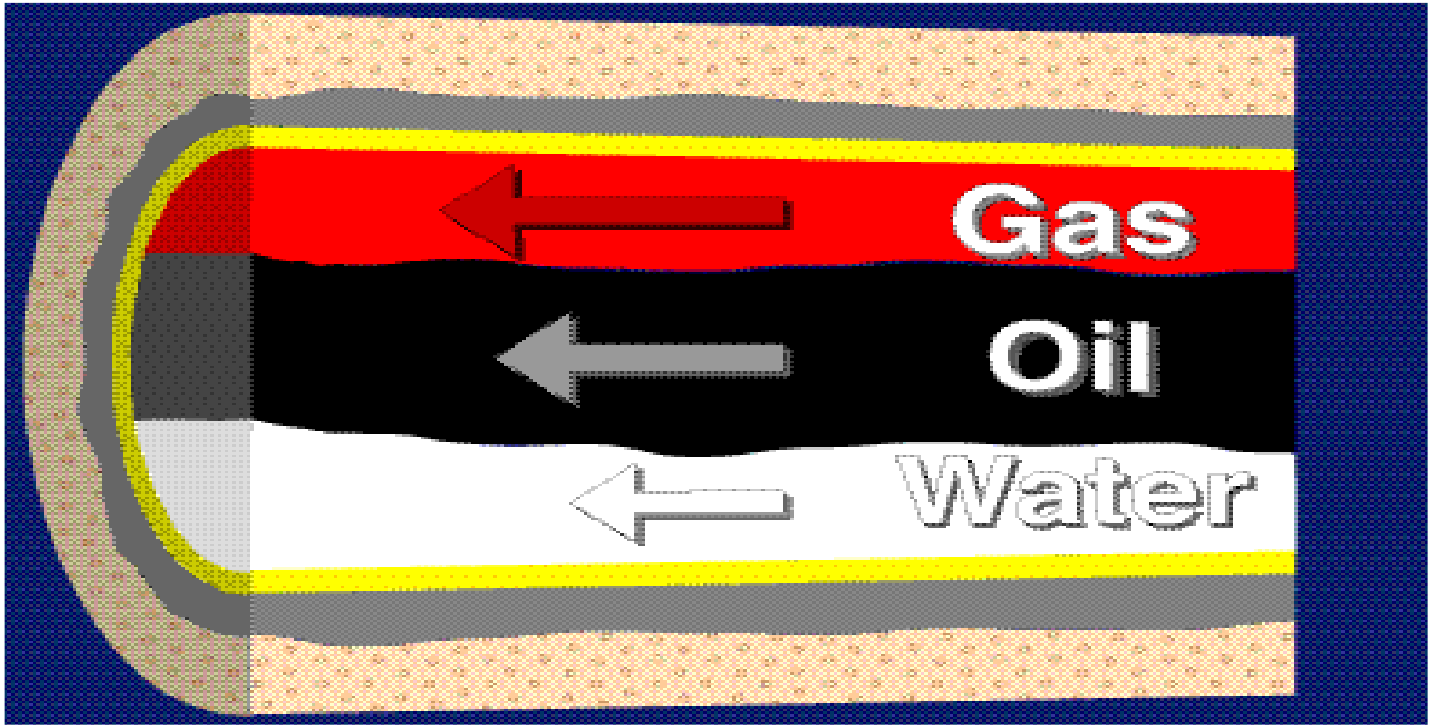
- Compute apparent borehole sigma every 0.2 sec
- Find signal peak & edge
- Compute velocity
- Compare measured & predicted peak width



