Drill Hole Geophysical Logging

using Wireline Probes

Government of South Australia
Primary Industries and Resources SA

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Department of Water, Land and Biodiversity Conservation

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I have always been intrigued by the idea that we can understand what is happening underground without having to physically go there.

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Their experience and knowledge have made it so much easier for me to explain the concepts and applications of Geophysics to understanding what goes on underground, through the use of very clever sensing technology.

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Introduction

Geophysical Logging is the recording of rock characteristics at regular intervals, along the depth of a drill hole.

The tools used are called Geophysical Probes.

These probes detect the rock's natural Radioactivity, Porosity, Density, Electrical Resistance and many other aspects. Video cameras can also be sent down the drill holes for a visual inspection.

The probes are usually lowered to the bottom of the drill hole and then switched on to record data as they are pulled up at a steady rate.

Why Log Drill Holes?

The logs will show the following rock properties.

- Define rock layer boundaries.
- Assist in correlation of important marker beds between wells.
- Define changes in rock type including:
  - The "clayeyness" of a rock formation.
  - Distinguishing **shale** and **claystone** from **sandstone** and **limestone**.
  - Where the aquifers are located down the hole.
  - Coal seams - depth, thickness and grade.
  - Where mineralised rocks are and their thickness.
  - Where petroleum reservoir layers are and cap rock.
  - Locating the depth to the water table for monitoring level changes.
- Indicate the depth at which casing should be set in new bore holes.
- Show the casing depth and size in old bore holes.
- Shows the condition of the casing eg corrosion.
- Reveal whether the aquifer is porous rock or fractured rock.
- Leakage between salty and fresh water aquifers can also be found.

Types of Probes

THE GAMMA PROBE
or GAMMA RADIATION DETECTOR PROBE

The Gamma Probe detects natural radiation (called Gamma Radiation) made by Potassium, Uranium and Thorium atoms during fission decay. These are found in clay minerals in larger concentrations than other rock forming minerals.

They also produce Alpha and Beta radiation, which is not detected because this radiation cannot go through the steel casing around the sensor, which is built to protect the electronics inside from high-pressure, and often saline corrosive water.

How it works

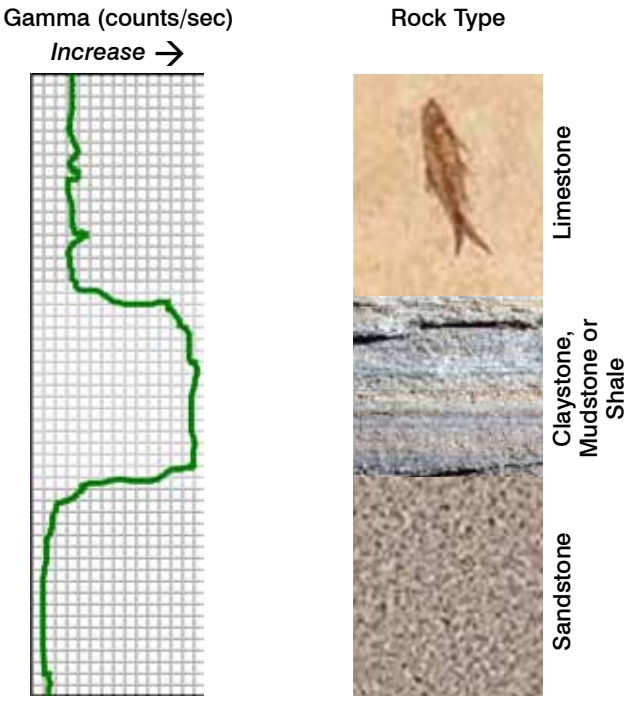
The probe has a scintillometer, which detects Gamma radiation from the rock.

CONCLUSION:
*Detection of low Gamma values indicates low radioactivity from rocks such as **quartz sandstone** or **limestone** or **salt** or **coal**.*

*High Gamma values detected, indicates higher radioactivity from rock such as **clay** rich rock formation like **claystone** or **shale** or **siltstone** or poorly sorted **sandstone** (eg **greywacke**).*

Example Log 1:

Rock Formation



Types of Probes

THE DENSITY or Cs137 GAMMA RADIATION EMITTING PROBE

The Density Probe detects the rock density, where density is the mass of one cubic centimetre of rock.

Uses

This is helpful in finding changes in rock type or cracks in the bore hole lining or rock formation.

The probe detects changes in rock density caused by minerals containing heavy elements or compaction and cementing between solid mineral grains.

How it works

The probe is pushed against the rock by a spring calliper. At the bottom of the probe is an onboard radiation source – Cesium 137, which sends Gamma radiation into the rock.

The Gamma radiation, hits electrons in the rock's minerals repeatedly, losing energy each time until they are absorbed completely. The remaining backscattered Gamma rays are detected by the sensor further up the probe.

Higher density minerals are made of atoms with larger atomic mass. These atoms have larger numbers of electrons in orbit (to balance the opposite nucleus charge) for the Gamma radiation to collide with.

