Well Logging Service Catalog

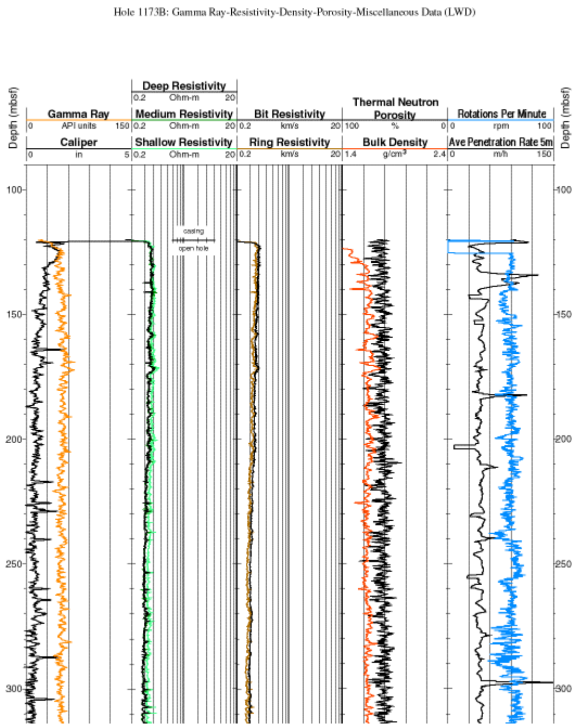
CDEX/JAMSTEC

Update 14 Sep, 2007

Introduction

Well logging

A well log is a record of one or more physical measurements as a function of depth in a borehole (From “Encyclopedic Dictionary of Applied Geophysics”). To measure the various values at once, one or more sondes comprise a tool string. Formation evaluation, lithological classification, and other geological interpretations are carried out from the logging curves or crossplots.



Examples of logging data

Wireline Log and Logging While Drilling (LWD)

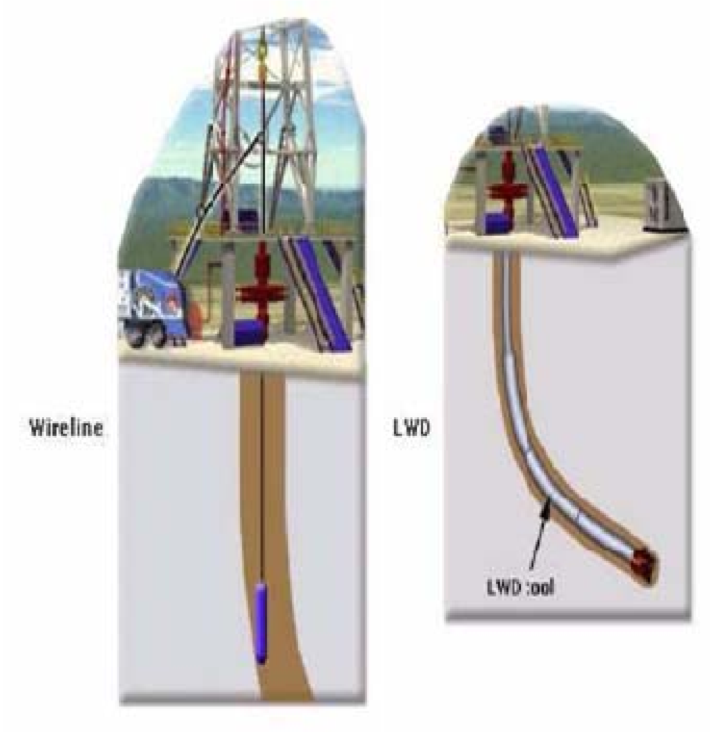
References

		Properties to measure									
		Natural Gamma Ray	Resistivity	P&S Velocity	Density	Litho Density	Porosiy	Dip meter/Borehole Imaging	NMR	Borehole Seismic	Borehole diameter (Caliper)
Principal Application	Lithostratigraphy	○	○	○	◎	◎	○	○	◎		
	Physical Properties		◎	◎	◎	◎	◎		◎	○	
	Structural Geology	○		○	○			◎		◎	
	Log-Seismic Integration	○		◎	◎			○		◎	
	Core-Log Integrattion	○	○	○	○	○	○	○	○	○	
	Rock Mechanics			◎	◎		○	◎		○	○
	Sedimentology	○	○	○	○	○	○	◎	◎	○	
	Hydrogeology		○				○		○		
	Paleoclimate, High Resolution	○	○	○	○		○	○			
	Gas Hydrates	○	◎	○	○	○	○	◎	○	○	○
Wireline Logging Tool	Natural Gamma Ray	●									
	Resistivity		●								
	Acoustic			●			●				
	Neutron Porosity						●				●
	Density				●	●	●				●
	NMR						●		●		
	Dip meter/Imaging							●			●*1
	Seismic			●						●	
LWD	andVISION				●	●	●				●*2
	CDN				●	●	●				●*2
	arcVISION	●	●								
	geoVISION	●	●					●			
	sonicVISON			●			●				
	proVISION						●		●		
	SeismicVISION									●	
	EcoVISION	●	●		●	●	●	●			

*1: FMI, *2: Ultrasonic caliper

Wireline Log and Logging While Drilling (LWD)

Wireline Logs are recorded by means of sondes carrying sensors which are lowered into the hole by a cable. Wireline Logs are done after drilling and tools are lowered into the borehole after removing drill pipes. Logging data are transmitted through wireline (cable) to the surface. LWD records bottomhole data acquired incrementally from sensors located in the drill string near the bit in a drilling well. Recording LWD are during drilling. Data can be transmitted to the surface in real time by pressure pulses through the mud inside the drill pipe. Large data files (e.g. waveforms) are temporarily stored in the memory of the tool for later recovery.



Wireline logging and LWD (from Schlumberger)

◀ return

Application to Science

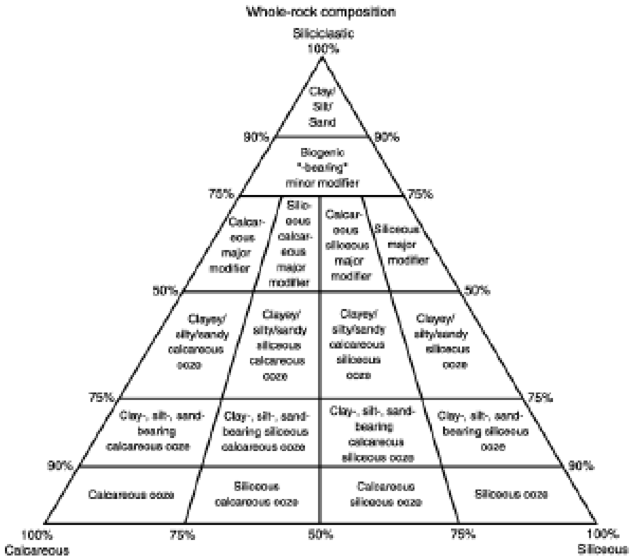
Lithostratigraphy

Lithostratigraphy is the study of sedimentary layers based on physical characteristics; or the study and correlation analysis of strata to reveal the sequences of stratigraphical history. Basic knowledge of each sequence lithology, the nature of well log responses, liquid and mineral contents, grain sizes, texture, color of rocks, physical attributes of rocks and other characteristics are required to study lithostratigraphy. The researcher who possesses complete knowledge of regional lithology and sedimentology, and experiences the handling of logging data in detail is requested from this kind of investigation as lithostratigrapher.

Major focuses of the study include geochronology, comparative geology and petrology. Stratum information can be used to complement the core record, to fill gaps of record, and to indicate pinpoint boundaries.

The basic unit of lithostratigraphy is the Formation: a mappable rock unit with distinct upper and lower boundaries. It will often represent a single depositional setting, and therefore a single rock-type or set of related facies. For example, the boundaries between beach sand, lagoonal mud, and carbonate bank depositional setting will migrate inland during a transgression. The lithostratigraphic boundaries are between each environment (sandstone, shale, limestone), but the time boundary will cut across the lithological boundaries.

After describing the sediment in each of the cores for a particular site, the next task is to define and categorize the sequence of sediment into particular lithostratigraphic units.



Sediment classification scheme used on ODP Leg 199.
From: http://www-odp.tamu.edu/publications/199_IR/chap_02/c2_f5.htm

(Figure from Joilearning: http://www.joilearning.org/schoolofrock/PDFs/Core_Description_Activity.pdf)

NanTroSEIZE Shipboard lithostratigrapher is responsible to describe lithology and stratigraphy of sediments, sedimentary rocks. The researcher who experiences the handling of logging data in detail to the feature and strata of the deposit in Nankai Trough is also requested. They divide characteristical unit based on the feature of logging profile and the statistical procedure of logging data, and lithofacies of a basic rock, hemiperagic sediment, and the alternation of strata. It is also available to analyse sedimentary facies and to recognize fault zone systems.

References

- Related publication during DSDP, ODP and IODP phases: the 807, 887, and 1256 Site chapters from ODP Initial Reports volumes 130, 145, and 206, respectively.
- NanTroSEIZE LWD reference site as follows:
- http://iodp.ldeo.columbia.edu/TOOLS_LABS/toolstring_selection.html
- http://www.joiscience.org/learning/undergrads
- http://www.joilearning.org/schoolofrock/PDFs/Core_Description_Activity.pdf
- http://iodp.ldeo.columbia.edu/TOOLS_LABS/toolstring_selection.html
- Mazzullo, J., Meyer, A., and Kidd, R.B., 1987. A new sediment classification scheme for the Ocean Drilling Program. ODP Technical Note, VIII.

