भारतीय प्रौद्योगिकी संस्थान (भारतीय खनि विद्यापीठ) धनबाद

IIT ISM

INDIAN INSTITUTE OF TECHNOLOGY (INDIAN SCHOOL OF MINES) DHANBAD

GPC510 - Well logging

Semester - Winter 2025; Lecture-3

Partha Pratim Mandal
Assistant Professor
Department of Applied Geophysics
E: partham@iitism.ac.in

TEACHING OUTLINE

Week 1/2

Tutorial 1 – Introduction, teaching overview, and assessment

Tutorial 2 – Well log definition, history, log format, types, units

Tutorial 3 – Borehole effects, environmental impacts

AGENDA

- Tool geometry
- Borehole effects
- Speed of the logging tool
- Environments

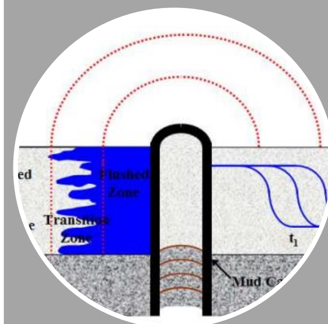
DIGITAL LOG FORMAT - LAS

```
~Version Information
VERS.                      2.0: CWLS log ASCII Standard Version 2.00
WRAP.                       NO: One line per depth step
~Well Information Block
#MNEM.UNIT                  Value                          Information
#------------               -----                          -----------
STRT.M                    2211.0192                       :START
STOP.M                    3529.1268                       :STOP
STEP.M                       0.1524                       :STEP
NULL.                      -999.25                        :NULL VALUE
COMP.         Woodside Energy LTD                         :Company
WELL.         Pluto-3ST1                                  :Well Name
FLD .         Pluto                                       :Field
LOC .         WA-350-P                                    :Field Location
PROV.                                                     :Province
CNTY.         Atwood Eagle                                :County or Rig name
STATE.                                                     :State
CTRY.         Australia                                   :Country
DATE.                                                     :Log Date
SRVC.         Schlumberger                                :Service company
UWI .         W002813                                     :Unique Well ID
API .                                                     :API Number
NATI.         Australia                                   :Nation
STAT.         Western Australia                           :State
FL1 .         X = 307 534.2 mE                            :Field Loc. 1 / Northing
FL2 .         Y = 7 797 210.8 mN                          :Field Loc. 2 / Easting
LATI.         019 54' 43.000" S     DMS                   :Latitude
LONG.         115 09' 40.820" E     DMS                   :Longitude
PD  .         LAT                                         :Perm. Datum
EPD .M             0.0                                    :Elevation Perm. Datum
EDF .M            22.4                                    :Elevation DF (wrt EPD)
EGL .M        -584.59998                                  :Elevation GL (wrt EPD)
ELZ .M            22.4                                    :Elev. Log Zero (wrt EPD)
APD .M            22.4                                    :Above Perm. Datum
LMF .         RT                                          :Log measured from
MP  .         RT                                          :Drill measured from
OS1 .         FMI-HNGS-MSIP                               :Other Services Ln 1
OS2 .         MDT-CMR                                     :Other Services Ln 2
OS3 .         FMI-MSIP                                    :Other Services Ln 3
OS4 .         VSI / MDT-FMI                               :Other Services Ln 4
OS5 .         MSCT / CST                                  :Other Services Ln 5
TD  .M        3530                                        :TD Date
~Curve Information
#MNEM    .UNIT              API CODE Curve Description
#------------               --------- -----------------
DEPT     .M             00 001 00 00:   0  Depth
DF       .N             00 000 00 00:   1  Uncalibrated Downhole Force {F13.4}
DSO8     .IN            00 000 00 00:   2  HRDD HiRes Density Standoff {F13.4}
EHGR     .GAPI          00 000 00 00:   3  HiRes Gamma-Ray {F13.4}
HCAL     .IN            70 280 00 01:   4  HRCC Cal. Caliper {F13.4}
HDRA     .G/C3          45 356 01 01:   5  HRDD Density Correction {F13.4}
HPRA     .              00 000 00 00:   6  HRDD Photoelectric Factor Correction {F13.4}
HTNP     .V/V           00 000 00 00:   7  HiRes Thermal Neutron Porosity {F13.4}
NPHI     .V/V           42 890 01 01:   8  Thermal Neutron Porosity (Ratio Method) {F13.4}
PEF8     .              00 000 00 00:   9  HRDD High Resolution Formation Photoelectric Factor {F13.4}
```

