Borehole Geophysics

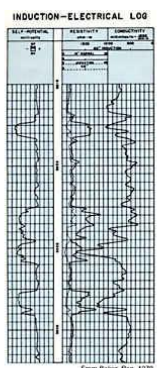
GEOLOGICAL SCIENCES CSU FULLERTON

Outline

- Why Geophysics?
- History
- Definitions
- Types
- Equipment
- Techniques
- Applications
- Interpretation

Why?

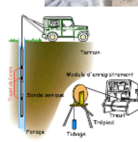
- Helps define geology better
  - To identify producing intervals and confining units
  - To identify zones of bad water
  - To make high resolution measurement of the variation in fluids and physical properties in and around the well bore.
  - To measure in-situ properties not easily measured in cuttings.
- Continuous log
- Correlation
- Can be used after the fact



From Baker, Ron, 1979

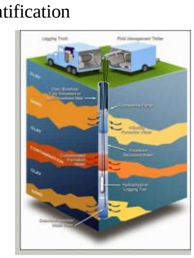
Where and When can it be used!

- Can be used in cased hole
- Can be used in auger or mud hole
- Can be used in bedrock or alluvium



Applications

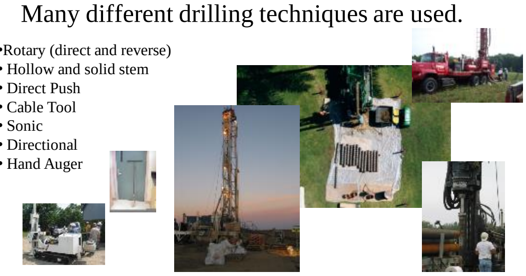
- Geologic Strata Mapping
- Well Inspection and Construction Identification
- Soil Layer Identification
- Fracture Location Mapping
- Void Mapping
- Calculated Porosity Measurements
- Fracture Size and Orientation Data
- Layer Property Determinations
- Borehole Fluid Properties
- Fracture Fluid Flow Data



Drilling Techniques

Many different drilling techniques are used.

- Rotary (direct and reverse)
- Hollow and solid stem
- Direct Push
- Cable Tool
- Sonic
- Directional
- Hand Auger



Drilling Continued

Sample collection can depend on drilling technology.





- Example:
  - Mud Rotary
  - Direct Push
  - Sonic

History of Well Logging

- Earliest well logging measurements collected by Claude Schlumberger in France in early 1900's
  - (In the early 1900s, Mr. Schlumberger envisioned the concept of using electrical measurements to map subsurface formations; and in 1927, he and his brother Marcel performed the world's first electrical resistivity well log in France. (Resistivity is the measurement of the level of difficulty an electric current has passing through a formation.))
- Method quickly embraced and expanded by oil industry
- Used extensively in Oil for many decades
- Used in groundwater less pervasive, but common in many areas.

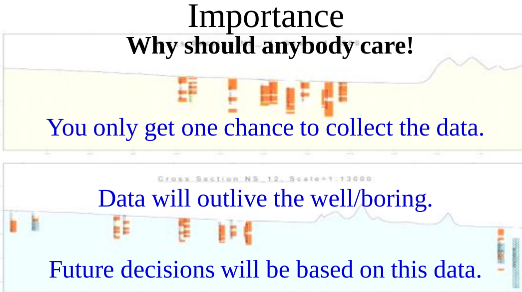
Well Logs

Tradition holds that the term "well logs" is borrowed from ship nomenclature. Similar to a ship's log that tracks the events aboard the vessel, a well log tracks the events of drilling, but instead of being plotted in a timeline, a well log is recorded by depth drilled.

In the early 1800s, well loggers scaled the oilfield derricks and simply wrote down what happened at certain depths, including problems, types of formations encountered, speed of drilling and, of course, oil or gas flows.

Importance

Why should anybody care!

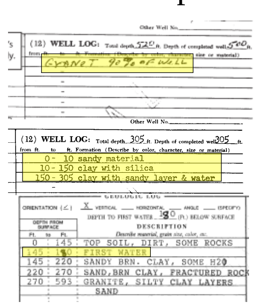


You only get one chance to collect the data.

Data will outline the well/boring.

Future decisions will be based on this data.

Examples – "not so good"

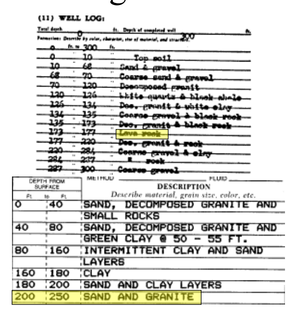


(12) WELL LOG: Total depth 520 ft. Depth of completed well 500 ft.
from ft. to ft. Formation (Describe by color, character, size or material)
GYBNET 90% OF WELL

(12) WELL LOG: Total depth 305 ft. Depth of completed well 305 ft.
from ft. to ft. Formation (Describe by color, character, size or material)
0 - 10 sandy material
10 - 150 clay with silica
150 - 305 clay with sandy layer & water