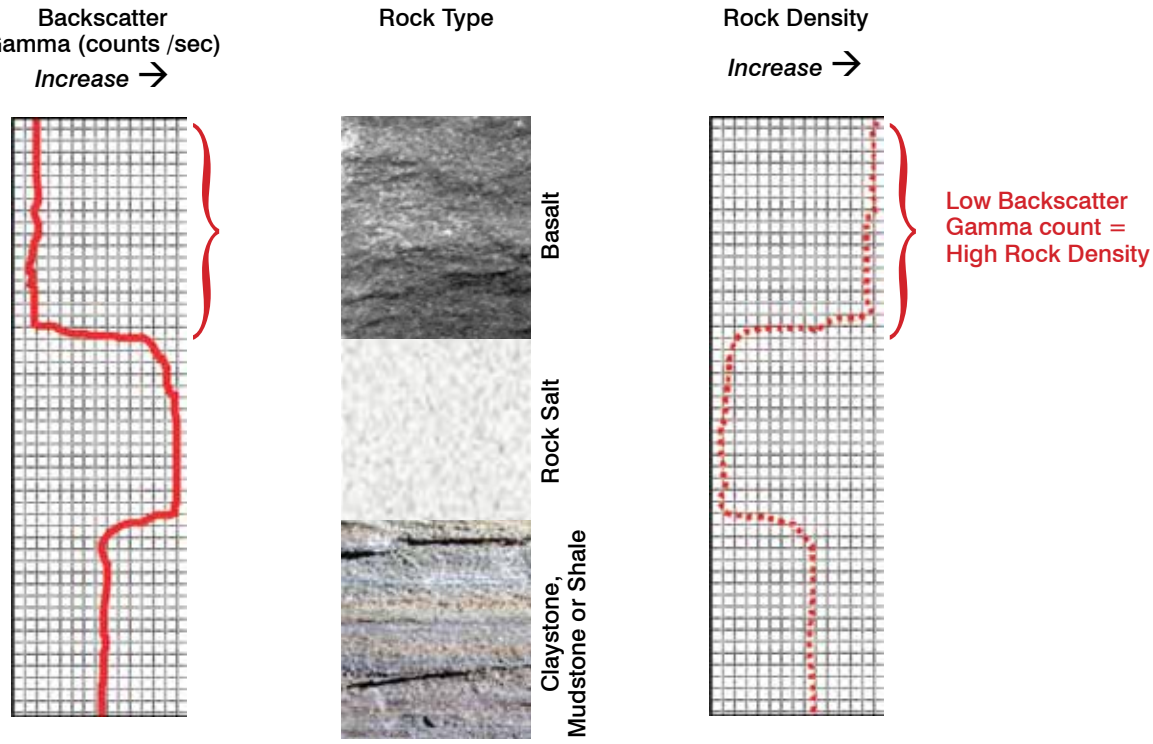
CONCLUSION:
The Radiation Count of surviving Gamma is inversely proportional to the rock density i.e., ***the lower the Gamma backscatter-count the higher the rock density.***

This is because rocks of higher density contain elements of higher atomic number or atomic mass, which in turn have larger electron clouds to balance the nucleus charge. The likelihood of Gamma radiation absorption increases with higher density rock.

Types of Probes

Example Log 2:

The Rock Density log is derived from the Gamma counts log



Note: that the Log of Gamma counts and the Interpreted Density Log have an inverse relation to each other i.e. mirror images.

Types of Probes

THE POROSITY or NEUTRON PROBE

The porosity of a rock is the amount of space between solid rock particles, which the Porosity Probe measures indirectly.

Uses

Porosity space in rock is filled by water and or petroleum fluids. These rocks are called aquifers and reservoir rocks respectively such as sandstone, gravel or limestone.

Low porosity rocks, usually made of clay or silt, stop liquids from moving.

How it works

The Porosity Probe has a Neutron source of Americium-Beryllium at the bottom, which makes high energy Neutrons, which travel into the rock formation.

The neutrons lose energy after every collision with atoms in the rock minerals. The greatest energy loss happens when the neutron hits an atom of similar atomic mass (eg Hydrogen in H_2O), which are mainly in the pore spaces. The more collisions with H_2O the more energy is lost, until the neutron is captured by a nucleus, signalled by a Gamma ray emission.

The probe has a detector, which is tuned to measure only the arrival of the surviving low energy neutrons, known as Epithermal neutrons. So the lower the surviving Neutron-count, the higher the water or hydrocarbon content of the rock's pore spaces.

CONCLUSION:

Low Neutron counts = High Water content

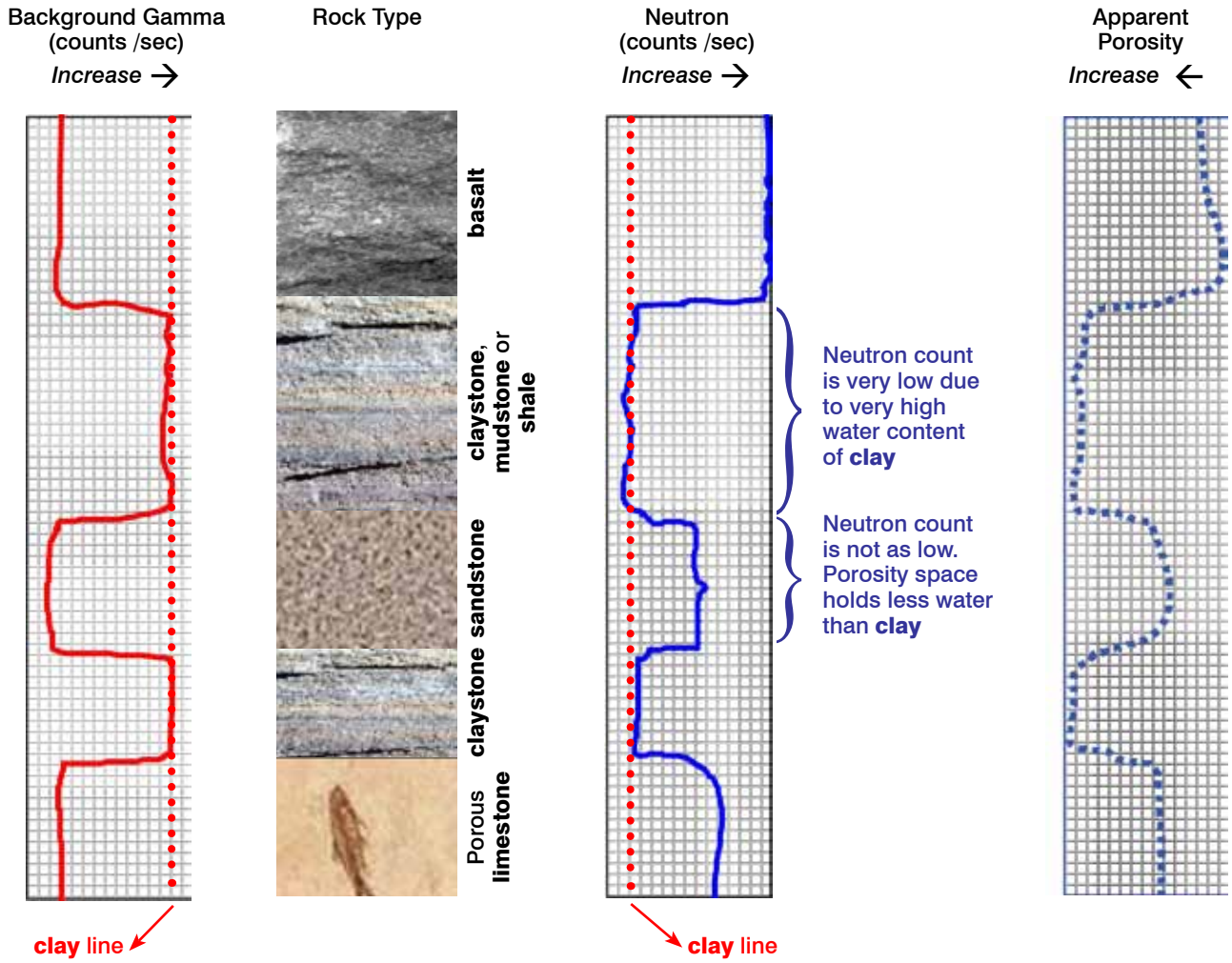
*= High clay-bound water content or pore space water (not as high)**