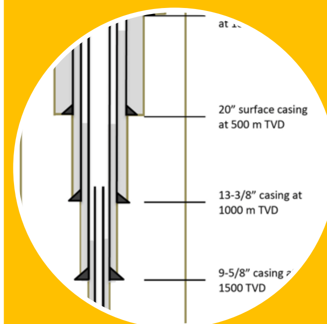
- ~V - contains the version and wrap mode information
- ~W - contains the well identification information
- ~C - contains log curve information
- ~P - contains well parameters and constants
- ~O - contains additional information such as comments
- ~A - contains the log data

BOREHOLE EFFECTS

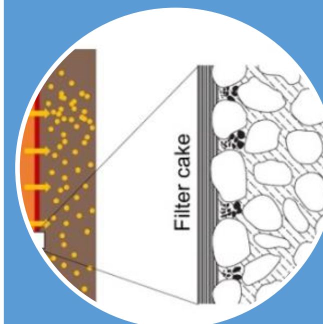
Drilling Mud



Invasion



Casing & Cement



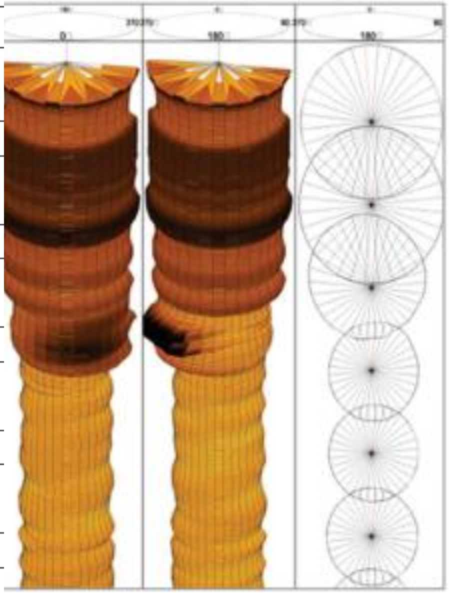
Fluid mobility

Ref: Won, Alpak, Liu and Santamarina

DRILLING MUD

- Influence of the drilling mud on log response depends upon:
- A: Diameter of the wellbore

Borehole Size Specifications for Large-Hole Tool Kits	Borehole Size—Min.	Borehole Size—Max.
Resistivity		
Platform Express* AIT* Array Induction Imager Tool (AIT-H)	9½ in. [24.13 cm]	20 in. [50.80 cm]
Powered Caliper Device (PCD-B)	7 in. [17.78 cm]	25 in. [63.50 cm]
Neutron porosity		
Platform Express Highly Integrated Gamma Ray Neutron Sonde (HGNS)	15 in. [38.10 cm]	22 in. [55.88 cm]
Compensated Neutron Tool (CNT-H)	14 in. [25.56 cm]	22 in. [55.88 cm]
Density		
Litho-Density* tool (LDT-D)	14 in. [25.56 cm]	30 in. [76.20 cm]
Platform Express High-Resolution Mechanical Sonde (HRMS)	16 in. [40.64 cm]	28 in. [71.12 cm]
Sonic		
Digital Sonic Logging Tool (DSLT)	14 in. [35.56 cm]	30 in. [76.20 cm]
DSI* Dipole Shear Sonic Imager	14 in. [35.56 cm]	20 in. [50.80 cm]
Sampling		
MDT tool with MRLH-AA	7½ in. [19.05 cm]	19 in. [48.26 cm]
MSCT with shoe extender	5½ in. [13.97 cm]	19 in. [48.26 cm]
Seismic		
CSI Combinable Seismic Imager	7 in. [17.78 cm]	22 in. [55.88 cm]