ORIENTATION (∠) X VERTICAL ___ HORIZONTAL ___ ANGLE ___ (SPECIFY)
DEPTH TO FIRST WATER 180 (Ft.) BELOW SURFACE

Depth from surface Ft.	to Ft.	DESCRIPTION Describe material, grain size, color, etc.
0	145	TOP SOIL, DIRT, SOME ROCKS
145	180	FIRST WATER
145	220	SANDY BRN. CLAY, SOME H20
220	270	SAND,BRN CLAY, FRACTURED ROCK
270	593	GRANITE, SILTY CLAY LAYERS
		SAND

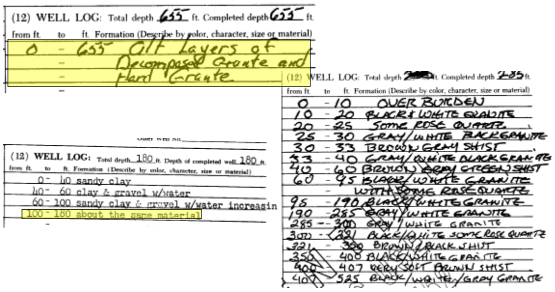


(11) WELL LOG:
Total depth 0 ft. Depth of completed well 300 ft.

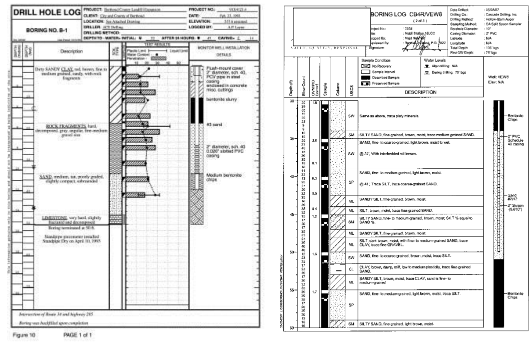
from ft.	to ft.	
0	300	
0	10	Top soil
10	68	Sand & gravel
68	70	Coarse sand & gravel
70	120	Decomposed granit
120	126	White quartz & black shale
126	134	Dec. granit & white clay
134	135	Coarse gravel & black rock
135	173	Dec. granit & black rock
173	177	Lava rock
177	220	Dec. granit & rock
220	284	Coarse gravel & clay
284	287	" rock
287	300	Coarse gravel

Depth from surface Ft.	to Ft.	DESCRIPTION Describe material, grain size, color, etc.
0	40	SAND, DECOMPOSED GRANITE AND SMALL ROCKS
40	80	SAND, DECOMPOSED GRANITE AND GREEN CLAY @ 50 - 55 FT.
80	160	INTERMITTENT CLAY AND SAND LAYERS
160	180	CLAY
180	200	SAND AND CLAY LAYERS
200	250	SAND AND GRANITE

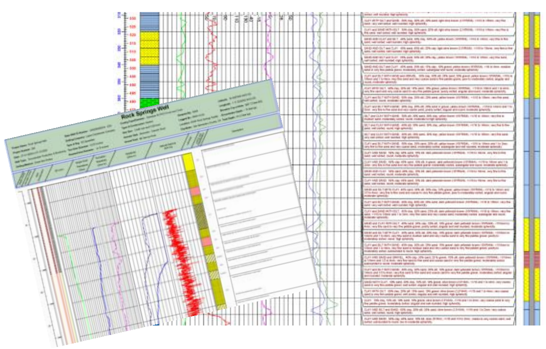
Examples – "not so good"



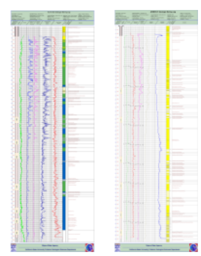
Examples – "Better to Good"



Examples – "Detailed"



Software for Logs



- LogPlot by Rockware
- Excel by Microsoft
- Borehole Mapper by MapInfo
- Strater by Scientific Software
- gInt by gInt Software
- Target by GeoSoft
- Petra by INH
- QuickLog by M-Tech

Great software does not substitute for detailed notes in the field!

Well Logging

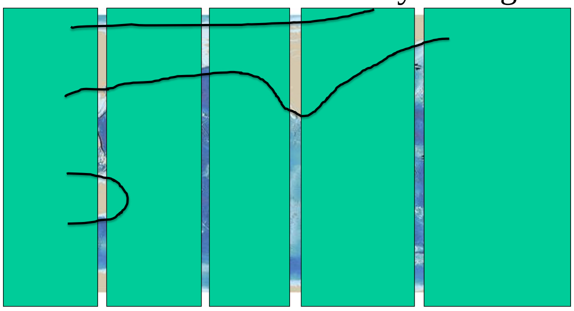
Well logging today means anything recorded having to do with the drilling versus the depth of the well at that moment, many times represented by a graph and corresponding notes. Logging tools are inserted into the well to measure the electrical, acoustic, radioactive and electromagnetic properties of the subsurface formations. Sometimes the logging tools are incorporated into the drilling tool, and sometimes the drilling tools are lowered into the well at regular intervals to collect data.

GEOLOGISTs!