- Shipboard Scientific Party, 1991. Site 807. In Kroenke, L.W., Berger, W.H., Janecek, T.R., et al., Proceedings of the Ocean Drilling Program, Initial Reports, 130: ODP, College Station, TX.
- Shipboard Scientific Party, 1993. Site 887. In Rea, D.K., Basov, I.A., Janecek, T.R., Palmer-Julson, A., et al., 1993. Proceedings of the Ocean Drilling Program, Initial Reports, 145: ODP, College Station, TX.
- Shipboard Scientific Party, 2003. Site 1256. In Wilson, D.S., Teagle, D.A.H., et al. Proceedings of the Ocean Drilling Program, Initial Reports, Volume 206: ODP, College Station, TX.
- Shipboard Scientific Party, 2002. Leg 196 summary: deformation and fluid flow processes in the Nankai Trough accretionary prism: logging while drilling and Advanced CORKs. In Mikada, H., Becker, K., Moore, J.C., Klaus, A., et al., Proc. ODP, Init. Repts., 196 B cker, C., Shimeld, J., Hunze, S., and Br ckmann, W., 2000. Data report: LWD data analysis of Leg 171A, a multivariate statistical approach. In Moore, J.C., and Klaus, A. (Eds.), Proc. ODP, Sci. Results, 171A.

return

Physical Properties

Physical properties of the formation are basic information of Geology. Logging data provides the gamma rays, resistivity, density, porosity, velocity, etc as in-situ. Other properties calculated from them, and relationships with depth or each other helps us to analyze and interpret geology.

return

Structural Geology

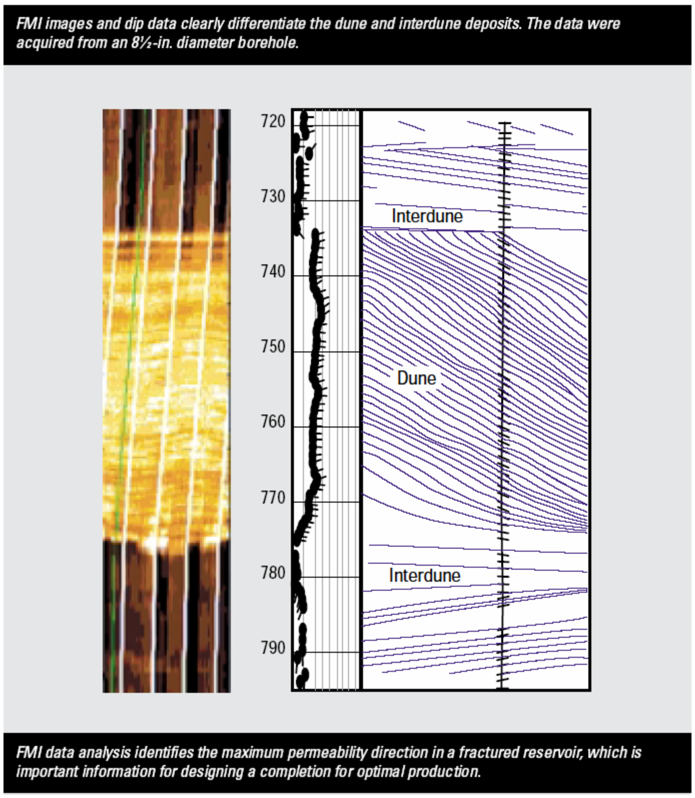
Structural geology is defined as the study of rock bodies, surfaces, internal fabrics and their characteristics. Structural geology includes features and overlaps of geomorphology, metamorphism and geotechnical studies. By studying the three dimensional structure of rocks and regions, inferences on tectonic history, past geological environments and deformation events can be made. Required structural geologist onboard NanTroSEIZE is a specialist for deformation structure of the deposit, fault system analysis, stress field for sequence stratigraphy. Structural geologist can recognize decollement, the splay fault system, past stress direction and tectonic setting by use of Borehole images and logging data.

How to approach:

FMS, UBI, LWD-geoVISION and LWD-EcoScope data provide physical property images of the borehole wall, showing detailed structural (faults, fractures), sedimentological (turbidites, beds, bioturbation, concretions, clasts), and igneous (veins, alteration, and basalt pillows, breccias, and flows) features. In the case of the FMS and UBI, the orientation of these features can be analyzed, since it is measured by the GPIT on the same tool string. Under favorable circumstances, an azimuthal resistivity imager (ARI) can provide images of the same features.

Applied field of Structural geology

The study of structural geology has been importance and basic knowledge in economic geology, both petroleum and mining geology. In general, petroleum and natural gas can be found and trapped in folded and faulted rock strata. Faulted and structurally complex areas are notable as permeable zones for hydrothermal fluids and the resulting concentration areas for base and precious metal ore deposits. Veins of minerals containing various metals commonly occupy faults and fractures in structurally complex areas. The NanTroSEIZE structural geological point of view for a plate boundary fault or megathrust within a subduction zone where great earthquakes (M ~ 8.0) have repeatedly occurred in the past might be top highlighted and ideal field.



(Figure from Schlumberger FMI brochure)

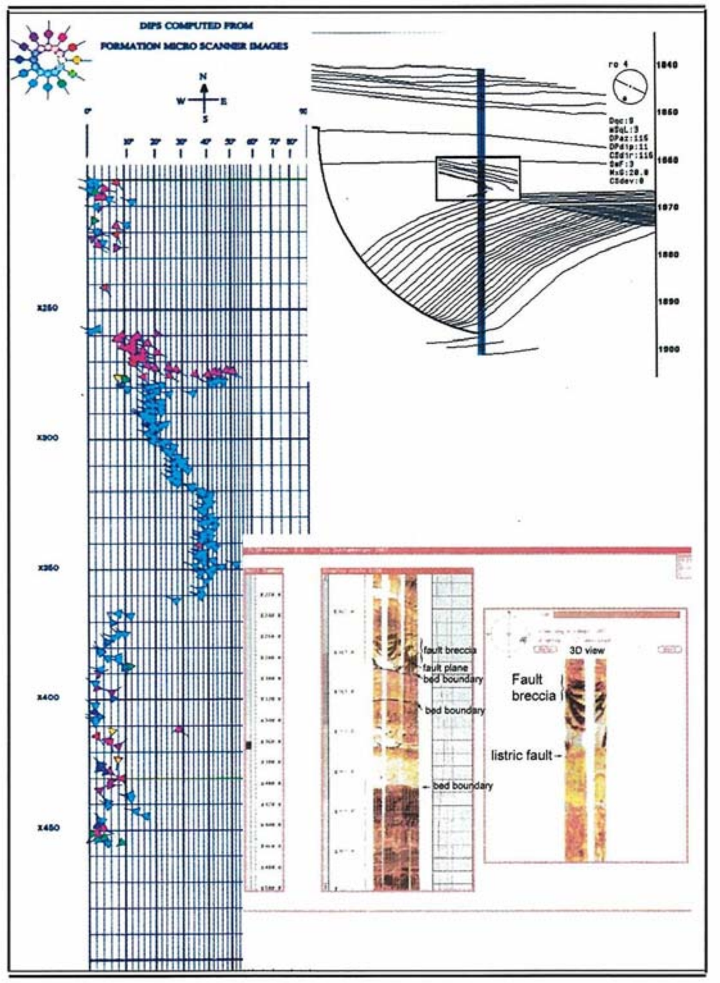


Figure 8-132 - Arrow-plot from FMS dips, section across the rollover zone and FMS image of the fault plane. The small deformation feature on the top of the rollover is an assumed slumped zone (from Etchecopar & Bonnetain, 1992).

Figure from "Well Logging and Geology, 2003"

Refference

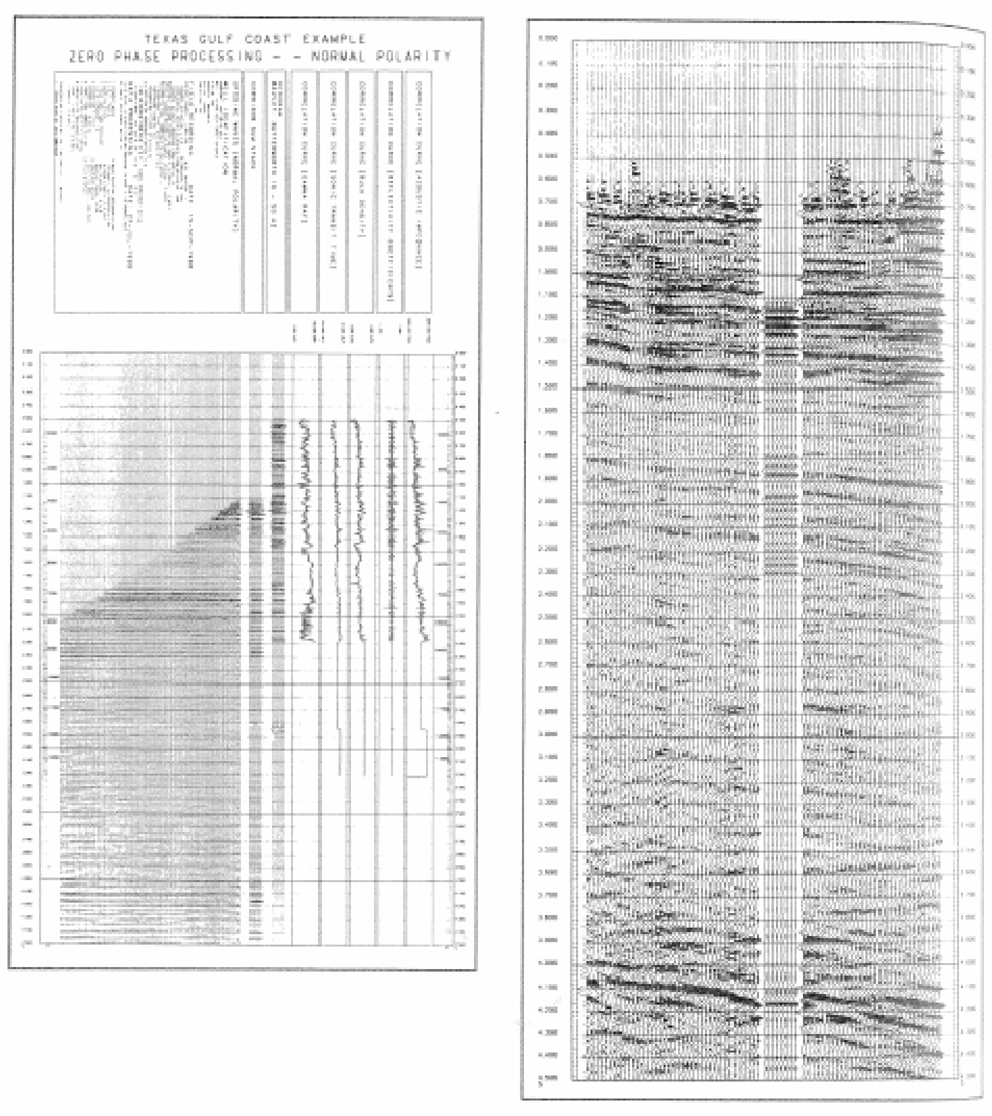
- http://iodp.ldeo.columbia.edu/TOOLS_LABS/toolstring_selection.html
- http://www.iodp.org/nantroseize-stage-1-scientific-prospectus/#1
- http://www.nantroseize.com/Discipline.htm
- McNeill, L. C., Ienaga, M., Tobin, H.J., Saito, S., Goldberg, D., Moore, J.C., and Mikada, H., 2004, Deformation and in situ stress in the Nankai Accretionary Prism from resistivity-at-bit images, ODP Leg 196. Geophy. Res. Lett., v. 31, L02602.
- Ienaga, M., McNeill, L.C., Mikada, H., Saito, S., Goldberg, D., and Moore, J.C., 2006, Borehole image analysis of the Nankai Accretionary Wedge, ODP Leg 196: structural and stress studies. Tectonophysics, v.426, 207-220.

return

Log/Seismic integration

Log seismic integration is a methodology to complete synthetic seismograms and to correlate with logs and seismic section in order to tie and link between both. A synthetic seismogram can be generated to provide the link between the logs and the seismic section and also provide physical properties and characteristics of seismic reflection layer. The basic idea is to achieve a match between seismic reflections in between the formations to create the synthetic seismogram and the reflections in the seismic data. The seismic data can be interpreted as the actual formations and to reveal how deep into the seismically strong reflection layers. The reflectors on the seismic section can be identified as lithological or petrophysical changes or boundaries in the borehole.