***Note:** Clay contains high levels of bound H_2O, in fact higher than porous sand aquifers. So when a high Gamma log corresponds to a very low Neutron reading the formation is a clay layer. But high Gamma opposite not so low Neutron means **sandstone** or porous **limestone** aquifer. That is, interpretation of water content should be made relative to the "Clay Line" indicated by the Gamma log and Neutron log.

Types of Probes

Example Log 3:

The Rock Density log is derived from the Gamma counts log



Types of Probes

Uses

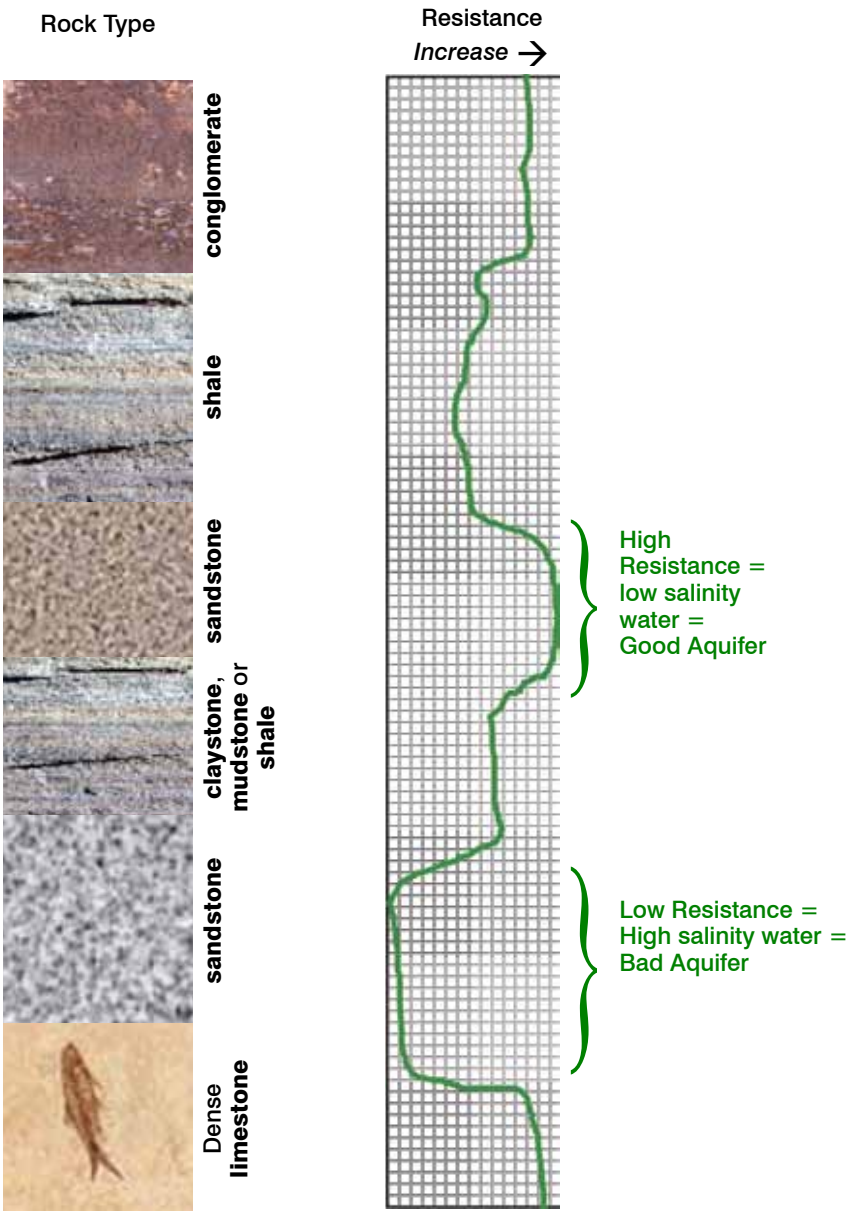
The probe can be used to find salty water or fresh water aquifers.

ELECTRICAL RESISTANCE or POINT RESISTANCE (PR) PROBE

The electrical resistance of the earth varies for several reasons, including:

- Salinity of water or electrolyte concentration.
- The rock porosity.
- The "connectivity" of the liquid in the formation i.e. permeability.
- The types of minerals in the rock formation i.e., sulphide minerals are good conductors of electricity while calcite, clay and quartz are not.

Example Log 4:



How it works

The resistance between a down-hole electrode and a reference surface electrode is measured.

The changes in current flow between the two points indicate the changes in rock formation Resistance. This is mainly caused by the amount of salt in water contained by the rock, i.e. less dissolved salt increases resistance.