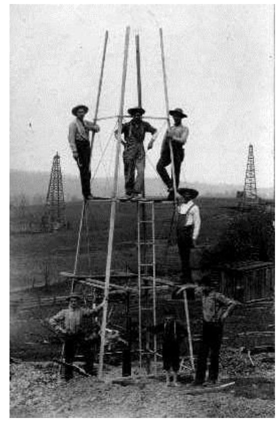
WARNING

Do not forget the big picture!

Remember You Are Only Seeing



What do you see?

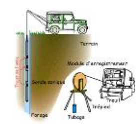


EEGS Definition of Geophysics

- Geophysics is: The subsurface site characterization of the geology, geological structure, groundwater, contamination, and human artifacts beneath the Earth's surface, based on the lateral and vertical mapping of physical property variations that are remotely sensed using non-invasive technologies. Many of these technologies are traditionally used for exploration of economic materials such as groundwater, metals, and hydrocarbons.

- Geophysics is: The non-invasive investigation of subsurface conditions in the Earth through measuring, analyzing and interpreting physical fields at the surface. Some studies are used to determine what is directly below the surface (the upper meter or so); other investigations extend to depths of 10's of meters or more.

What is Borehole Geophysics



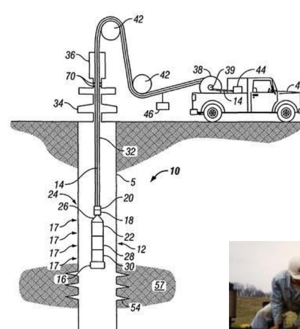
- Geophysical borehole logging can provide accurate data of the physical properties of geologic units and groundwater within the borehole environment.
- Borehole logging is a time and money-saving approach to gaining detailed information which is otherwise only obtainable from performing and analyzing numerous cores. Borehole logging data is typically used to characterize geology, fracture patterns, fluid flow, and geologic structural properties.
- Common borehole logging techniques such as video, resistivity, natural gamma, electromagnetic induction, 3-arm caliper, spontaneous potential, borehole deviation, and temperature can be deployed and interpreted quickly and cost effectively.

Borehole geophysics is simply geophysics in a nontraditional environment.

In mineral exploration, tradition dictates that airborne and surface geophysical measurements be made prior to drilling the target. In the past, borehole geophysical measurements, which were feasible, were not used to any great extent to obtain additional information because it was cheaper to drill more holes.

Since drilling is now such an expensive part of exploration, it is important that maximum advantage be taken of the methods offered by geophysics to evaluate apparently barren ground (i.e. a "dry" hole) and to increase the probability of striking significant mineralization during subsequent drilling.

The primary objectives of drilling a hole is to obtain information about the geological environment. The information obtained from the borehole has until recent years been entirely based on the drill core taken from the hole.

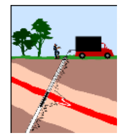


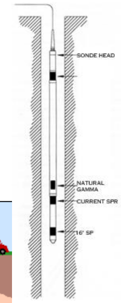
Types Borehole Tools

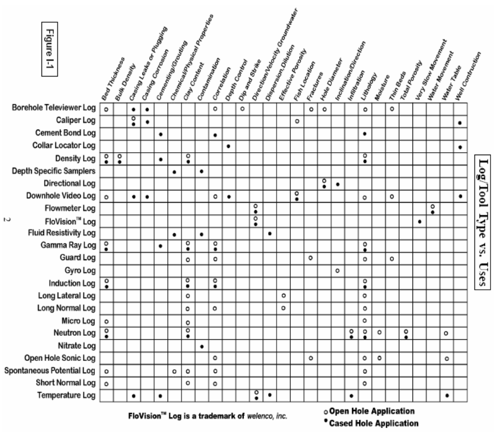
- Gamma-ray
- Spontaneous Potential
- Single Point Resistivity
- Caliper
- Temperature / Fluid Resistivity
- Electromagnetic Induction
- Borehole deviation
- Triple Gamma
- Neutron-thermal
- Magnetic susceptibility
- Video
- Dual Induction

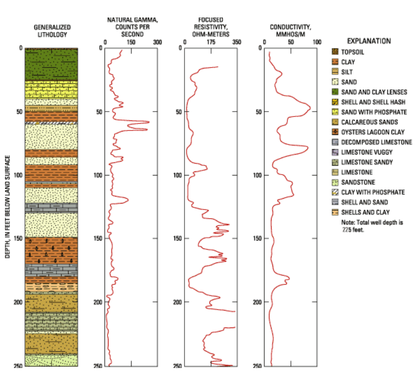
E-log

The ELOG or electric log is the classic water-well combination probe combining **shallow, medium and deep penetrating resistivity measurements with self-potential (SP) and natural gamma (optional).**

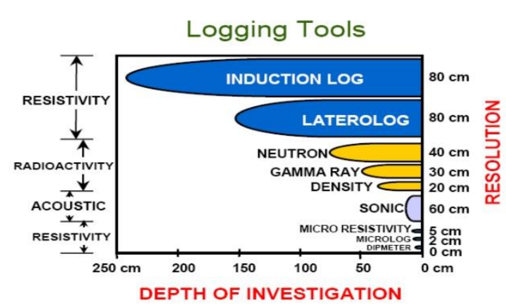








Which one do I use for what purpose?