The seismic tools (eg. WST, WST-3, ASI, VSI) are used for check shot surveys to obtain a depth-travel time relation and zero-offset VSP experiments to obtain seismograms at the site. The depth-travel time relation can be derived from the sonic velocity log, which together with the density log and seismic source wavelet combine to make a synthetic seismogram. The reconstruction of the complete lithologic section from downhole logs is a two-stage process, which involves the initial identification of rock types within recovered core sections and calibration with the downhole logging data. Doing this allows us to understand the source of the measurement made by each tool and to establish the expected response in a particular lithology. The most useful logs for lithological discrimination are resistivity, P wave velocity, and gamma ray logs because they have a greater depth of investigation and are the least sensitive to poor hole conditions. The information is then used to extrapolate into un-recovered intervals and reconstruct a continuous lithology profile using the log data.



Left: VSP corridor stack, logging curves. Right: VSP corridor stack on seismic reflection section. (Figure from Shulumberger)

References:

- http://iodp.ldeo.columbia.edu/TOOLS_LABS/toolstring_selection.html
- http://www-odp.tamu.edu/publications/176_SR/chap_05/c5_6.htm
- http://www.ldeo.columbia.edu/BRG/ODP/LOGGING/MANUAL/Pages/iesx.html
- Bangs, N.L.B., and Gulick, S.P.S., 2005. Physical properties along the developing d collement in the Nankai Trough: inferences from 3-D seismic reflection data inversion and Leg 190 and 196 drilling data. In Mikada, H., Moore, G.F., Taira, A., Becker, K., Moore, J.C., and Klaus, A. (Eds.), Proc. ODP, Sci. Results, 190/196.
- Goldberg, D., Cheng, A., Gulick, S.P.S., Blanch, J., and Byun, J., 2005. Velocity analysis of

LWD sonic data in turbidites and hemipelagic sediments offshore Japan, ODP Sites 1173 and 808. In Mikada, H., Moore, G.F., Taira, A., Becker, K., Moore, J.C., and Klaus, A. (Eds.), Proc. ODP, Sci. Results, 190/196.

- Gulick, S.P.S., and Bangs, N.L.B., 2004. Negative polarity at the frontal thrust–is free gas the culprit?: insights from Nankai accretionary prism off Cape Muroto using seismic-logging integration. In Mikada, H., Moore, G.F., Taira, A., Becker, K., Moore, J.C., and Klaus, A. (Eds.), Proc. ODP, Sci. Results, 190/196.
- http://www-odp.tamu.edu/publications/190196SR/352/352.htm
- Velocity Analysis of LWD Sonic Data in Turbidites and Hemipelagic Sediments Offshore Japan, ODP Sites 1173 and 808

return

Core-Log integration

Cores provide the base material, while lab measurements provides the detailed properties of the formation. However, core recovery is sometimes low, and therefore results in missing data and depth information. Logging data provides continuous data and in-situ environmental data along the well. Disadvantages of core measurements are lower resolutions and limited measurement methods and conditions. The integrated analysis of core and log compensates for the disadvantages of each method while enhancing the advantages, and provide new points of view.

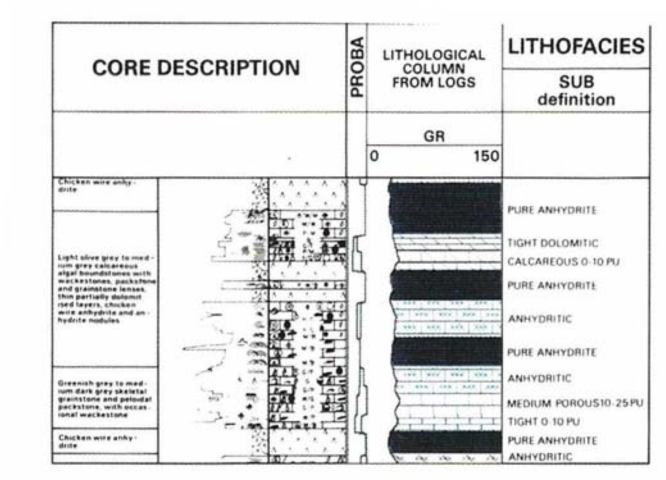


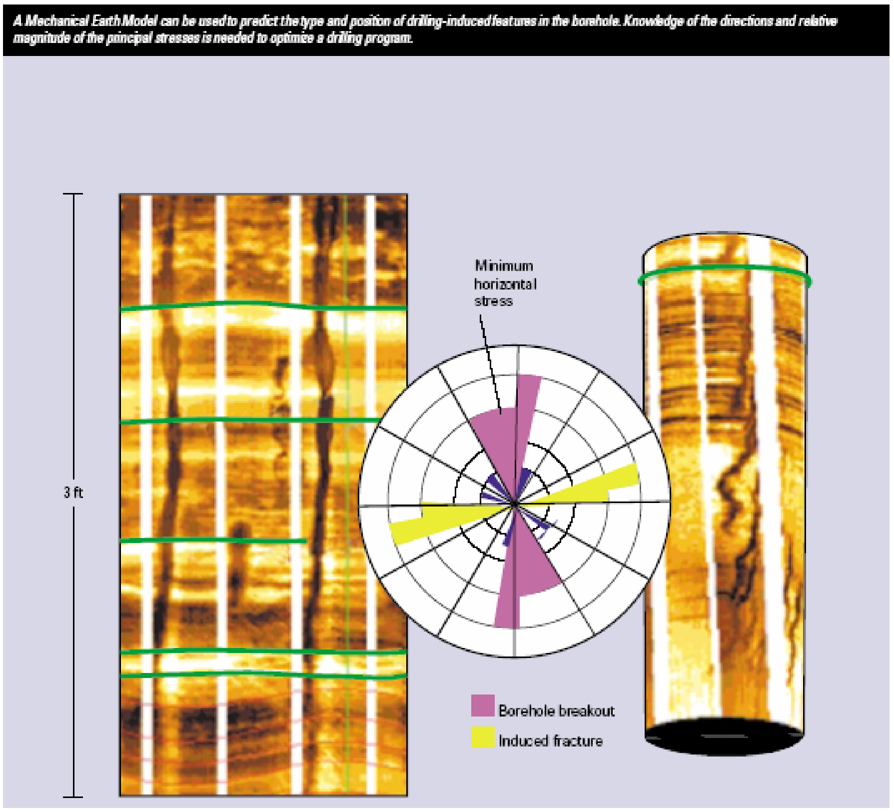
Figure 2-103 - Example of LITHO processing results. Observe the good agreement between the lithology from logs and the lithological description from core. Too thin layers are not seen by the logs.

(From "Well Logging and Geology, 2003")

return

Rock Mechanics

The mechanical characteristics of rock are important in order to understand the geology and structures in a region. Also, they influence the pressure and mechanical properties of boreholes. Due to the changes in mechanical characteristics after drilling, there is no method to directly measure *in-situ* mechanical properties. One example of this kind of analysis, is the analysis of fractures (borehole breakout) in the side of borehole after drilling, for which they use borehole imaging logging (e.g. FMI, RAB, UBI). Another method is to evaluate the physical properties from seismic properties, *e.g.* velocities and densities from logging, cores and seismic reflection methods. Rock mechanics are also important for drilling operations.



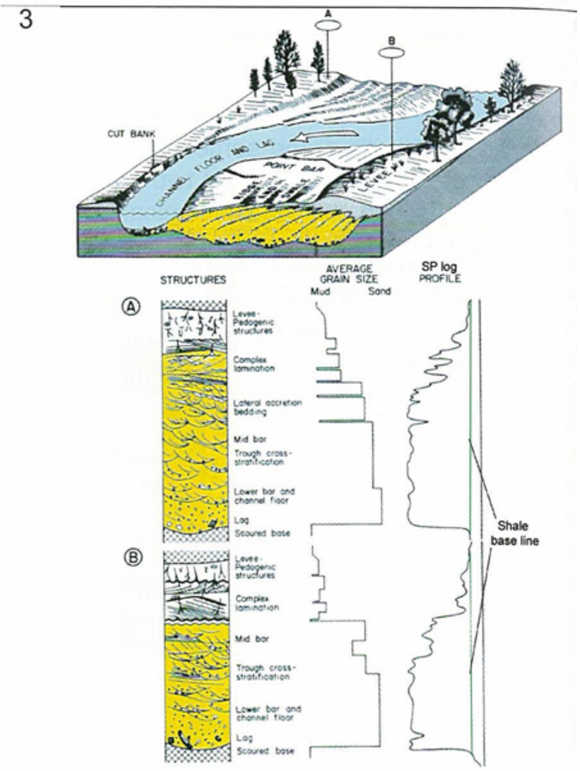
(Borehole breakout analysis (from Schlumberger FMI brochure))

return

Sedimentology

Sedimentology is the study of how sediments are eroded by wind, water flow, glaciers, biological activities, and chemical reactions, and are transported to oceans, rivers and lakes, and then deposited to the bottom. Sediments are composed of mud, sand, gravel, volcanic ash, chert, etc.

Logging data are sensitive to its characteristics and indicate the boundaries of layers. Borehole imaging provides visual information regarding the process and characteristics of sediment deposition.



(From “Well Logging and Geology”)

return

Hydrogeology

Hydrogeologists are interested in the hydrogeological characteristics and fluid flow in the formation. Compaction, dehydration, pressure of the fluid in pores, and permeability are evaluated from the data recorded. NMR logs are sometimes used to evaluate and interpret permeability. Hydrogeological properties of cores measured in the laboratory are collaborated with logging data. Hydrogeology is related to Physical properties studies.

return

Gamma Ray

Definition

Natural Gamma-ray radioactivity from the formation.

Matter exhibits radioactivity depending on its' component ingredients (rocks, minerals, etc). Two types of Gamma-ray logs measure natural radioactivity.

a) Natural gamma ray log:

   Total intensity of radioactivity of uranium (U), thorium (Th), and potassium (K). Often called by the nomenclature "gamma ray".

b) Spectral gamma ray log:

   Spectrum of radioactivity of uranium (U), thorium (Th), and potassium (K).