Types of Probes

THE CALIPER PROBE

Uses

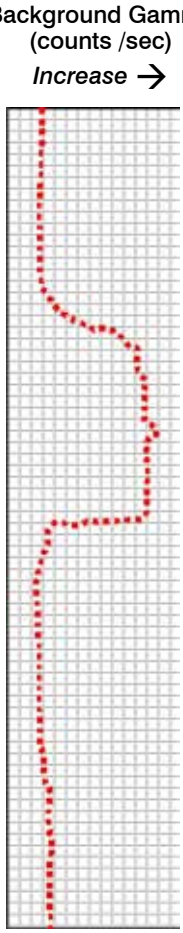
This probe is used to measure the diameter of the drill hole from bottom to top.

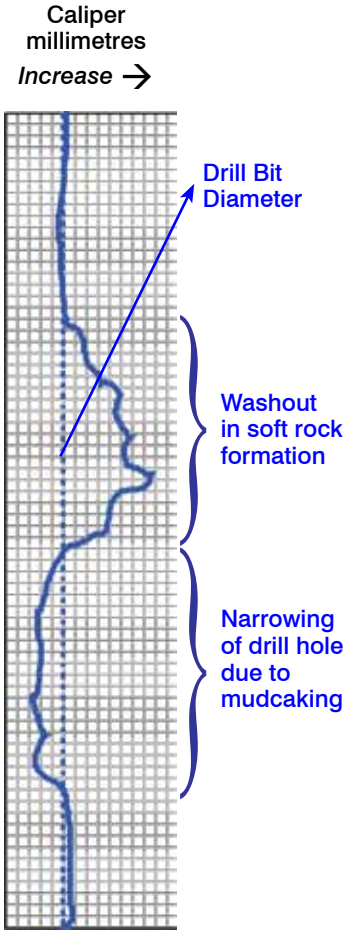
Changes in the regular diameter of the hole may be due to:

- Wearing of the bit as it drills down through the rock.
- Collapse of the softer rock formations.
- Minerals deposited around the inner wall of the casing.
- Rusting out of metal casing or damaged plastic casing.
- Clay formation swelling into the drill hole as it absorbs water from the drilling mud.
- Drilling mud deposits on the aquifer wall as drill mud water is absorbed into the aquifer.

How it works

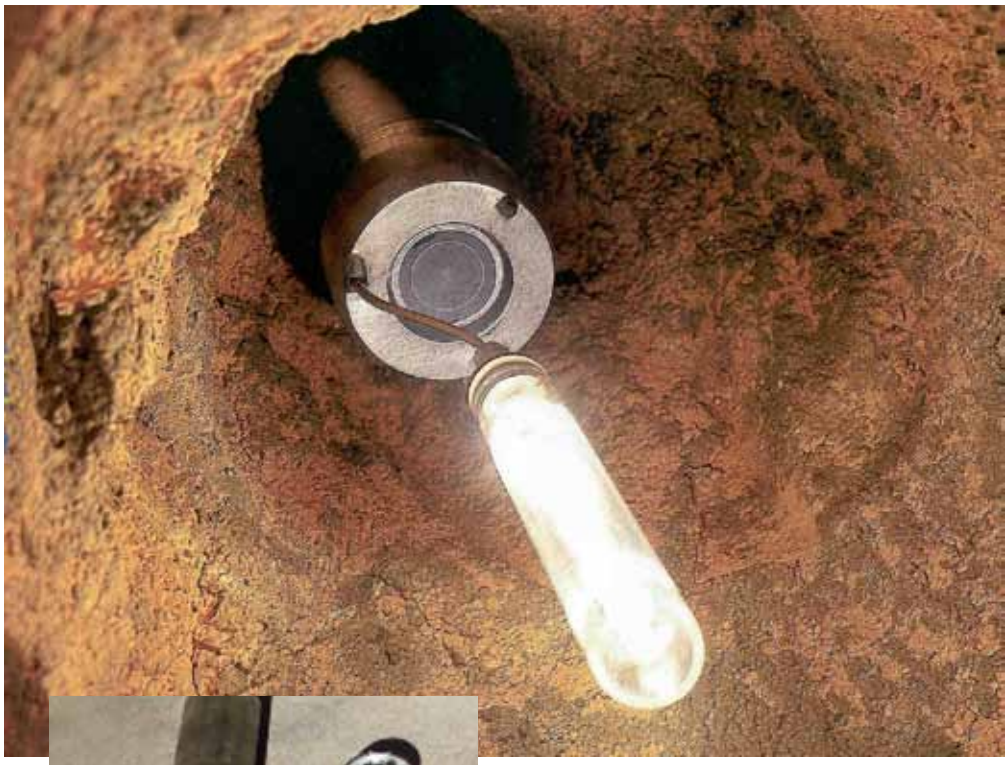
The Caliper Probe is lowered to the bottom of the hole and the probe calliper arms are opened by a motor drive till they contact the sides of the hole. The distance between the arms is the diameter of the hole. The probe is then pulled to the surface measuring the diameter of the hole as it goes.





Types of Probes

THE VIDEO PROBE



Uses

The Video Probe is switched on from ground level to record a continuous video of the drill hole wall rock or casing all the way to the bottom.

It can then be used to inspect the condition of the drill hole.

How it works

The video camera has a small light to shine on the drill hole walls and the picture is sent via cable to the surface where it is recorded on DVD or VHS cassette.

Check your facts with Practice Problems

Problem 1

Caliper Probe

Study the drill hole diameter logged by the Caliper Probe on the following Geophysical Data Logs of the "KAPI" drill hole.

Question 1:
Identify and mark where the:

- *Drill Bit started to show wearing out?*
- *The rock formation was softer and collapsed?*

Problem 2

Natural Gamma Probe

Study the Rock Formation Gamma Radiation Log for the KAPI drill hole.

Question 1:
Study the Log of natural Gamma radiation emitted by rock, find the clay-rich formation layers on the graph and mark their upper and lower boundaries.
Note: Clay rich layers may be Claystone, Mudstone, Shale or poorly sorted Gravel or **sandstone**.

Question 2:

- *How many clay rich layers did you find?……..*
- *Also mark the non - clay rock formation layers.*

Question 3:
Line up all the clay rich segments and draw a vertical line to join them all up, this will be your "Clay Line".