Schlumberger, 2021
[extracted from website]

DRILLING MUD

- B: Type of mud and density
- Two categories of mud:

1. Water-based
2. Oil-based

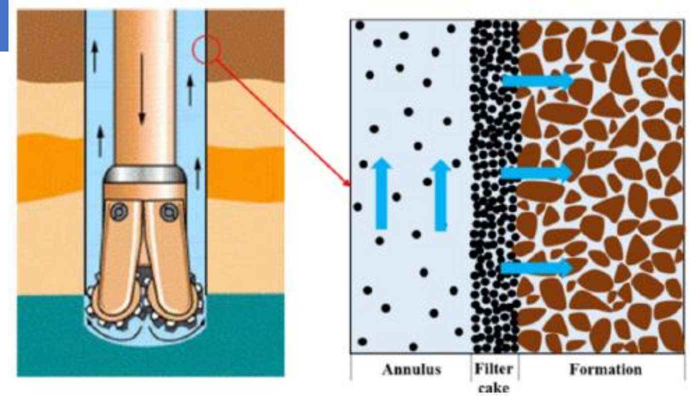
- For oil-based mud - acoustic signal propagation is poor and non conduct of electric current
- Water-based mud with added salinity affects electric property measurements and hydrogen index
- Mud density influences absorption of gamma rays

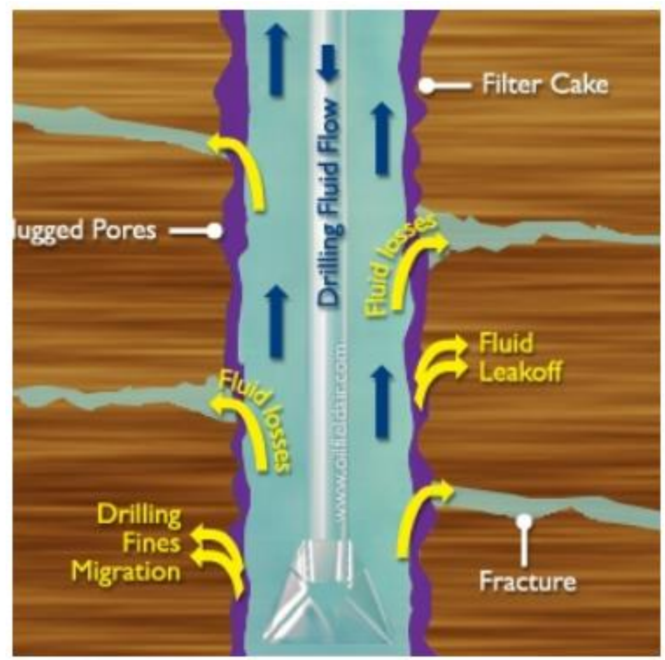
INVASION

- Main functions of the drilling mud are:

1. Cooling down of drill bit
2. Avoid borehole collapse
3. Prevent blow-out
4. Allow flow of cuttings to the surface

- Mud density depends upon formation pressure to make a safer drilling scenario [ranges from 1 to 2.4 g/cm^3]