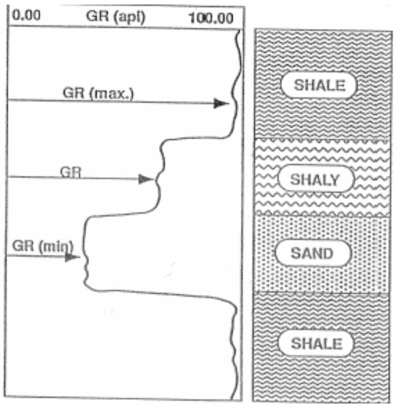
Gamma Radiation is the most energetic radiation in the electromagnetic spectrum; it has the lowest wavelength and the highest frequency in the spectrum. Gamma rays are sent out by some radioactive nuclei. Unlike alpha radiation and beta radiation, gamma rays are not made up of particles, and they have no charge. (By Science Dictionary)

Applications

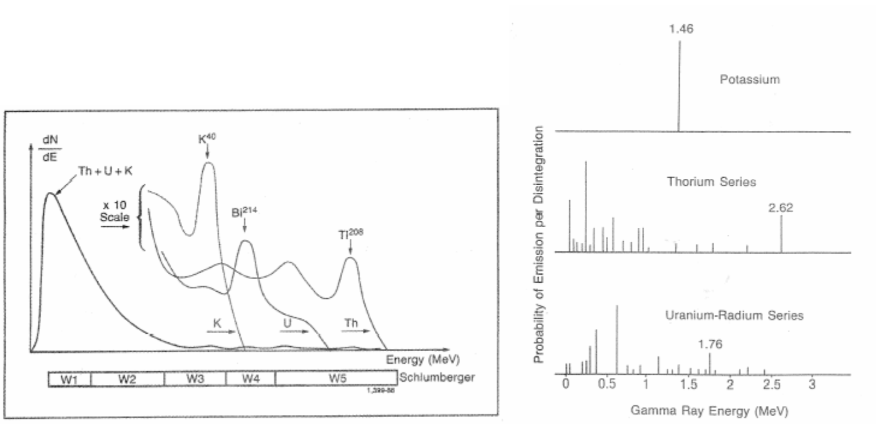
Gamma-ray measurements detect variations in the natural radioactivity originating from changes in concentrations of the trace elements as uranium (U), thorium (Th), and potassium (K). Since the concentrations of these naturally occurring radio elements vary between different rock types, natural gamma-ray logging provides an important tool for lithologic mapping and stratigraphic correlation. Therefore, Gamma-ray data is an important indicator for detecting alteration zones, and for providing information on rock types. For example, in sedimentary rocks, sandstones can be easily distinguished from shales due to the low potassium content of the sandstones compared to the shales.

http://gsc.nrcan.gc.ca/borehole/gamma_e.php

- Shale indicator
- Reservoir delineation
- Detailed well-to-well correlation
- Definition of facies and depositional environment
- Igneous rock recognition
- Recognition of other radioactive materials
- Estimated uranium and potassium potentials
- Lithologic analysis log input



Schematic of natural gamma-ray log (From Schlumberger).



Spectral Gramma-ray log (From Schlumberger).

<u>Principle of measurement</u>

The technique of measuring the spectrum, or number and energy, of gamma rays mitted as natural radioactivity by the formation. There are three sources of natural adioactivity in the Earth: 40K, 232Th and 238U, or potassium, thorium and uranium. These radioactive isotopes emit gamma rays that have characteristic energy levels. The quantity and energy of these gamma rays can be measured in a scintillation detector. A log of natural gamma ray spectroscopy is usually presented as a total gamma ray log and the weight fraction of potassium (%), thorium (ppm) and uranium (ppm). The primary standards for the weight fractions are formations with known quantities of the three isotopes. Natural gamma ray spectroscopy logs were introduced in the early 1970s, although they had been studied from the 1950s.

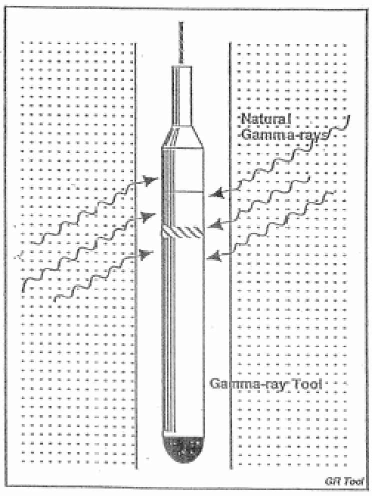


Figure: “Gamma ray” measurement (From Schlumberger)

http://www.slb.com/media/services/evaluation/petrophysics/gamma/sgrt.pdf

Link to Logging Tools

return

Resistivity

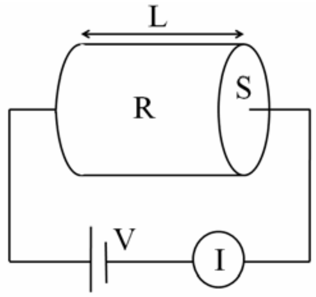
<u>Definition</u>

Resistance is a kind of measurement of how strongly a material opposes the flow of electric current. A low resistivity indicates a material that readily allows the movement of electrical charge.

Ohm's law is:

$$R = \frac{V}{I}$$

Where *R*, *V* and *I* are electrical resistance (Ohm), voltage (Volts) and current (A), respectively.



Definition of resistivity. *R, I, V, L* and *S* are electrical resistance (Ohm), current (A), voltage (Volts), length (m) and area (m^2), respectively.

The resistivity ρ (Rho) characterizes the material independent of its shape.

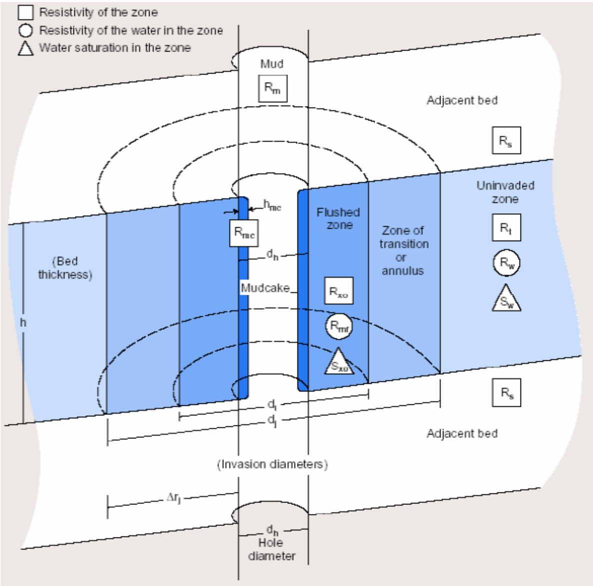
$$R = \rho \frac{L}{S}.$$

$$\rho = R\frac{S}{L} = \frac{V}{I}\frac{S}{L}.$$

The SI unit of electrical resistivity is the ohm meter. Conductivity is the reciprocal of resistivity.

Formations consist of various minerals, which have their own resistivities. In the logging term, the resistivity of formation is the mean of the resistivities. Formations sometimes include pores, and the resistivity of liquid in pores strongly affects the formation resistivities. (See Arche's Low)

The resistivity around a borehole is not homogeneous, because mudcake, mud in the borehole covering the wall, has much lower resistivity than that of the formation. The mud also infiltrates deeper into the formation from the borehole. There are several resistivity tools to measure the different depths.



Symbols used in log interpretation (From Schlumberger)

Applications

- Lithological classification
- Saturation
- Reservoir evaluation
- Mud invasion (permeability) evaluation

Principle of measurement

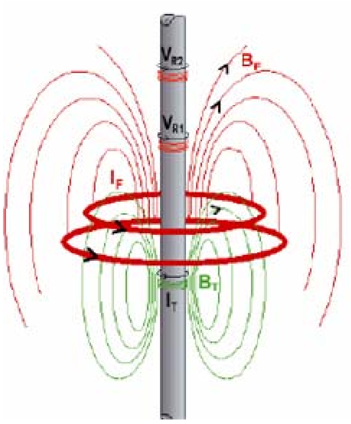
Resistivity can be measured by resistivity logs. The resistivity differs as the depth from borehole wall because of mud invasion. They can be divided into two different principles, induction log and laterolog. Currently, to measure deeper, un-invaded (formation) resistivity, 'focusing' techniques are used.

Induction Logging

This is an electrical conductivity/resistivity well log based on electromagnetic induction. A high-frequency AC of constant intensity induces current flow in a formation (Foucault current). This current (also called ground loop) produces an alternating magnetic field that induces a current in a receiving coil; the current is nearly proportional to the conductivity of the formation. Induction sondes may have several transmitting and receiving coils to produce highly focused logs. While most effective with fresh mud, an induction log can be recorded in air-filled boreholes or moderately conductive muds. A dual induction log measures different depths of penetration.

The Array Induction Imager Tool generates resistivity logs with different depths of investigation.

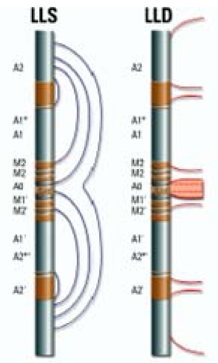
Multichannel signal processing gives robust and stable tool responses with enhanced radial and vertical resolution; there is also correction for environmental effects. These are the measurement benefits: Measure openhole formation conductivity accurately, Ensure real-time quality control, Realize significant rig-time savings, and Enhance analysis in oil-base mud systems



Schematic of induction logging (From Schlumberger).

Latero Log

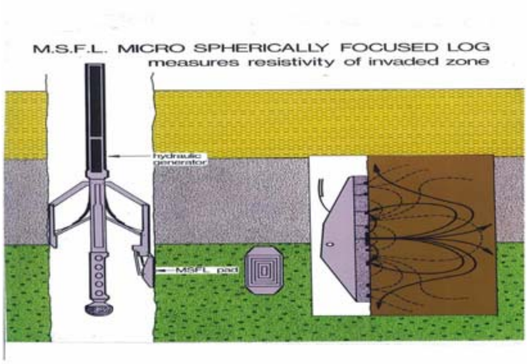
A resistivity log made with a sonde that is focused by use of guard or backing electrodes which focus the “surveying current” to flow nearly at right angles to the logging sonde. Also called a guard log or a focused log. The dual laterolog measures resistivity at different depths of penetration. The array laterolog determines resistivities by processing the data from an array of detectors rather than by focusing the current. Laterolog is a Schlumberger tradename.



Schematic of laterolog. LLS (LateroLog Shallow) focuses on transition zone and LLD (LateroLog Deep) focuses on un-invaded zone. (From Schlumberger)

Microresistivity log

A well log designed to measure the resistivity of the flushed zone, recorded with electrodes on a pad pressed against the borehole wall.