Check your facts with Practice Problems

Problem 3

Density or Cs137 Gamma back-scatter Probe

Question 1:

Study the Density Log, which has been interpreted from the Cs137 back-scattered Gamma rays, recorded by the probe's sensor.

- *Now draw in the missing sections of the Cs137 back-scattered Gamma radiation Log.*

Question 2:

The rock formation between 42 metres to 60 metres down the drill hole, shows a gradual change in Density. How is it changing, and what could cause this in the sediment composition?

Answer.....

.....

.....

Question 3:

There are two possible Coal Seams (layers). Mark where they are on this log.

Main Rock - forming mineral	Density in gm/cc	Pore - space Fluid	Density
Dolomite	2.87	Fresh water	1.00
Calcite	2.71	Salt water	1.13
Shale	2.7	Fresh water +3% oil	0.9 - 0.94
Quartz	2.65	Fresh Water +30% gas	0.73 - 0.78
Rock Salt	2.03		
Coal	1.1 – 1.5		

Check your facts with Practice Problems

Porosity or Neutron Probe

Problem 4

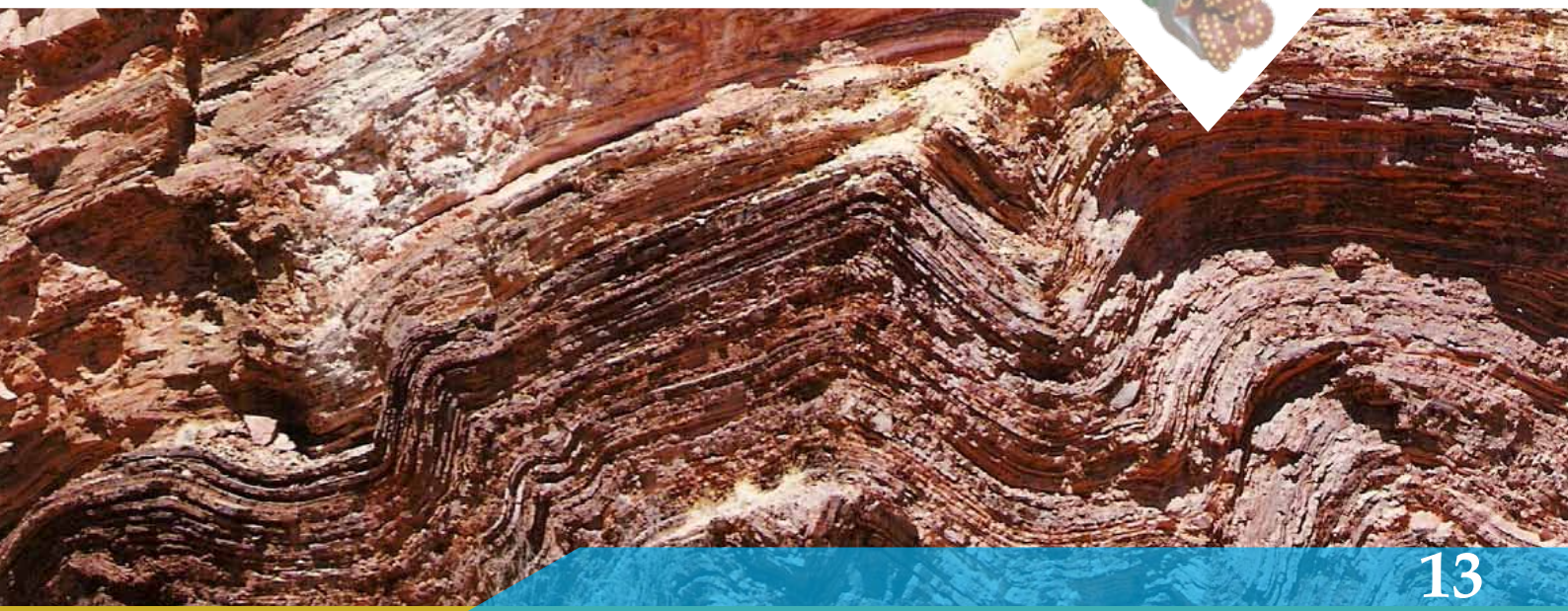
Question 1:

Complete the statement.

- *The (Lower / Higher) the fluid content of the rock, the bigger the P……value of the rock formation.*
- *Draw the missing segments of the Porosity Log.*
- *Mark the sections where the rock porosity is high.*
- *Mark the sections of very low porosity.*
- *Label the rock formations which could be aquifers.*

Question 2:

Find the clay line on the Natural Gamma Log and then see where the Neutron Log corresponds for the clay rich formations and draw a similar line on the Neutron Log and Porosity Log. Does this help show where the aquifers are?



Check your facts with Practice Problems

Problem 5

Resistance Probe

Question 1:
Choose the correct term in the brackets to complete the sentence:

The lower the total dissolved salts in the water the (Lower / Higher) will be its Electrical Resistance.

Question 2:
Dry Rock will show (High/Low) Electrical Resistance unless it contains conductive Sulfide minerals, in which case it will show (High / Low) Electrical Resistance.

Question 3:
Show on the Fluid Log where fresh low salinity water is located as a possible aquifer. This should be isolated for the bore to supply good quality water.

Question 4:
If the depth scale is 2 metres per increment, calculate the thickness of the aquifer (……) metres.

Question 5:
Which layers are **sandstone** and which are porous limestone and explain why?

Answer……

……

……

Hint: Study the Rock Density table and the Density log.

Question 6:
Study the Resistance Log and the Porosity Log to decide where petroleum might be found.

Hint: think about whether oil and gas are good or bad conductors of electricity.