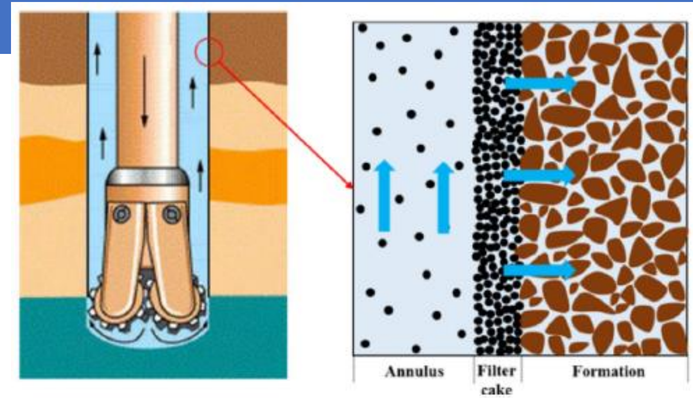


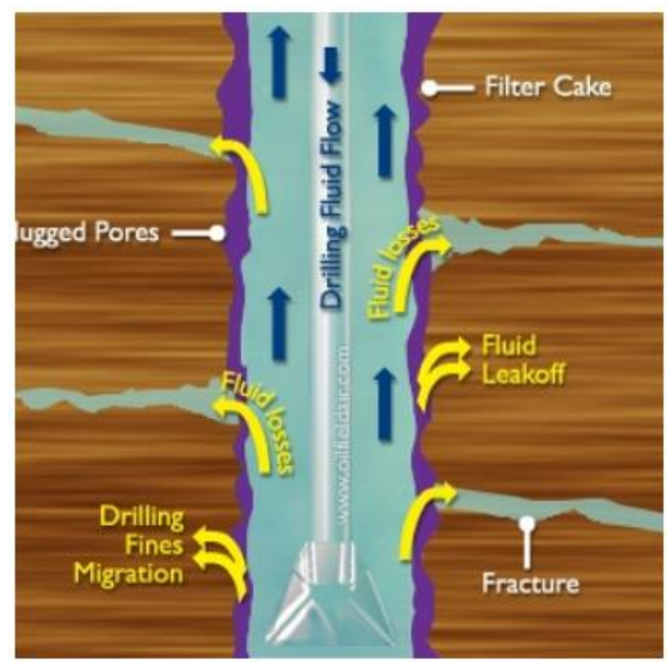


Ma et al., 2020; OILFIELD Team, 2021

INVASION

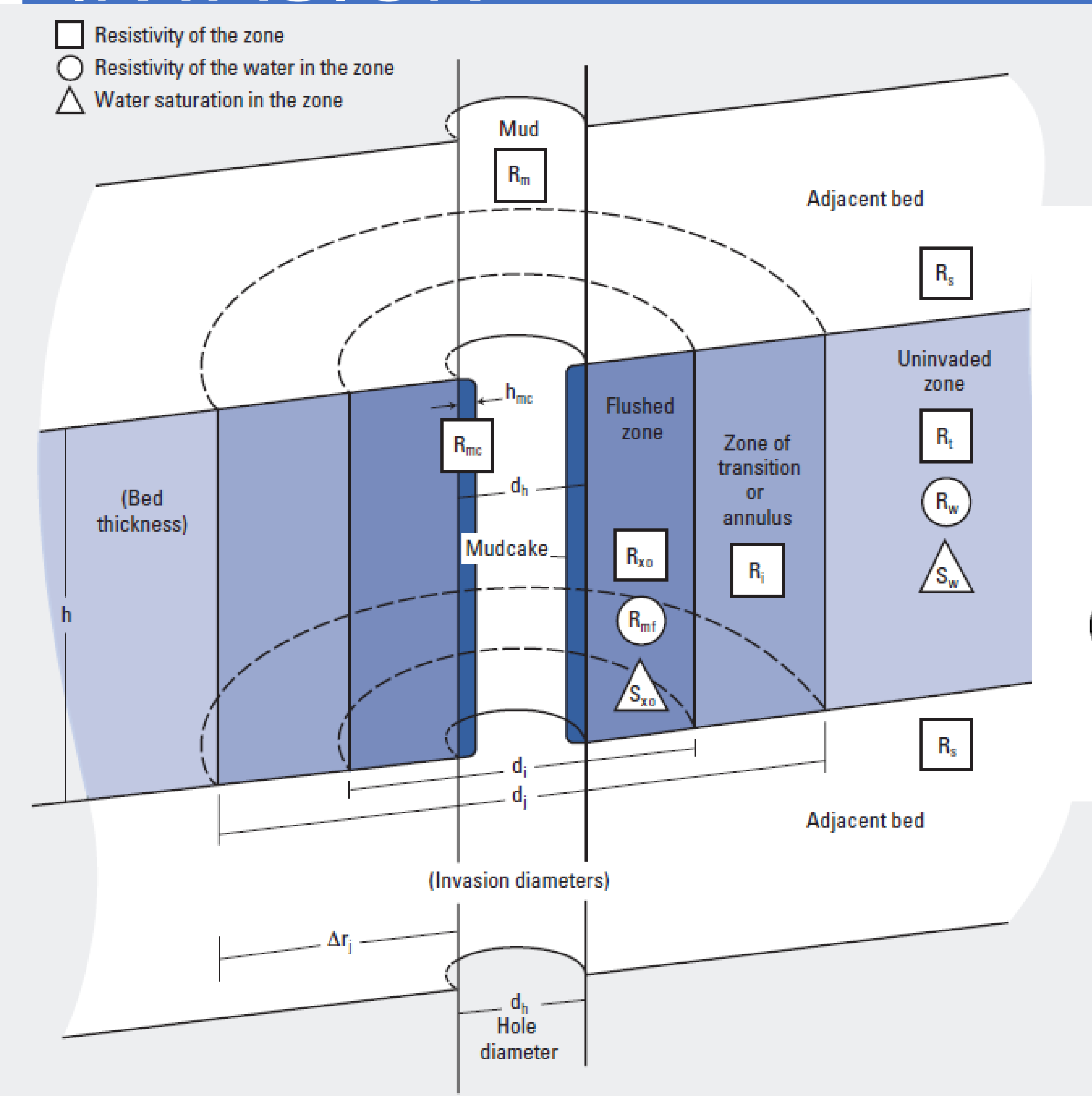
- Mud is kept slightly higher than formation pressure, which causes mud to infiltrate porous and permeable beds
- Solid particles in the mud are slightly larger than pores, therefore only liquid content can invade
- Mud cake will form during drilling wherever mud filtrate infiltrates. Therefore, with time an impermeable membrane form which prevents further invasion
- Mud-filtrate displaces some of the interacting formation fluids.
- Following factors define the depth of invasion (i) porosity (ii) permeability (iii) water loss factor of mud (iv) pressure difference