Schematic of laterolog. LLS (LateroLog Shallow) focuses on transition zone and LLD (LateroLog Deep) focuses on un-invaded zone. (From Schlumberger)

Link to Logging Tools

References

- Barber, T. D., Broussard, T., Minerbo, G. N. Sijercic, Z. and D. Murgatroyd, 1999, Interpretation of multiarray induction logs in invaded formations at high relative dip angles: The Log Analyst, 40, No 3 (May-June), 202 - 217.
- Fang, S., and T. Wang, 2000, Accurate Born simulation of induction response using an optimal background: SEG 2000 Expanded Abstracts, Calgary, 1806-1809.
- Cheryauka, A. and M. S. Zhdanov, 2001a, Electromagnetic tensor Green's functions in transverse isotropic layered media: IEEE Transactions on Geoscience and Remote Sensing, in submission.
- Cheryauka, A. and M. S. Zhdanov, 2001b, Focusing inversion of tensor induction logging data in a deviated well in layered anisotropic formations: Petrophysics, in submission.
- Zhdanov, M. S., Kennedy, D., Cheryauka, A, and E. Peksen, 2001, Principles of the tensor induction well logging in a deviated well in an anisotropic medium, 42th SPWLA Transactions, in press.
- Zhdanov, M. S., 1993, Tutorial: Regularization in inversion theory; Colorado School of Mines, Golden, Colorado, CWP-136,47pp.
- Zhdanov, M. S., Kennedy, D., and E. Peksen, 2001, Foundations of tensor induction well logging: Petrophysics, in press.

return

Compressional & Shear Velocity

Definition

Velocity of compressional (P-) and shear (S-) waves traveling through the formation. Slowness is reciprocal of velocity.

Applications

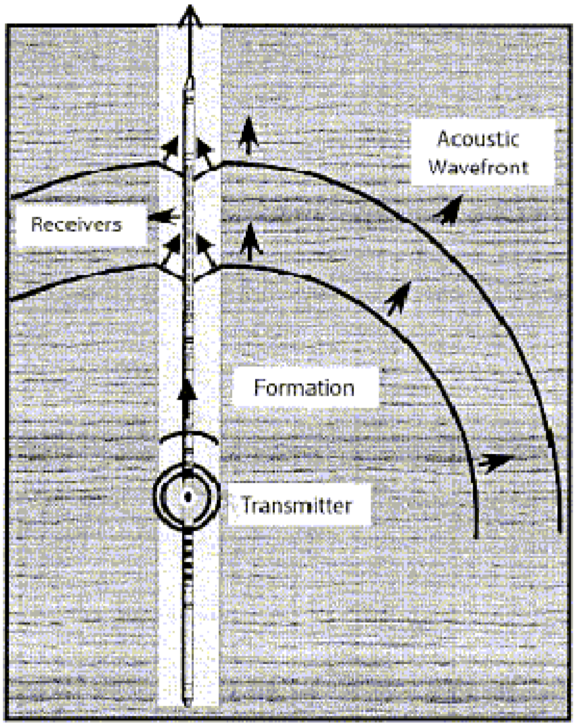
Compressional and shear waves can be expressed in terms of the elastic solids and their density. Therefore the velocities are related to the physical properties of rocks, seismic reflection survey results.

Main applications:

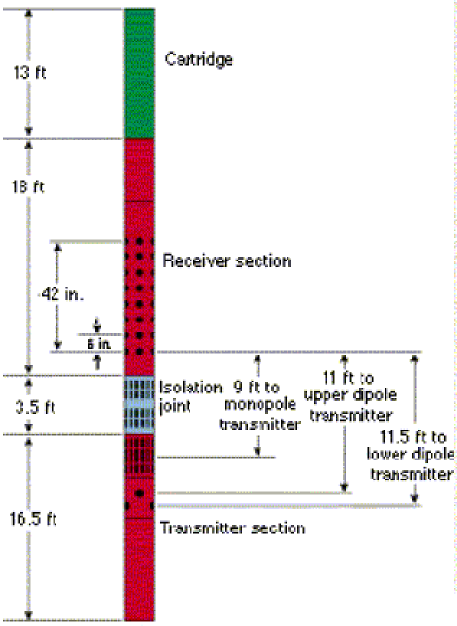
- Geophysics
  - Velocity calibration, time/depth conversion
  - Synthetic seismograms
  - Amplitude variation with offset (AVO) calibration
  - Shear seismic interpretation
- Anisotropy
- Petrophysics
  - Porosity estimation (sonic porosity)
  - Gas identification
- Stoneley wave analysis
  - Fracture evaluation
  - Permeability (mobility)
- Geomechanics
  - Pore pressure
  - Wellbore stability
  - Hydrofracture design
  - Sand strength

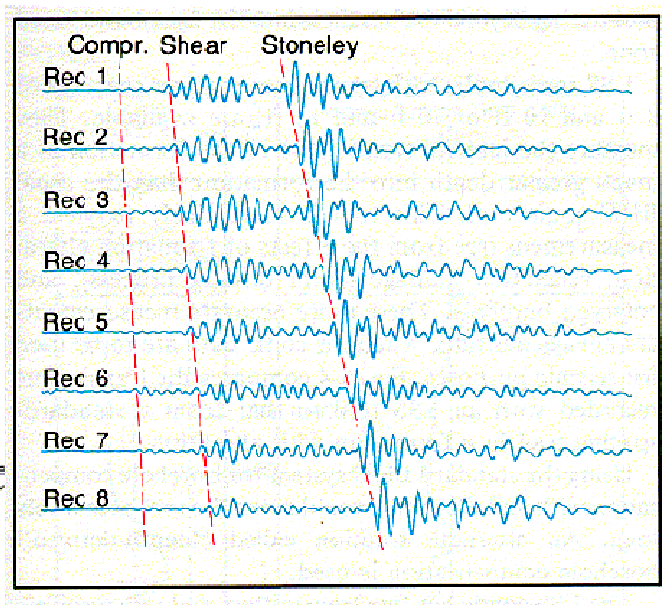
Principle of measurement and calculation

Sonic logs, also called acoustic logs, are records of the travel time of pulsed acoustic waves from one or more transmitters to one or more receives in the borehole. The acoustic waves travel through the fluid in the well and through the surrounding material at a velocity that is related to the lithology and porosity of the rocks. (After Borehole Geophysics in Environmental Investigations)



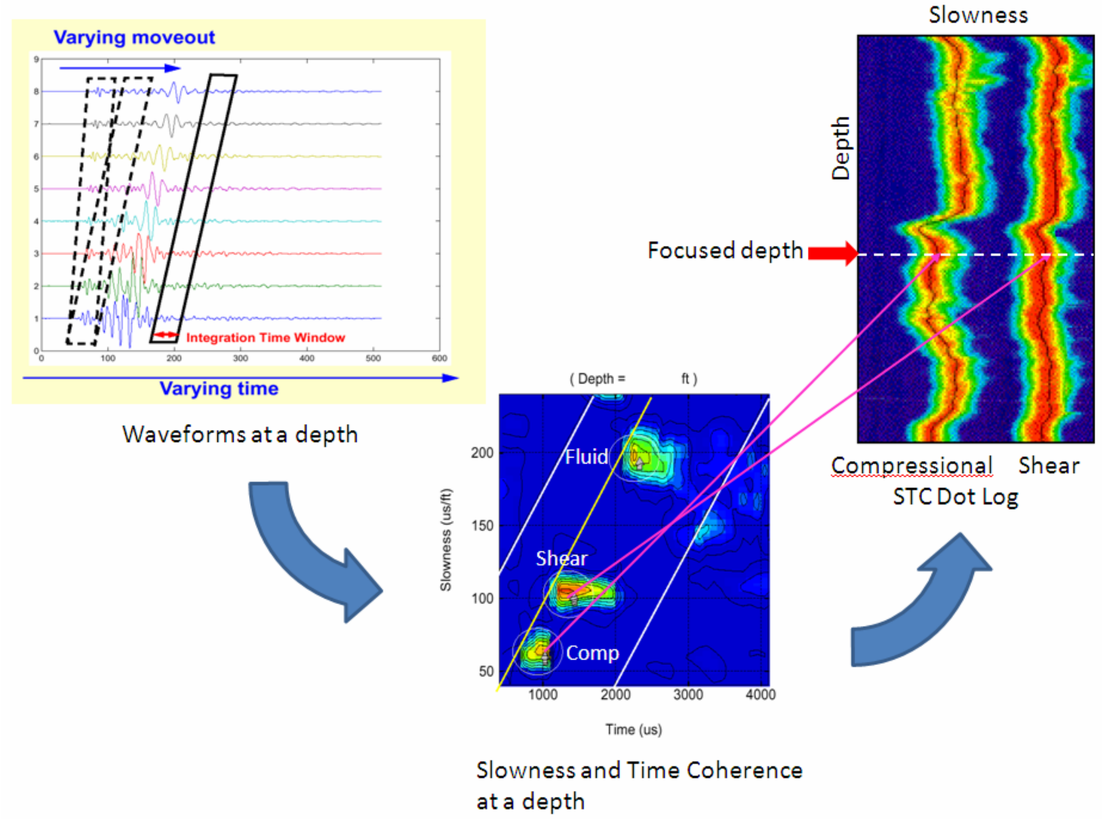
Pulsed acoustic waves from a transmitter to receivers in the borehole. The acoustic wave travels through the fluid in the well and through the surrounding formation. (From Schlumberger)





Sketch of DSI tool (Shulumberger) and waveforms at the receivers. (From Schlumberger)

Slowness Time Coherent (STC) method is shown below:



STC (Slowness and Time Coherence) method. Top left: Time windows to integrate STC on raw waveform recorded at geophones. The increase lag with time in the indicated windows show waveform slowness and "Varying time" indicates arrival time. Bottom center: The STC maps display enhanced slowness and arrival time matching. Top right: STC Dot log (stacking along time and plotting along various depths) indicates the most enhanced velocities at depth. (From Schlumberger)

Please consult the reference for further study, e.g. slow formation (formation velocity is slower than that of mud), dispersion, anisotoropy, etc.

[Link to Logging Tools]

References

- Quantitative Borehole Acoustic Methods (Handbook of Geophysical Exploration Seismic Exploration), Tang, X.-M., Cheng, A., Elseview , 2004.

return

Density

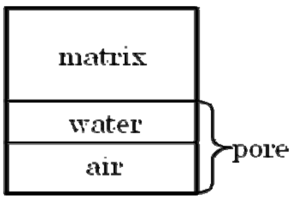
Definition

Density ρ “Rho” is defined as the quotient of the mass “m” and the volume “V” of a material.

$$\rho = \frac{m}{V}$$

(Note: Rho is sometimes used for the symbol of the electrical resistivity.)

Rocks are composed of solid matrix material and pore fluid (air, water, etc).



Density model

There are some alternate definitions of density.

- Bulk density (Rho_b): the mean density of the considered rock volume (including pores); for example: the density of sandstone
- Density of a matrix (Rho_m): the mean density of the solid matrix material; for example: the density of a carbonate matrix (i.e. without pores)
- Density of a fluid (Rho_fl): the mean density of the pore (or fracture) fluid; for example: the density of pore water

For porous rock, the volume fraction for the pore space is given by the porosity and can be written as:

Pho_b=(1-Phi)*Rho_m+Phi*Rho_fl

Where Phi is the total porosity.