Check your facts with Practice Problems

Problem 6

Video Probe

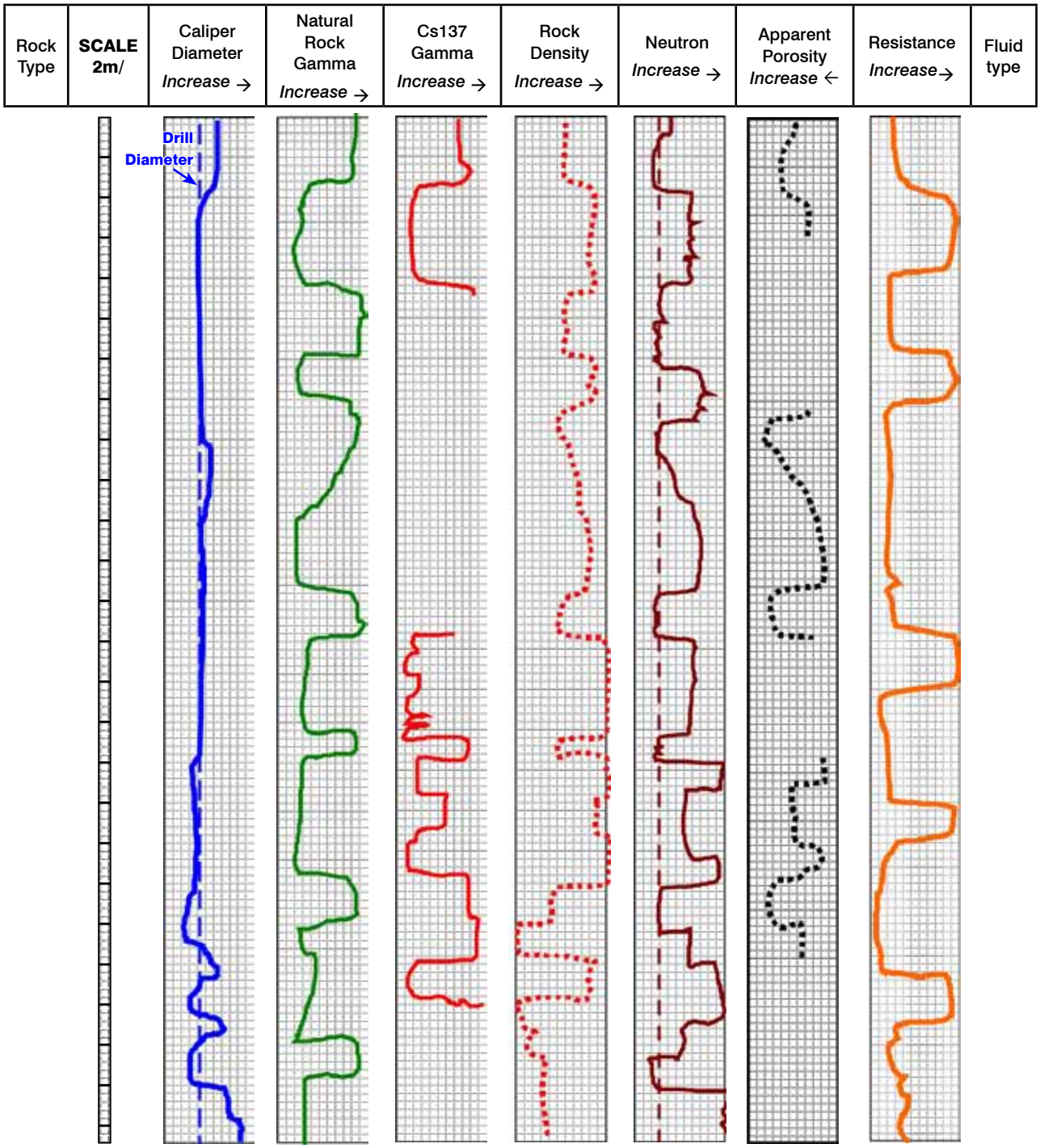
Question 1:
Why are all the other probes sent to the bottom and are then switched on to record data while the Video Probe is always used first and is switched on to record from top to the bottom of the drill hole?

Answer.....

.....

Question 2:
List some uses of the Video Probe.

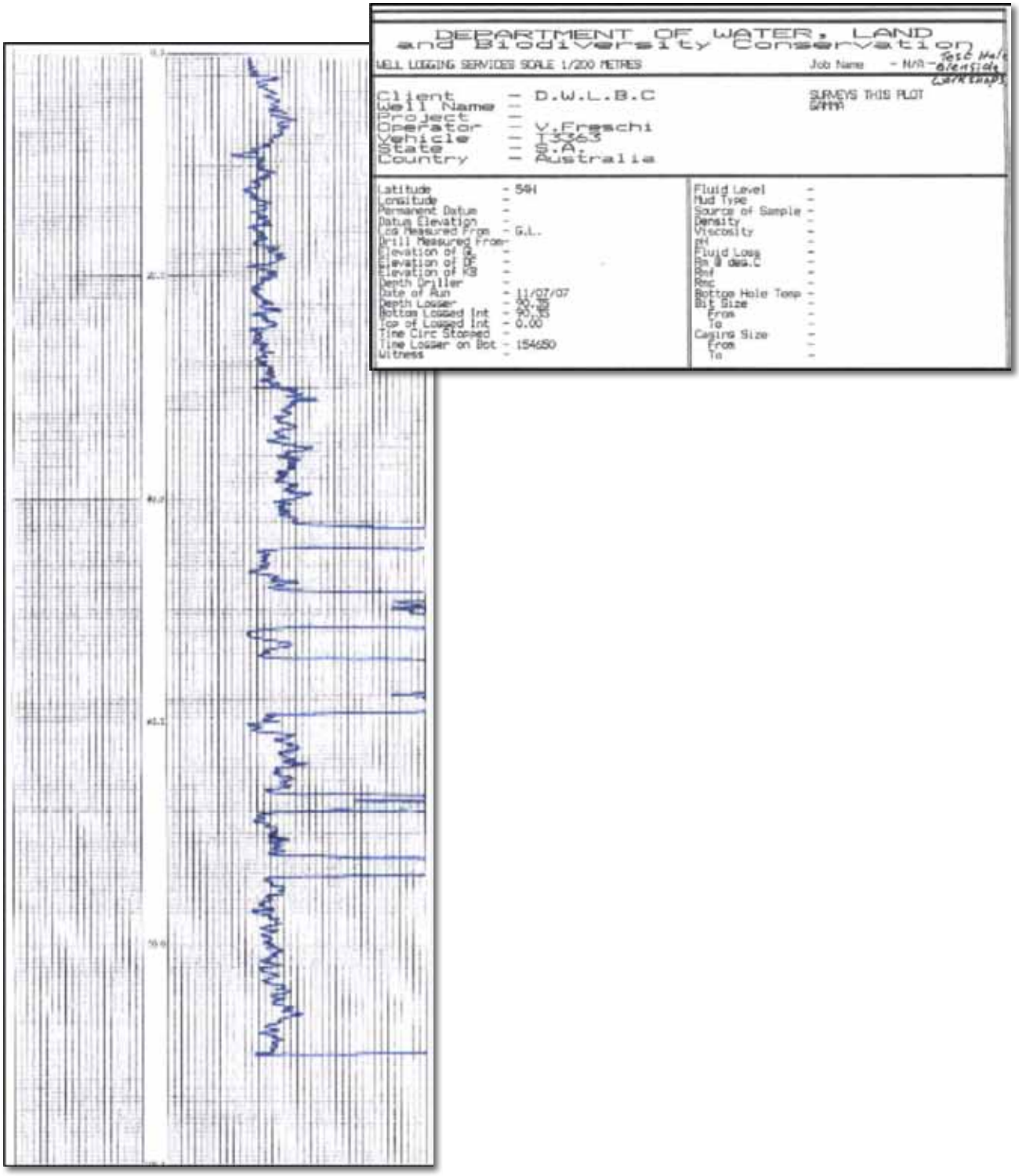
Geophysical data logs for "KAPI" Drill Hole