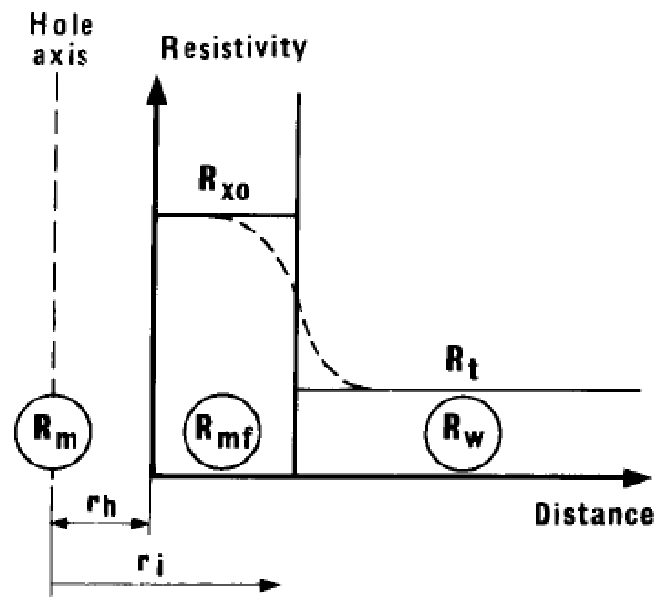




Ma et al., 2020; OILFIELD Team, 2021

INVASION

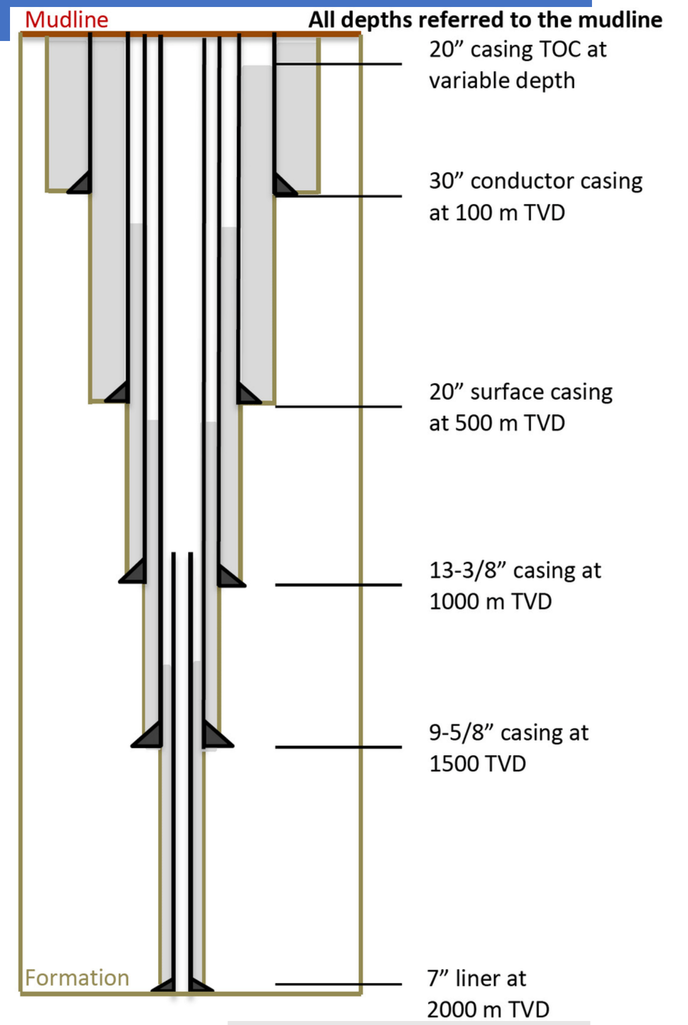




Serra, 1985; Schlumberger, 2013

CASING & CEMENT

- Casing followed by cementing is required for a safer well bore design.
- Design of casing is the beyond the scope of this unit
- Casing and cement prevent certain logging measurements (resistivity)
- Nuclear measurement can be done



Example of a casing setup

FLUID MOBILITY

- Saturation - ratio of pore volume occupied by fluid to the total pore volume
- Invasion can be used as an indicator of mobility of the reservoir fluids
- We need to derive saturations from invaded S_{xo} and virgin zones S_w
- $POI = \emptyset\ (S_{x0} - S_w)$, producible oil index (POI) can be act as an indicator of recoverable hydrocarbon
- Recoverability factor is defined as $f = \frac{(S_{x0} - S_w)}{(1 - S_w)}$

S_w = water saturation

LOGGING SPEED

- The speed of the logging tools are not same
- Natural and radio-active phenomena are random in nature, therefore necessary to accumulate count data over a period of time and compute the average to obtain a representative reading.
- Sufficient period of time to obtain a reading is required. It referred as “Time constant” (TC)
- Other factors such as uniformity of cable tension and risk of damage of pad type equipment are also considered

Recommended maximum logging speeds.

Survey		Maximum logging speed (ft/min)	(m/min)
SP		100	30
Induction		100	30
Laterolog		50	15
Microlaterolog		35	10
Neutron	TC = 2 sec	30	9
GR	TC = 3 sec	20	6
Density	TC = 4 sec	15	4.5
TDT			
Sonic		70	20
Amplitude		35	10