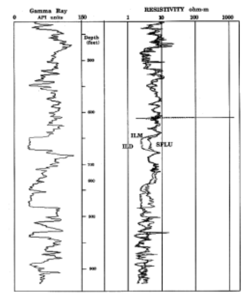


Gamma Ray

Gamma logs record the amount of natural gamma radiation emitted by the rocks surrounding the borehole. The most significant naturally occurring sources of gamma radiation are potassium-40 and daughter products of the uranium- and thorium-decay series. Clay- and shale-bearing rocks commonly emit relatively high gamma radiation because they include weathering products of potassium feldspar and mica and tend to concentrate uranium and thorium by ion absorption and exchange.

Gamma Ray

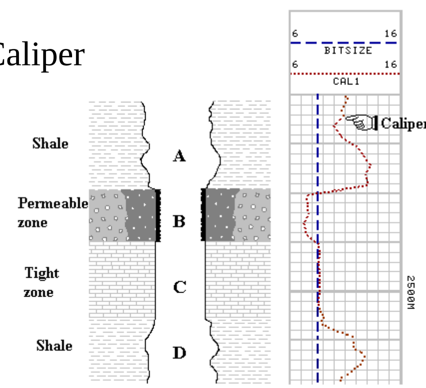
A common and inexpensive measurement of the natural emission of gamma rays by a formation. Gamma ray logs are particularly helpful because shales and sandstones typically have different gamma ray signatures that can be correlated readily between wells.



Caliper

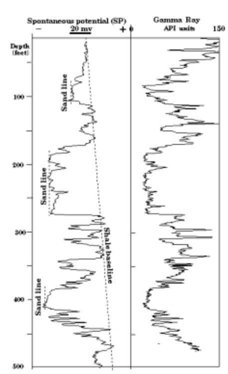
Caliper logs record borehole diameter. Changes in borehole diameter are related to well construction, such as casing or drilling-bit size, and to fracturing or caving along the borehole wall. Because borehole diameter commonly affects log response, the caliper log is useful in the analysis of other geophysical logs, including interpretation of flowmeter logs.

Caliper

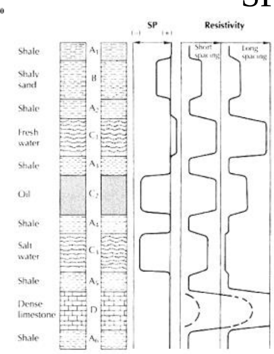


SP

Spontaneous Potential (SP) Logs show the permeability of the rocks in the well by calculating the electrical currents generated between the drilling fluids and formation water held in the pore spaces. SP is used a lot to determine the difference between shale and sandstone.



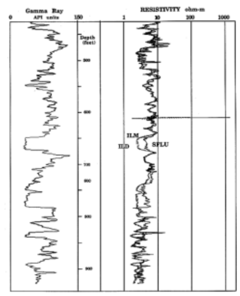
SP

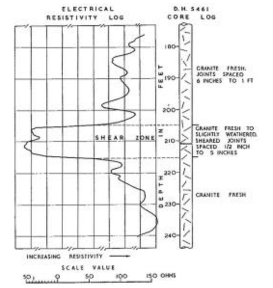


Resistivity

Resistivity Logs measure how electricity travels through rocks and sediments. This determines what types of fluids are present because oil and fresh water are poor conductors of electricity, while formation waters are salty and easily conduct electricity.

Resistivity



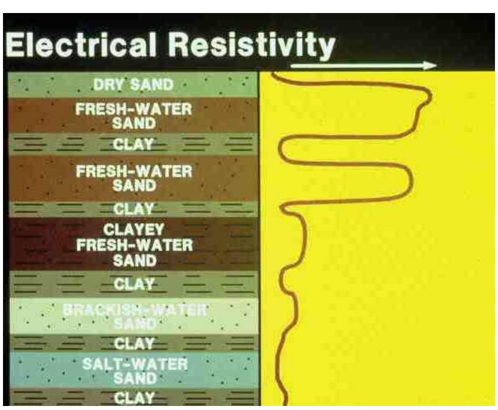


Single Point Resistivity

Single-point resistance logs record the electrical resistance from points within the borehole to an electrical ground at land surface. In general, resistance increases with increasing grain size and decreases with increasing borehole diameter, fracture density, and dissolved-solids concentration of the water. Single-point resistance logs are useful in the determination of lithology, water quality, and location of fracture zones.

Normal Resistivity

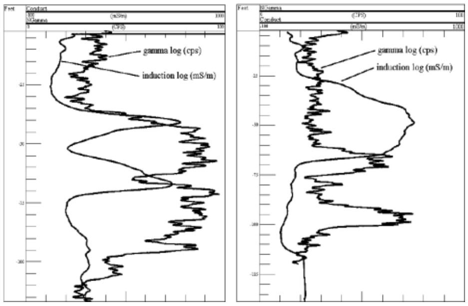
Normal-resistivity logs record the electrical resistivity of the borehole environment and surrounding rocks and water as measured by variably spaced potential electrodes on the logging probe. Typical spacing for potential electrodes are 16 inches for short-normal resistivity and 64 inches for long-normal resistivity. Normal-resistivity logs are affected by bed thickness, borehole diameter, and borehole fluid and can only be collected in water- or mud-filled open holes.