Case Study 1

Glenside Geophysical Technical Services Laboratories Test Bore Hole.

Below is the Gamma Log printout of the Glenside Geophysical Technical Services Laboratories Test Bore Hole for you to study.



Case Study 1

Glenside Geophysical Technical Services Laboratories Test Bore Hole.

Question 1:
What type of Logging probe was used in this part of the survey?

Answer.....

Question 2:
What does the probe detect and what is producing the signal in the rocks?

Answer.....

Question 3:
Is this signal source a problem for the use of the water from this bore?

Answer.....

Question 4:
What is the maximum depth to which the bore hole descends?

Answer.....

Question 5:
Mark the depths at which anomalies were detected and record depths on this page.

Answer.....

Question 6:
What is the total thickness of the anomalies?

Answer.....

Question 7:
Use the water level probe to find how far underground the water level is - this is called the Water Table.

Answer.....

Question 7:
Is it possible to tell whether there is an aquifer underground. How deep and how thick it is? Explain your answer.

Answer.....

Case Study 2

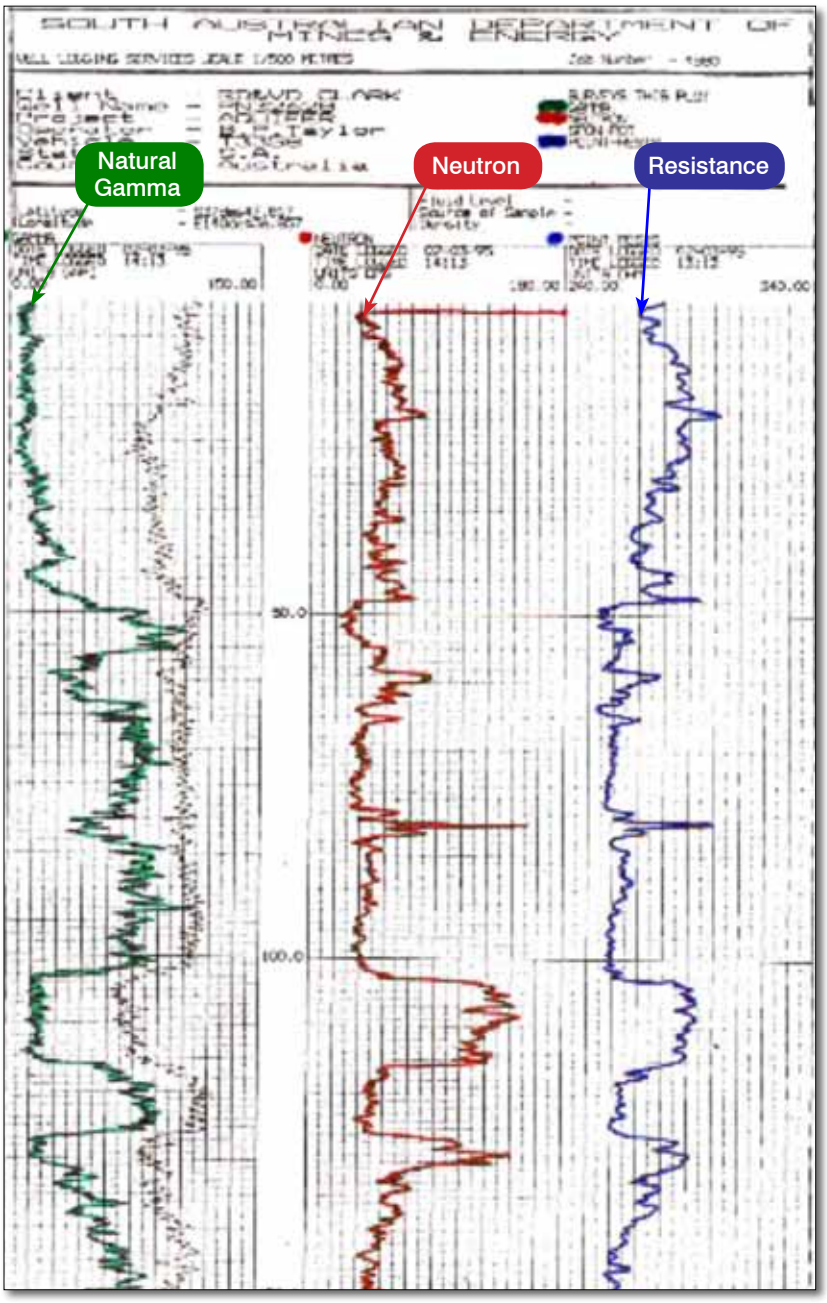
C? Bore Hole

Question 1:

Study the logs in colour (disregard the black log), then find and mark where the three aquifers are on the log i.e. two thin ones and a thicker one below. Explain your answer

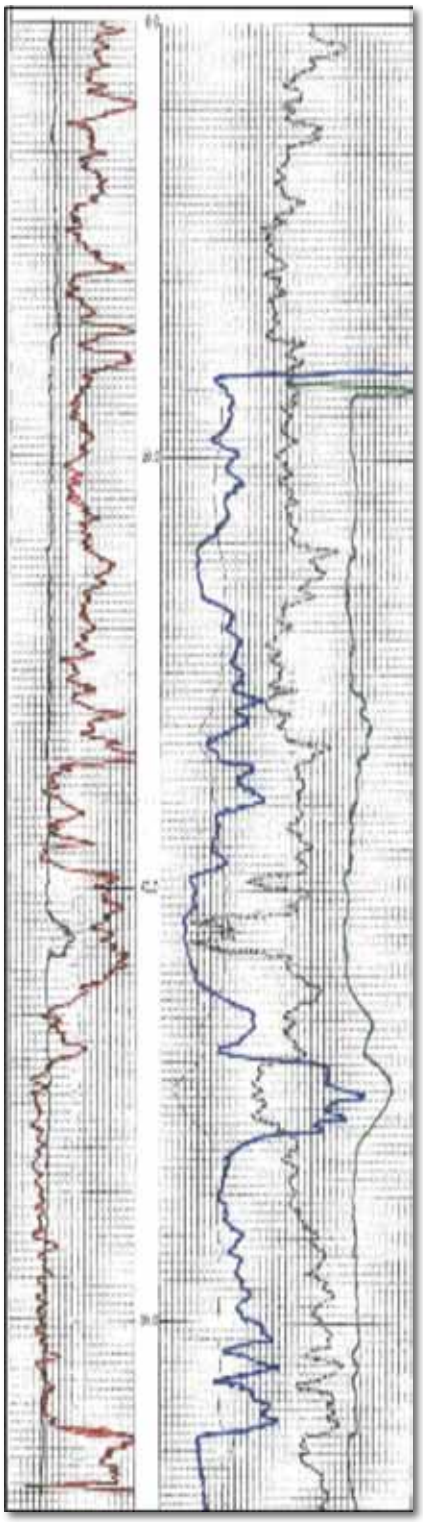
Answer.....

.....



CASE STUDY 3

Blewitt Springs Log



— Caliper — Neutron
— Gamma — Resistance
— Density

Question 1:
Using the Gamma log only draw in the "clay line" and identify the sections that could be aquifers.

Question 2:
In the section 39 – 44 metres the clay layer shows a sudden drop in density at the 42 m depth. What could it be made of to show such a low density?

Answer……

……

Question 3:
Study the Caliper log and explain what the condition of the drill hole is like and why and where there are any washouts?

Answer……

……

……

Question 4:
At 48 – 52 metres the Neutron count goes high indicating the water content is (Low / High).

This coincides with an increase in Resistance and a Density drop. Which of the following could explain these readings? Explain your answer.

a. Salt formation
b. Lignite coal formation
c. Gas e.g. air pocket
d. Fresh water spring

Answer……

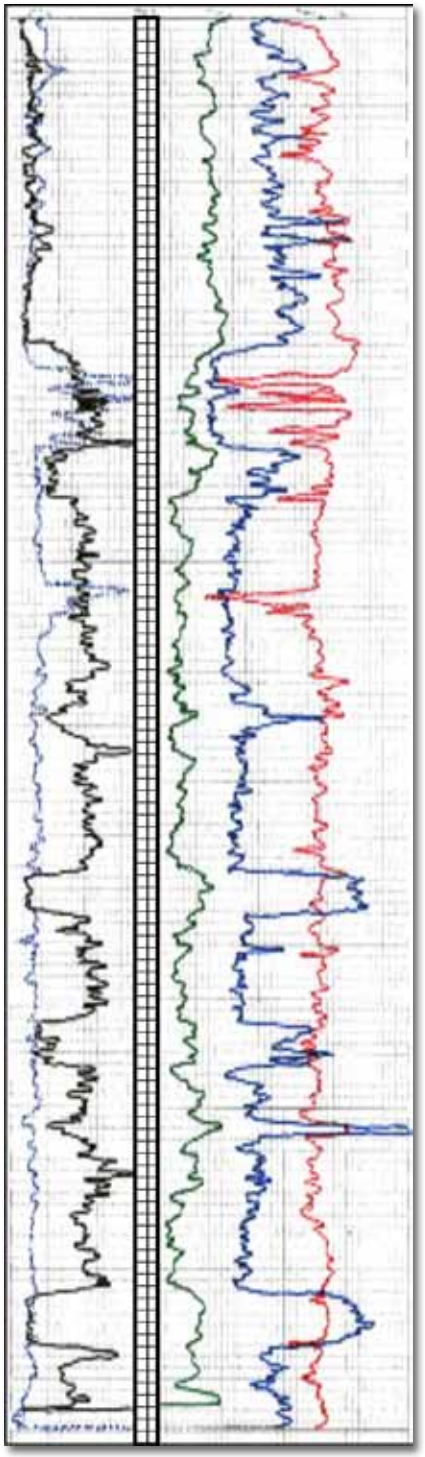
……

……

CASE STUDY 4

Blue Lake, Mt Gambier

Study the logs and answer the questions at the end.



Caliper
Gamma
Neutron
Resistance
Density

Question 1:
Mark the Clay formations.

Question 2:
Mark the Clay Line on the Gamma Log and corresponding Neutron Log.

Question 3:
Mark the aquifers.

Question 4:
Is there any area of wall collapse in the bore hole?

Answer……..……..

Question 5:
Why should all these aquifers be sealed off to stop water flow into the bore hole?……

Answer……..……..

Question 6:
The Density is very low in several places, mark these sections and suggest why.

Answer……

……

Question 7:
Why are these lower density sections not likely to be Sink Holes?

Hint: look back at the Formation Density Table.

Answer……

……

……..……

Solutions to Check Your Facts Problems