Example of a logging setup

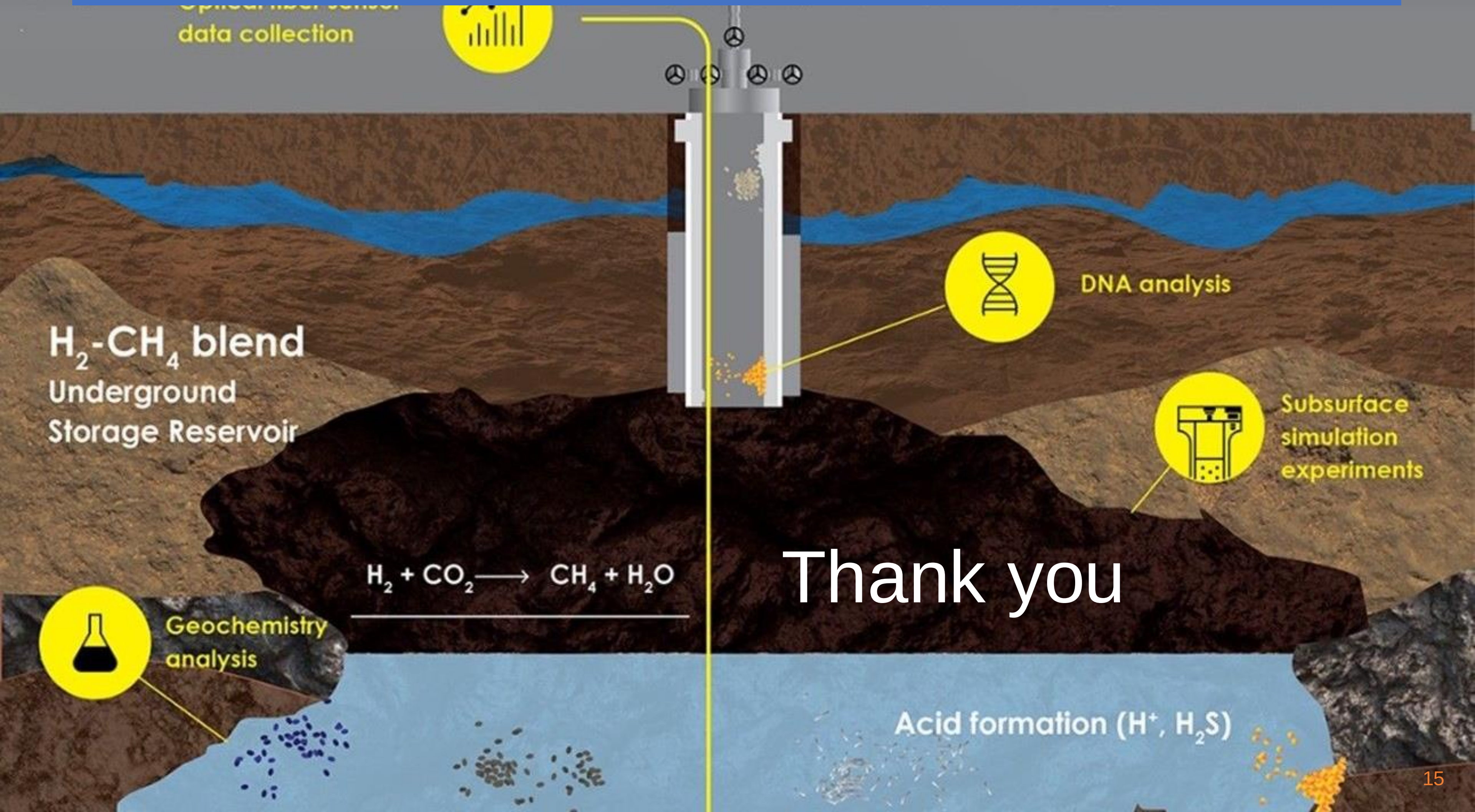
WORKING ENVIRONMENTS

- Subsurface pressure (~10 MPa/km) and temperature (~25 -30 ^{0}c /km) normally increase with depth
- Logging companies provide operating conditions of the tools. Beyond that scenario, it is not recommend to run any of those logs

Example of a particular tool's environment specification

Environmental specifications	
Max. vibration, g_n [m/s^2]	20 [200] (G_{rms} random, 5 to 1,000 Hz)
Max. shock, g_n [m/s^2]	500 [5,000]
Max. temperature, degF [degC]	302 [150], 350 [175][§§]
Max. working pressure, psi [MPa]	25,000 [172]
Mud sand content, %	1

END OF LECTURE



Thank you