(from “Physical Properties of Rocks”)

Applications

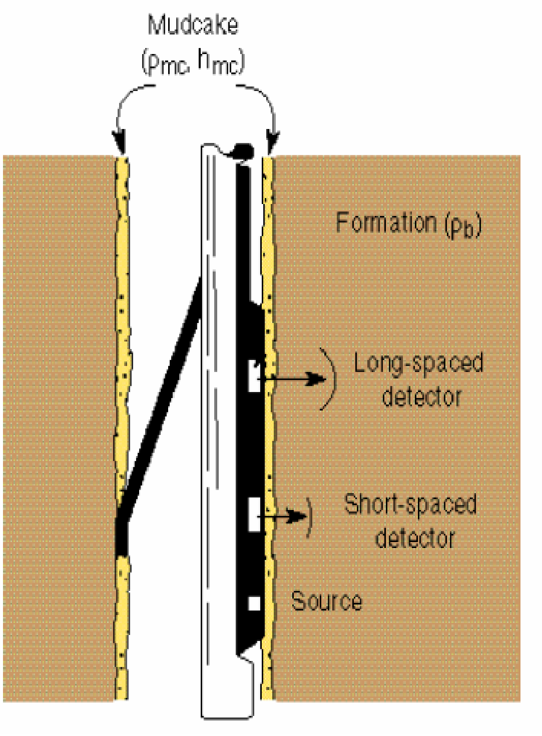
- Lithological classification
- Density-porosity (see porosity)

- Acoustic impedance (Products of velocity and density)
- Saturation estimation

Principles of measurement

Density logs, sometimes called gamma-gamma logs, consist of a gamma-ray source (e.g. cesium-137) and a scintillometer detector which records backscattered, Compton-scattered, gamma rays from the formation. The backscattered radiation depends on the density of electrons, which is roughly proportional to the bulk density.

Some gamma rays are also absorbed or scattered by the mud and mudcake between the tool and the formation. The compensated density logging tool includes a second detector. Its response is used to correct the effect of mudcake and small borehole irregularities.



Density tool has two detectors push against the formation. (From Schlumberger)

Link to Logging Tools

return

Photoelectric Effect (Litho-Density)

Definition

The emission of electrons from matter after the absorption of energy from electromagnetic radiation such as x-rays, or visible light[1].

Applications

The photoelectric effect is strongly dependent on atomic number and hence lithology.

***Table 6.1** Densities, atomic numbers, molecular weights, and photoelectric cross sections of various materials. Adapted from Bertozzi et al. (1981) and Ellis et al. (1988). ρ_t is the bulk density and ρ_e the electron density measured by a density log. P_e is the average photoelectric cross-section per electron calculated from equation (6.56), U is the average photoelectric cross section per unit volume calculated from equation (6.57) and Z_{eff} is the effective atomic number calculated from equation (6.58)*

Name	Formula	ρ_t	ρ_e $(2\rho_t Z/A)$	Z_{eff}	Molecular weight	P_e	U
Minerals							
Anhydrite	$CaSO_3$	2.960	2.957	15.6	136.14	5.05	14.95
Barite	$BaSO_4$	4.500	4.011	47	233.37	267	1070
Calcite	$CaCO_3$	2.71	2.708	15.7	100.09	5.08	13.77
Corundum	Al_2O_3	3.970	3.894	11.2	101.96	1.55	6.12
Dolomite	$CaCO_3MgCO_3$	2.870	2.864	13.7	184.42	3.14	9.00
Feldspar orthoclase	$KAlSi_3O_8$	2.55	2.52	13.39	278	2.86	7.29
Feldspar plagioclase	$NaAlSi_3O_8$	2.62	2.59	11.55	262	1.68	4.35
Feldspar plagioclase	$Ca_2Si_2O_8$	2.76	2.74	13.73	278	3.13	8.57
Gypsum	$CaSO_4 \cdot 2H_2O$	2.320	2.372	16.4	172.18	3.99	9.46
Halite	$NaCl$	2.165	2.074	14.0	58.45	4.65	9.63
Hematite	Fe_2O_3	5.240	4.987	23.8	159.70	21.48	107
Illite		2.77	2.76	14.22		3.08	8.37
Kaolinite		2.64	2.64	11.85		1.49	3.92
Magnetite	Fe_3O_4	4.870	4.708	23.6	231.55	22.08	109
Montmorillonite		2.62	2.62	12.19		1.63	4.29
Siderite	$FeCO_3$	3.96	3.83		115.86	14.69	56.22
Pyrite	FeS_2	5.000	4.834	22.0	119.98	16.97	82.2
Quartz	SiO_2	2.654	2.650	11.8	60.00	1.81	4.79
Liquids							
Water	H_2O	1.000	1.110	7.5	18.016	0.36	0.40
Salt water	120000 ppm	1.086	1.185	9.4		0.81	0.96
Oil	(Typical)	0.850	0.948	5.5		0.12	
Rocks							
Sandstone (clean, saturated)		2.308	2.33	11.6		1.75	
Average shale		2.65	2.645	14.0	3.42	6.52	
Anthracite coal		1.70	1.75	6.0		0.16	0.28
Bituminous coal		1.40	1.47	6.2		0.18	0.26

From "Well Logging for Physical Properties, 2000"

Principle of measurement and calculation

A Litho-Density Sonde measures the photoelectric effect. Measurement of induced gamma radiation (gamma-gamma) in two energy windows allows discrimination of the radiation resulting from Compton scattering (above 0.6 MeV) from that of photoelectric absorption (below 0.6 MeV).

Link to Logging Tools

Reference

- Serway, Raymond A. (1990). Physics for Scientists & Engineers. Saunders, p. 1150. ISBN 0030302587.

◀ return

Porosity

Definition

Porosity Φ (Phi) is defined as the ratio of the volume of void or pore space V_p to the total or bulk volume V of the rock.

$$\Phi = \frac{V_p}{V} = 1 - \frac{V_m}{V}$$

Where V_m is the volume of the solid matrix substance. Porosity is a dimensionless quantity and expressed either as a decimal fraction or as a percentage (from “The Rock Physics Handbook”).

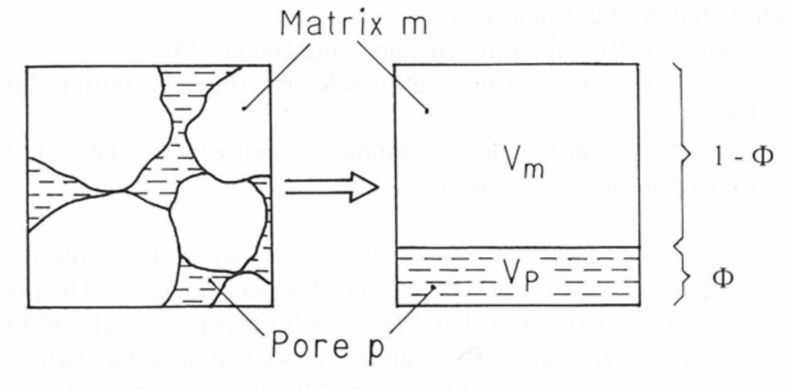


Figure 2.1. Definition of porosity

(From “Physical Properties of Rocks”, 2004)

Porosity is the result of various geological, physical and chemical process, and is generated during the genesis of the rock as “primary porosity” (Clastic sedimentation organogenesis) and/or during the geological history of the rock as “secondary porosity” (tectonic processes, chemical processes, dissolution, etc.).

a. Total porosity Φ_{total} is related to all void spaces (pores, channels, fissures, vugs) between the solid components. It is defined by equation following where V_p is the volume of all empty spaces. The total porosity can have two constituents – primary and second porosity:

$$\Phi = \Phi_{total} = \Phi_{primary} + \Phi_{secondary}$$

b. Interconnected porosity $\Phi_{connected}$ is related only to those spaces which are connected. Pores are considered to be connected when electrical current and fluids can flow between them.

c. Effective porosity Φ_{eff} is the porosity that is available for free fluids; it excludes all non-connected porosity including the space occupied by the clay-bound water.

(Courtesy of “The rock physics handbook”)

Applications

Porosity is one basic rock property. Porosity and pore shape are affected by generation of the rock. Rock mechanics, permeability, density, sonic velocity, resistivity are sensitive to porosity.

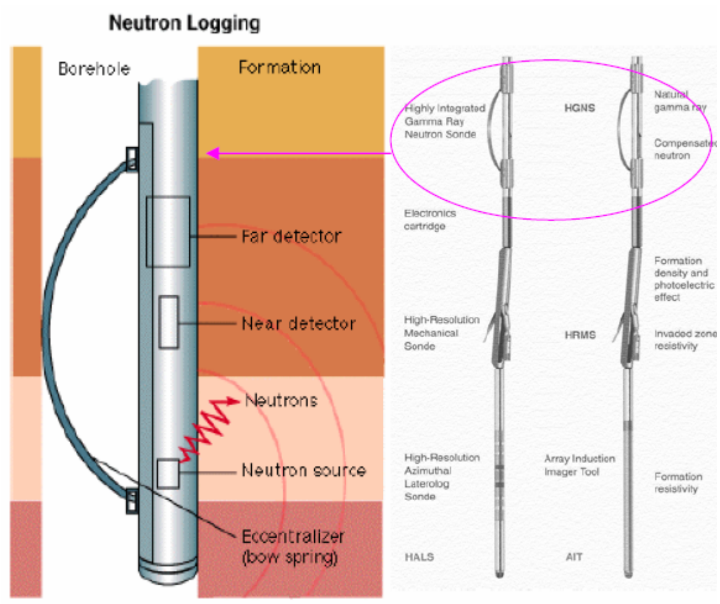
Principles of measurement and calculation

There is no direct measurement of porosity. The methods used today are i) lab measurement, ii) measurement of other properties under some assumptions (Neutron porosity log, nuclear resonance log), and iii) calculation from other logs (density porosities, sonic porosities). There are also many relationships e.g. Archie’s low, etc. Here, four well-known methods using well logs are described below. They are all sensitive to borehole conditions.

- Neutron porosity

  Neutron tools have a radioactive source that emits neutrons into the formation, and collected by two scintillations counters held against the side of the hole. Neutrons traveling through the formation only slow down significantly when they collide with atoms of a similar mass, that is hydrogen atoms. Once they have been slowed by repeated collisions, they are absorbed into the nuclei of the heavier atoms present and cause them to emit gamma rays, some of which are recorded by the counters. The more rapidly the neutrons slow, the nearer to the counters the gamma rays are produced, resulting in a stronger signal. As hydrogen is an important component of water, which fills pore spaces, the response increases with greater filling of pore spaces.

  Neutron porosity results are affected by shale formations.



Left: Schematic of neutron log measurement. Right: Neutron sonde in combination logging tools. (From Schlumberger)

- Density porosity

This is calculated from density. The equation is:

$$\Phi = \frac{\rho_m - \rho_b}{\rho_m - \rho_f}$$

Where ρ_b (rho b), ρ_m (rho m) and ρ_f (rho f) are bulk density, matrix density and fluid density, respectively. The density tool measures neutrons scattered by electrons in matrix and fluid in the formation (See “density”).

Note that the porosity calculated from the density log is a total porosity value; that is water bound to clays or held in clay pores is included.