Induction

Induction Logs are used in wells that do not use mud or water, but oil-based drilling fluids or air, which are nonconductive and, therefore, cannot use electric logs. Induction uses the interaction of magnetism and electricity to determine Resistivity.

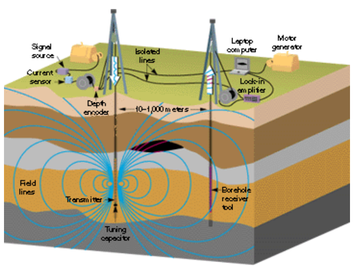
Induction



EM

Electromagnetic-induction logs record the electrical conductivity or resistivity of the rocks and water surrounding the borehole. Electrical conductivity and resistivity are affected by the porosity, permeability, and clay content of the rocks and by the dissolved-solids concentration of the water within the rocks. The electromagnetic-induction probe is designed to maximize vertical resolution and depth of investigation and to minimize the effects of the borehole fluid.

EM



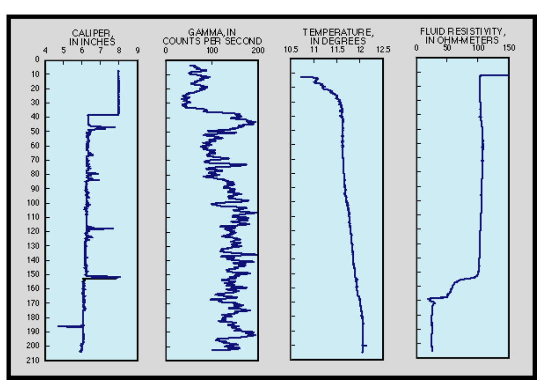
Schematic of the crosshole electromagnetic induction system.

Fluid Resistivity

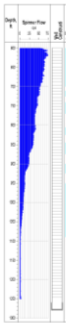
Fluid-resistivity logs record the electric resistivity of water in the borehole. Changes in fluid resistivity reflect differences in dissolved-solids concentration of water. Fluid-resistivity logs are useful for delineating water-bearing zones and identifying vertical flow in the borehole.

Temperature

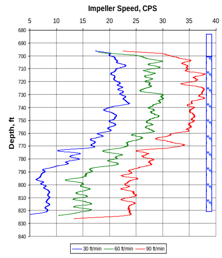
Temperature logs record the water temperature in the borehole. Temperature logs are useful for delineating water-bearing zones and identifying vertical flow in the borehole between zones of differing hydraulic head penetrated by wells. Borehole flow between zones is indicated by temperature gradients that are less than the regional geothermal gradient, which is about 1 degree Fahrenheit per 100 feet of depth.



Water Quality Impacts

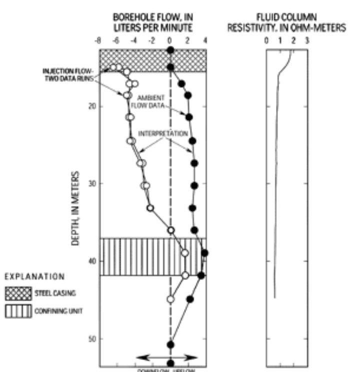


- Changes in water quality
  - Alteration of well hydraulic performance
  - Changes in concentrations
  - New constituents in lab reports above background
  - Brackish water intrusion
  - Upwelling of brackish water



Flowmeter

Flowmeter logs record the direction and rate of vertical flow in the borehole. Borehole-flow rates can be calculated from downhole-velocity measurements and borehole diameter recorded by the caliper log. Flowmeter logs can be collected under non-pumping and(or) pumping conditions. Impeller flowmeters are the most widely used but they generally cannot resolve velocities of less than 5 ft/min. Heat-pulse and electromagnetic flowmeters can resolve velocities of less than 0.1 ft/min.

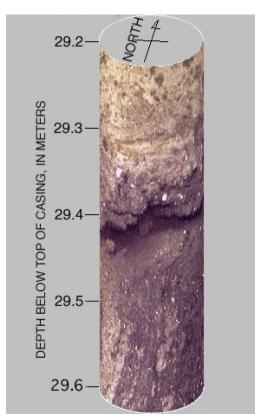


Flowmeter

Video

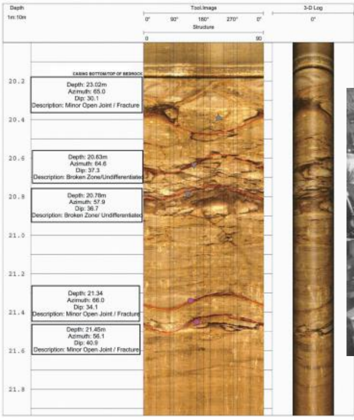
Television logs record a color optical image of the borehole. In addition to being recorded on video-cassette-recorder tape, the optical image can be viewed in real time on a television monitor. Well construction, lithology and fractures, water level, cascading water from above the water level, and changes in borehole water quality (chemical precipitates, suspended particles, and gas) can be viewed directly with the camera.