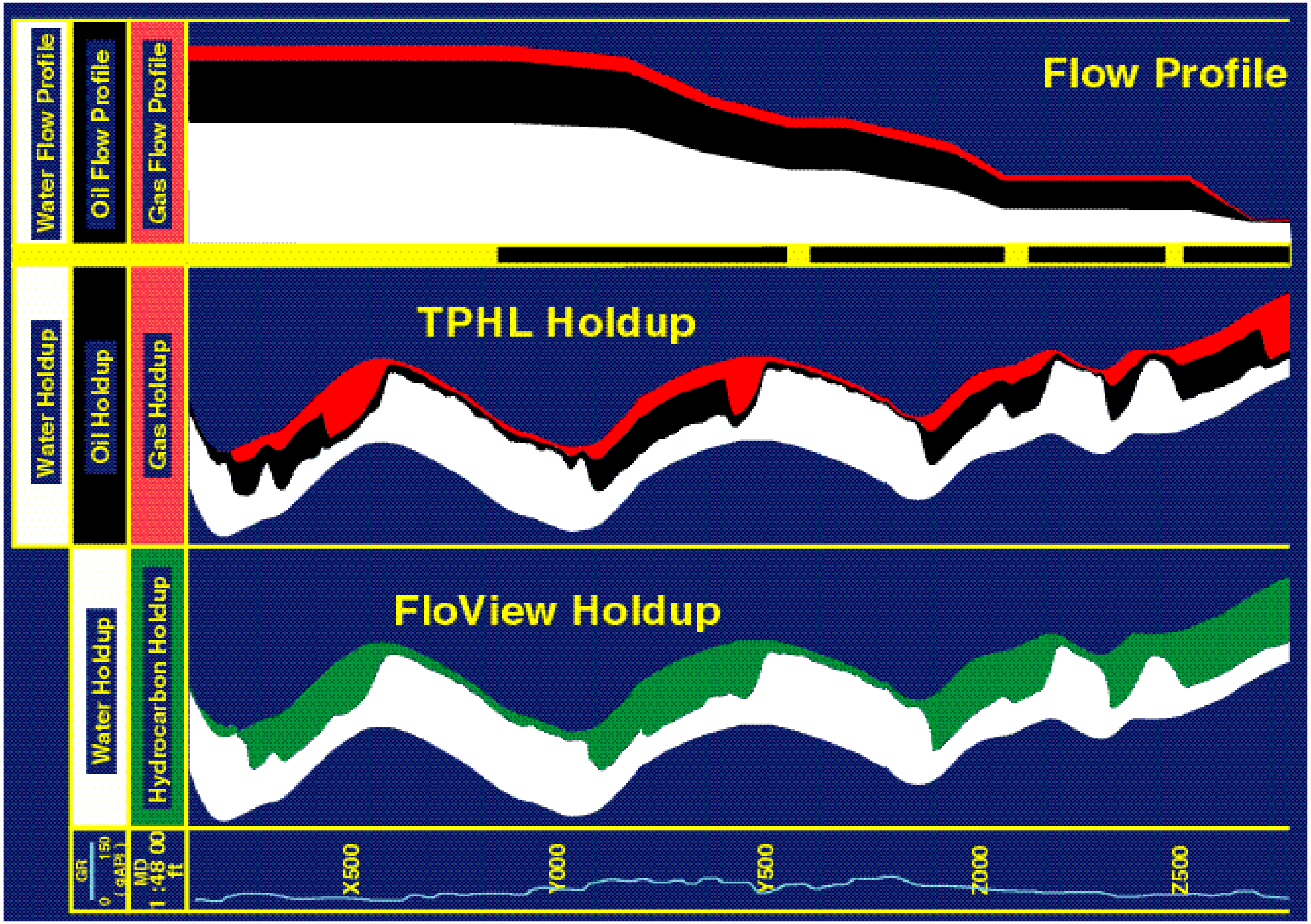
# RST Pro with Flagship service



# RST -TPHL mode (Three Phase Holdup Log )-in PLT



# Example-RST -TPHL mode (Three Phase Holdup Log )-in PLT

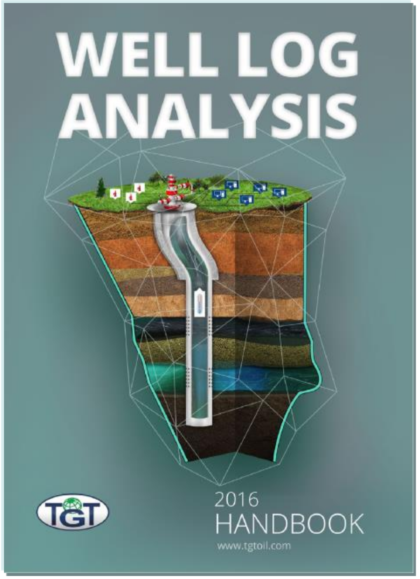


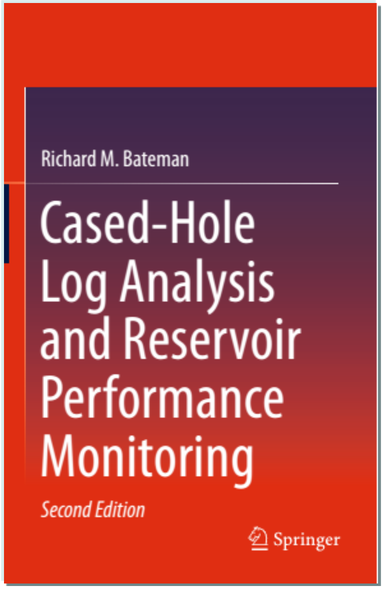
# RST summary

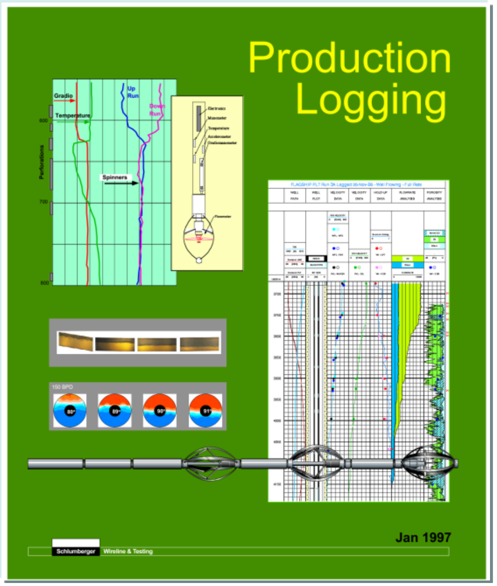
- RST applications
  - Sigma mode
    - Sw when formation water is Saline
    - Porosity through tubing/casing
    - Reservoir monitoring
    - Gas detection
  - (IC) Inelastic capture mode
  - WFL (Water Flow Log)
  - PVL (Phase Velocity Log)
  - TPHL(Three Phase Holdup Log)

# Reference


1. Reservoir Saturation Tool (Pitinun Matitanaviroon ) –Schlumberger company
2. Cased hole logging – Schlumberger company
3. Production logging – Schlumberger company
4. Cased-Hole Log Analysis and Reservoir Performance Monitoring (2nd ed.) [R.M. Bateman, 2015]
5. Cement Evaluation- Schlumberger company
6. Well integrity technology ( oilserv-company )

# About Authorized

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# Thanks