- Sonic porosity

This is calculated from sonic velocity. Wyllie et al. (1956, 1958, 1963) approximated relations between porosity and velocity in sedimentary rocks when (1) they have relatively uniform mineralogy, (2) they are fluid-saturated, and (3) they are at high effective pressure. The Wyllie’s Time Average Equation, is :

$$\frac{1}{V_{\log}} = \frac{\Phi}{V_f} + \frac{1-\Phi}{V_{ma}}$$

Where V_{log}, V_f, and V_{ma} are the P-wave velocities of sonic log, of the matrix making up the formation, and of the pore fluid, respectively.

There are many other velocity-porosity models. Please see “Physical Properties of

Rocks" for more detail.

- Porosity from nuclear-magnetic resonance (NMR) log

  The NMR tool measures the spin (gyromagnetic ratio) of hydrogen nuclei and thus the properties of pore fluids. The transverse relaxation time T2 is lithology independent and is a function of the hydrogen nuclei content in the pore fluid. T2 is proportional to volume/surface ratio which in turn is proportional to pore size. Interpretation of the pore size distribution and the logarithmic mean T2 are used to calculate parameters such as permeability and free-fluid porosity.

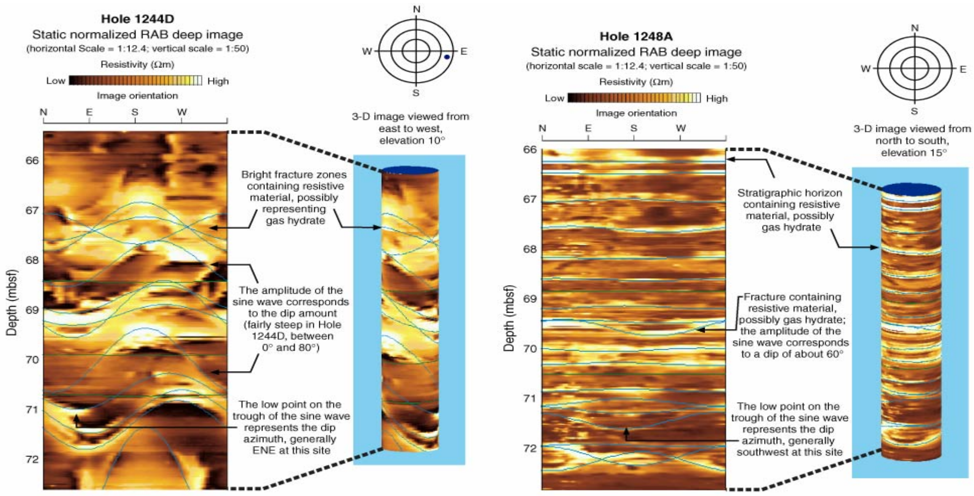
Link to Logging Tools

return

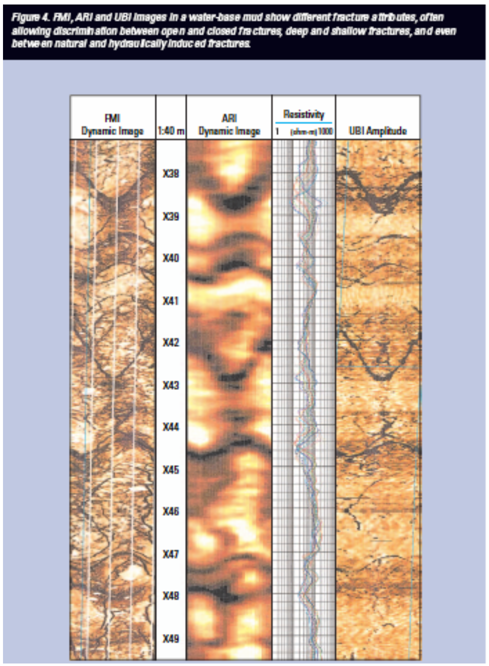
Borehole Imaging

Definition

High resolution graphical image of borehole wall. The walls are scanned with optical, acoustic, and resistivity instruments.



Resistivity image by RAB (Shulumberger).



Unwrapped images by FMI (high resolution resistivity), ARI (resistivity) and UBI (ultrasonic) tools. (From Schlumberger)

Applications

- Structural Applications
  - Dip determination
  - Fracture Identification
  - Fault Identification

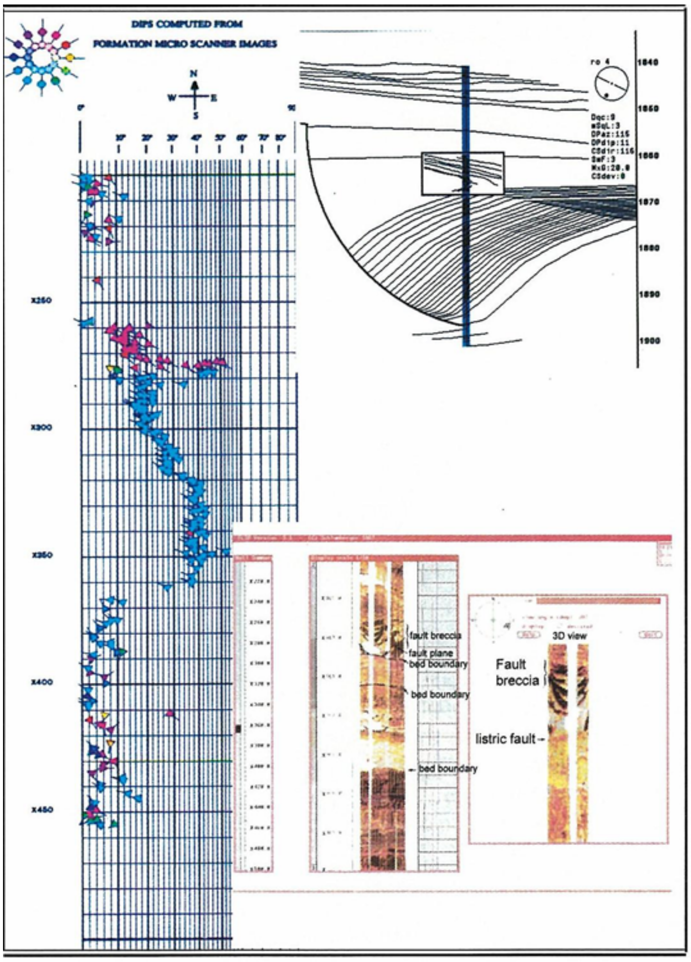


Figure 8-132 - Arrow-plot from FMS dips, section across the rollover zone and FMS image of the fault plane. The small deformation feature on the top of the rollover is an assumed slumped zone (from Etchecopar & Bonnetain, 1992).

(From " Well logging and Geology", 2003)

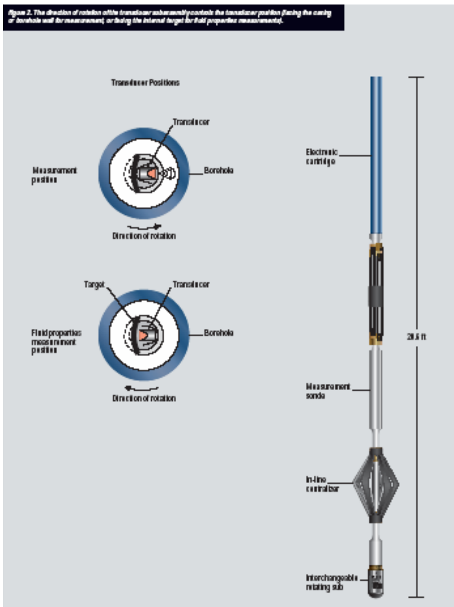
- Stratigraphic Applications
  - Net pay count
  - Deposit identification
  - Transport direction
- Borehole condition
- Stress (rock mechanics) analysis around borehole

- Borehole breakout
- Drilling parameter

Principles of measurement and calculation

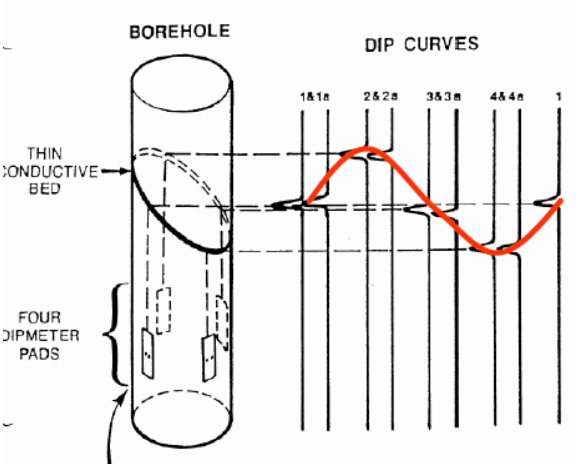
For resistivity images, electrodes on arms pushed lightly against borehole wall are continuously brushed against the borehole wall. For ultra-sonic images, the ultra-sonic transmitter and receiver are scanned around the wall of boreholes.

High resolution resistivity imaging tool (FMI of Schlumberger)

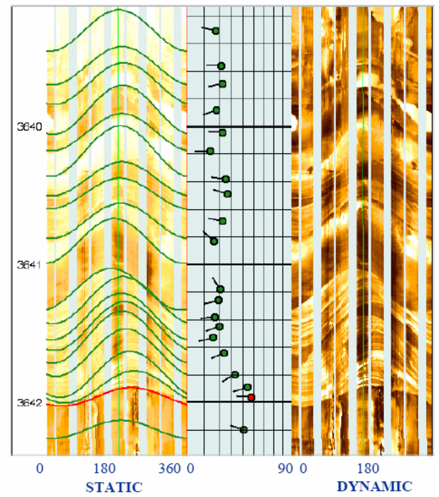


UBI tool (from Schlumberger brochure)

Identifying and interpreting dips, by automatically scanning selected electrodes or manually editing an unwrapped image so that dip curve fits with images.