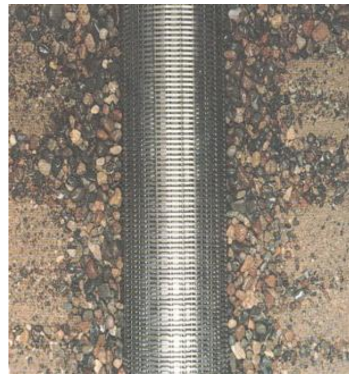
Video



Fancy Video

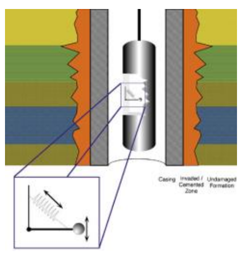
Acoustic-televiewer logs record a magnetically oriented, photographic image of the acoustic reflectivity of the borehole wall. Televiewer logs indicate the location and strike and dip of fractures and lithologic contacts. Collection of televiewer logs is limited to water- or mud-filled open holes.



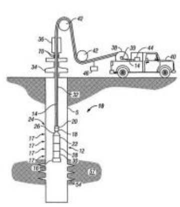


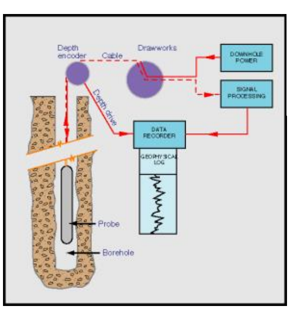
Borehole Environment

- The borehole environment consists of several zones
- The borehole filled with some type of fluid (air, water or mud)
- A flushed zone around the hole.
- An invaded zone a little further into the formation
- An undisturbed zone deeper into the formation
- The drilling method and borehole history greatly influence the thickness of these zones.



How does it work!





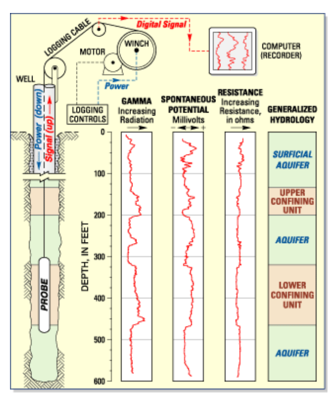
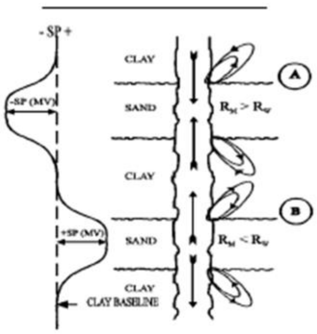


Diagram of geophysical well-logging equipment and recorded logs with generalized hydrologic units.



Pos. and Neg. SP Curves Relative to Mud and Water Resistivities

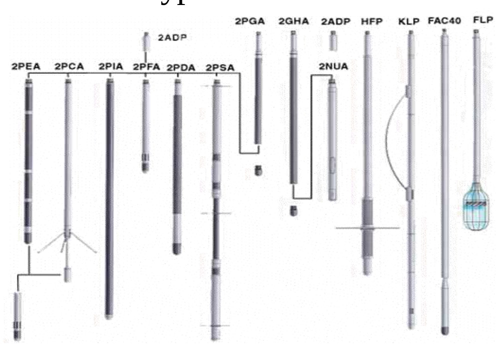
Equipment



Equipment




Types of Tools



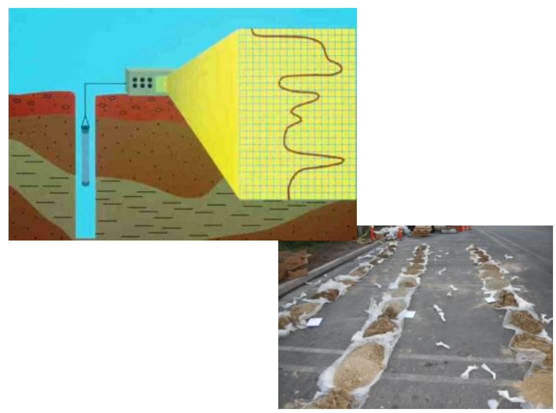
Tools


Field Setup

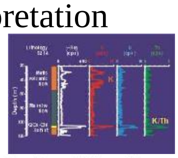


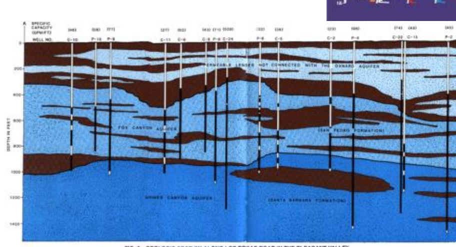
What does all this mean?

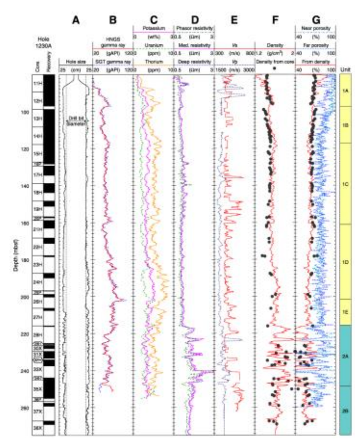
How to read the logs!

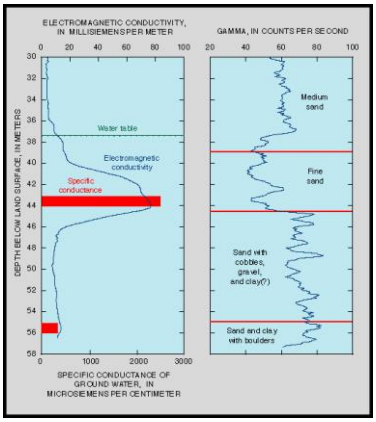


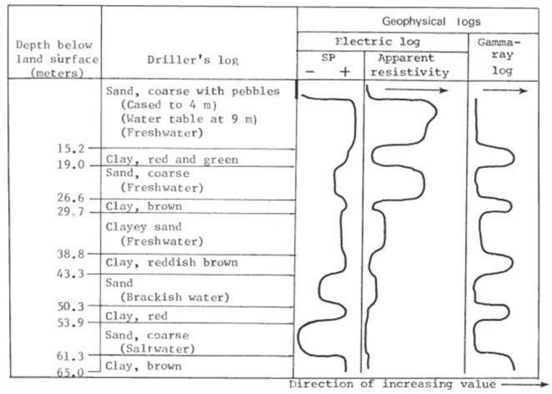
Interpretation

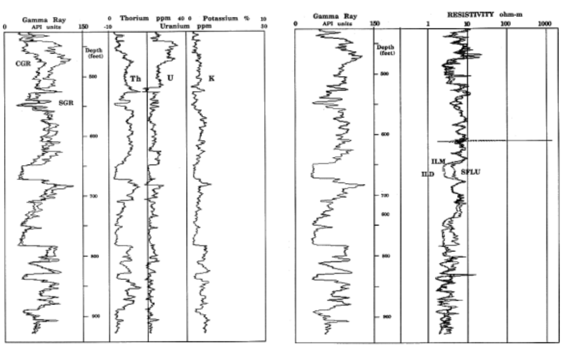


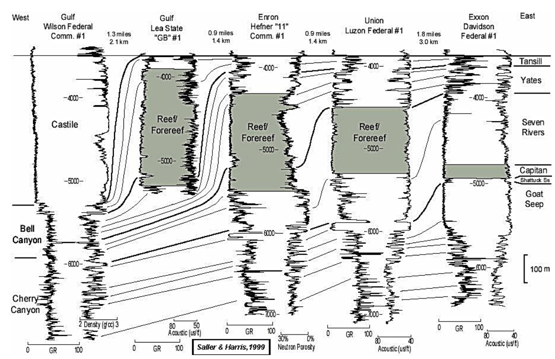


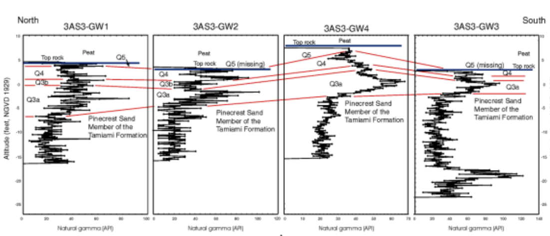


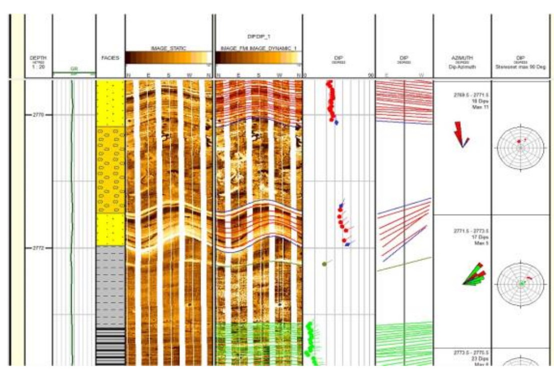

ELECTROMAGNETIC CONDUCTIVITY, IN MILLISIEMENS PER METER
GAMMA, IN COUNTS PER SECOND
DEPTH BELOW LAND SURFACE, IN METERS
Water table
Electromagnetic conductivity
Specific conductance
Medium sand
Fine sand
Sand with cobbles, gravel, and clay(?)
Sand and clay with boulders
SPECIFIC CONDUCTANCE OF GROUND WATER, IN MICROSIEMENS PER CENTIMETER

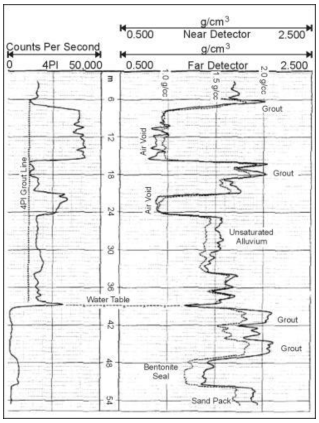

Depth below land surface (meters)
Driller's log
Geophysical logs
Electric log
SP
− +
Apparent resistivity
Gamma-ray log
Sand, coarse with pebbles (Cased to 4 m) (Water table at 9 m) (Freshwater)
15.2
19.0
Clay, red and green
Sand, coarse (Freshwater)
26.6
29.7
Clay, brown
Clayey sand (Freshwater)
38.8
43.3
Clay, reddish brown
Sand (Brackish water)
50.3
53.9
Clay, red
Sand, coarse (Saltwater)
61.3
65.0
Clay, brown
Direction of increasing value

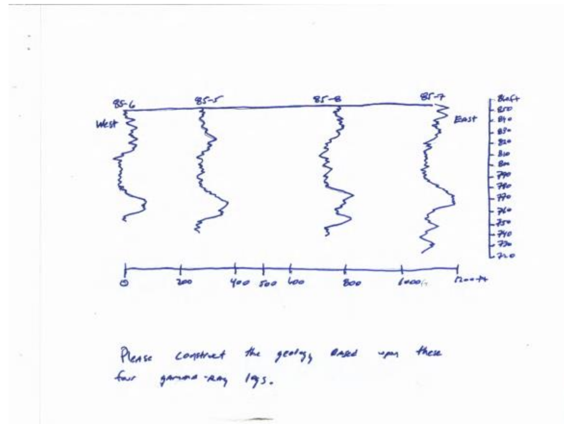

Gamma Ray API units
Thorium ppm
Uranium ppm
Potassium %
Depth (feet)
CGR
SGR
Th
U
K
Gamma Ray API units
Depth (feet)
RESISTIVITY ohm-m
ILM
ILD
SFLU

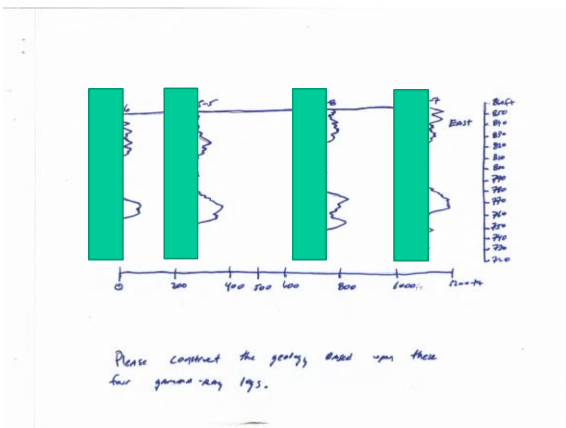

West
East
Gulf Wilson Federal Comm. #1
Gulf Lea State "GB" #1
Enron Hefner "11" Comm. #1
Union Luzon Federal #1
Exxon Davidson Federal #1
Castile
Bell Canyon
Cherry Canyon
Reef/ Forereef
Tansill
Yates
Seven Rivers
Capitan
Goat Seep
100 m
Saller & Harris, 1999

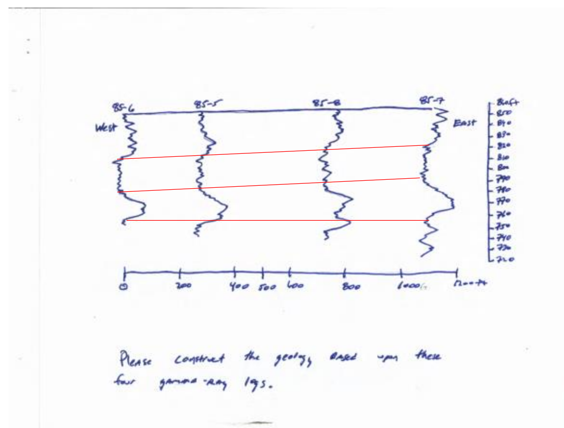

North
South
3AS3-GW1
3AS3-GW2
3AS3-GW4
3AS3-GW3
Top rock
Peat
Q5
Q5 (missing)
Q4
Q3b
Q3a
Pinecrest Sand Member of the Tamiami Formation
Altitude (feet, NGVD 1929)
Natural gamma (API)
Off Island
On Island


DEPTH
FACIES
IMAGE_STATIC
DIP
AZIMUTH

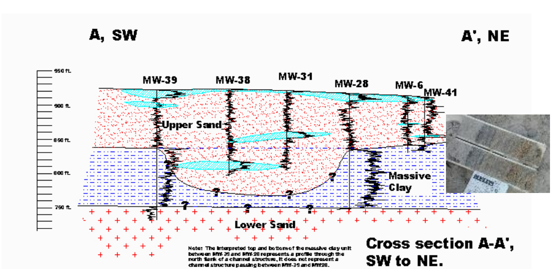








Correlation of geologic units



Now Go Log the World!