Scanning selected electrodes to identify and interpret dips. (From Schlumberger)



Manually editing an unwrapped image to identify and interpret dip. (From Schlumberger)

[Link to Logging Tools]

[return]

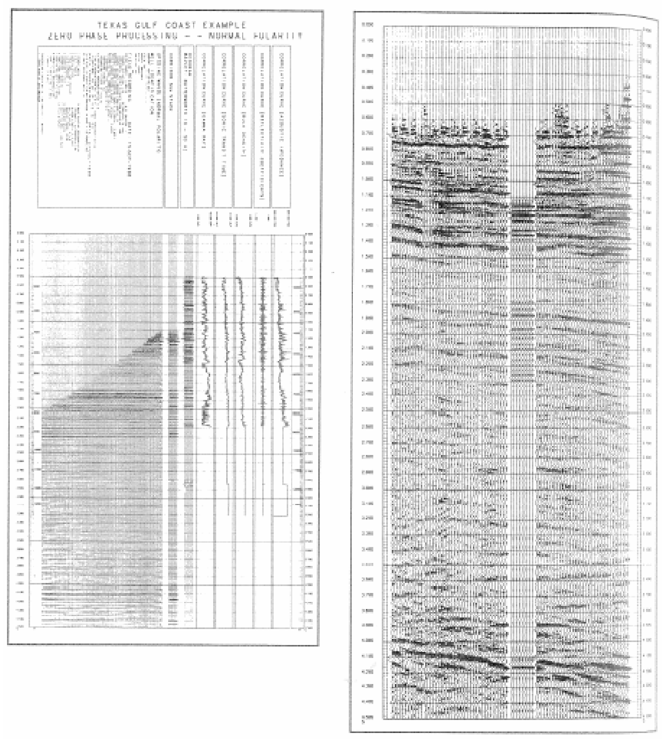
Borehole seismic

Definition

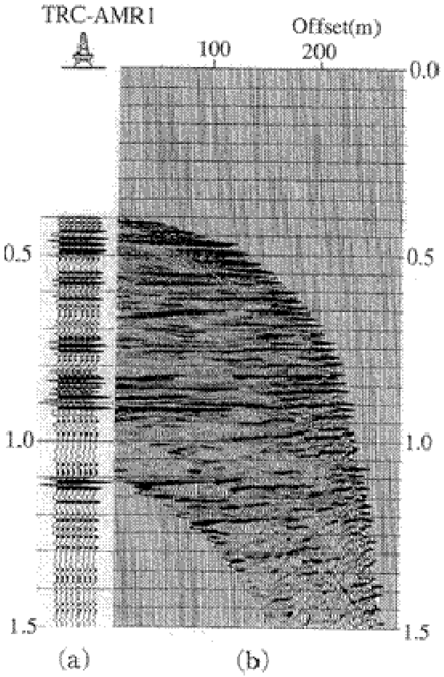
Measurement (sometimes including processing and analysis) of seismic (elastic) waves using borehole.

Applications

- Depth-Velocity table (Checkshots)
- Imaging around borehole
- Corridor stack
- Seismic Tie (corridor stack on seismic section)
- Wavelet analysis



Left: VSP corridor stack, logging curves. Right: VSP corridor stack on seismic reflection section. (Figure from Shulumberger)

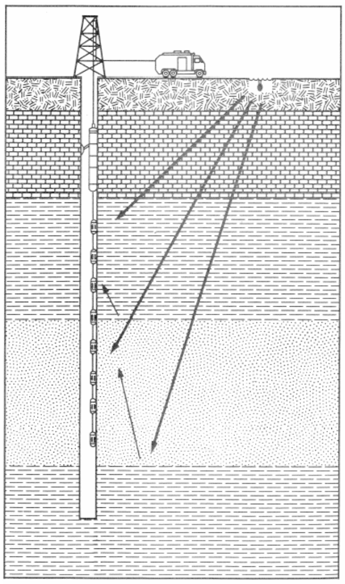


Corridor stack and Offset-VSP image. (Shimizu, et al, 1989)

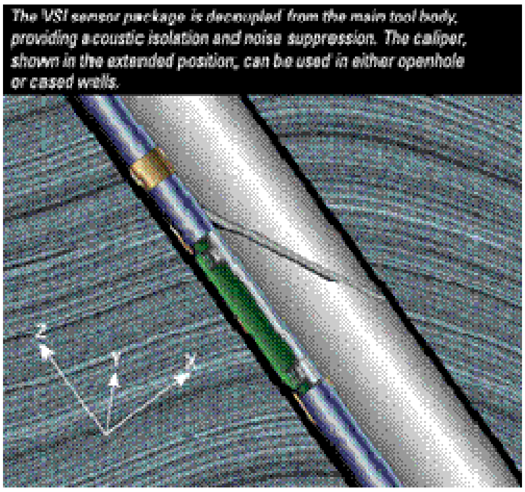
Principle of measurement and calculation

- Checkshots: Direct measurement of traveltime between the surface and a given depth. Usually sources on the surface are recorded by geophones in a well to determine time-depth relationships at the well location. (SEG Encyclopedic Dictionary)
- VSP (Vertical Seismic Profiling)

  Measurements of the response of a geophone at various depths in a borehole to source on the surface. Sometimes the surface sources are moved about the area as well as the geophone depth being changed, e.g. Offset-VSP, Walkaway-VSP, Walk abve-VSP. In the reversed VSP the source is in the borehole and Geophones are on the surface. Outputs are corridor stacks or seismic image near the well. The advantages of VSP over surface seismic reflection are (1) depth is correct because of geophone depth, (2) smaller noise contaminant (3) higher resolution. To compare them the corridor stack and images are usually inserted or overlapped on seismic sections.



Borehole seismic survey. Shot at surface and Geophones in a well. (From Schlumberger)



Three component Geophone. (VSI from Schlumberger).

[Link to Logging Tools]

[◀ return]

Borehole diameter

Definition

Diameter of borehole.

Applications

Changes in borehole diameter are related to both drilling technique and lithology, because borehole diameter is affected by borehole condition, mechanical strength of formation, permeability, etc. Caliper logs are essential to guide the interpretation of other logs, because most types of logs are affected by changes in well diameter.

Principle of measurement and calculation

Caliper logs provide a continuous record of borehole diameter.

- Mechanical Caliper

  A caliper is lightly extended against the sides of the hole, and this distance is converted by an electromechanical device into an electronic signal suitable for recording. Due to subsurface stresses, holes are seldom circular in section, so the tool usually has more than one caliper. Sometimes the caliper arm of includes other measuring tools, e.g. Microresistivity, FMI, Density tool.

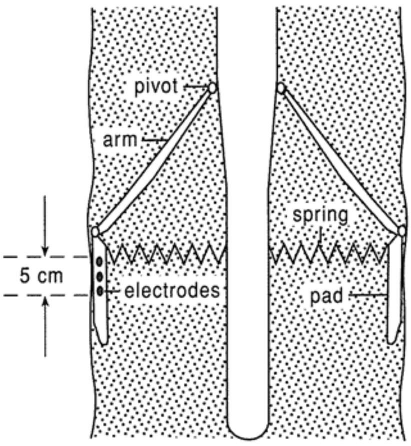
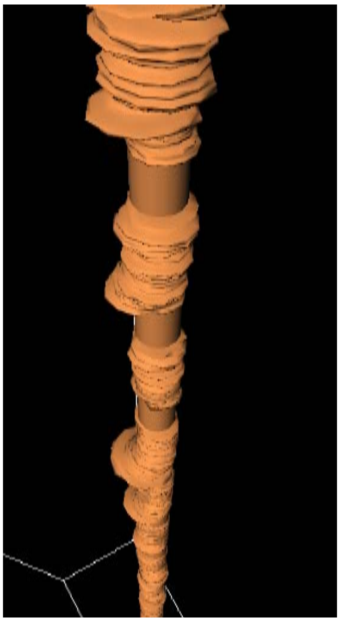


Figure 18.4 The calliper log with microlog electrodes.

(From “Looking into the earth”, 2003)

- Ultrasonic Caliper

  An Ultrasonic transducer scans around the borehole walls, and the reflected travel time is converted to the distance between the sonde and the wall.



3D image of the ultrasonic caliper. (From Schlumberger)

Link to Logging Tools

◀ return

References

- Borehole Geophysics in Environmental Investigations, Kets, W.S., CRC Press, Inc., 1997.
- Log Data Acquisition and Quality Control, Theys, P., Editions Technip, 1999.
- Looking into the Earth: An Introduction to Geological Geophysics, Mussett, A. E. Aftab Khan, M., Cambridge University Press, 2000.
- Physical Properties of Rocks: Fundamentals and Principles of Petrophysics, Handbook of Geophysical Exploration Seismic Exploration, Schon, J.H., Elisevier, 2004.
- Quantitative Borehole Acoustic Methods (Handbook of Geophysical Exploration Seismic Exploration), Tang, X.-M., Cheng, A., Elseview , 2004.
- The rock physics handbook, Mavko, G., Mukerji, T. and Dvorkin, J., Cambridge University Press, 1998.
- Schlumberger Curve Mnemonic Dictionary http://www.slb.com/modules/mnemonics/index.aspx?
- Schlumberger Oilfield Glossary http://www.glossary.oilfield.slb.com/
- Schlumberger's web and brochures http://www.oilfield.slb.com/
- Seismic Surveying and Well Logging: Oil and Gas Exploration Techniques (Oil and Gas Exploration Techniques), Boyer, S., Mari, J.-L., Editions Technip, 1997.
- VSP Interpretive Processing: Theory and Practice (Open File Publications, No. 3), Hinds., R.C., Anderson, N.L, Kuzmiski, R.D. , Society of Exploration Geophysicists,1996.
- Well Logging and Formation Evaluation, Darling, T., Elsevier, 2005.
- Well Logging and Geology, Serra, O. & L., Serralog, 2003.
- Well Logging for Physical Properties: A Handbook for Geophysicists, Geologists and Engineers, Hearst, J.R., Nelson, P.H., Paillet, F.L., John Wiley & Sons Inc , 2000.

return

Logging Tool Catalog (Schlumberger Tool)

(Note that we do not list up all tools. Please confirm latest information to Schlumberger http://www.slb.com)

Main Wireline Logging Tools

Gamma Ray

Gamma Ray Tools

HGNS (part of Platform Express), HTGC, SGT, STGC, QTGC, CGRS, geoVISION (LWD), arcVISION (LWD)

Spectral Gamma Ray Tools

NGS, HNGS

Resistivity

Induction log

AIT-B, AIT-C, AIT-H, AIT-M, SAIT, HIT, QAIT, arcVISION (LWD)

Laterolog Tools

ARI, HRLA, HALS (part of Platform Express)

Microresistivity Tools

MicroSFL Tool, MCFL (part of Platform Express), PCD with Microlog

Others

geoVISION(LWD)

SP

AIT-B, AIT-C, AIT-H, AIT-M, SAIT, HIT, QAIT

Acoustic

Monopole Acoustic Tool

DSLT, HSLT with BHC, HSLT with DDBHC, SSLT, QSLT, sonicVISION(LWD)

Dipole Shear Sonic Imager

Dipole Shear Sonic Imager (DSI)

Sonic imaging

Sonic Scanner

Porosity

Neutron Porosity

CNT, SCNT, HGNS (part of Platform Express), QCNT, APS, HAPS, adnVISION(LWD), CDN (LWD)

Density-Porosity

See Density

Sonic-Porosity

See Acoustic

NMR-Porosity

See NMR

Density (Bulk Density, Porosity Litho-density (Pe))

TLD(part of Platform Express), LDS(Part of IPLT), HLDS(Part of Xtreme), SLDT(part of SlimAccess), QLDT(part of SlimXtreme) , adnVISION(LWD), CDN(LWD)

NMR

CMR-Plus, MR Scanner, proVISION

Dip meter and Imaging

Resistivity

FMI, FMS, geoVISION (LWD)

Ultrasonic

UBI

Inclinometer

GPIT, geoVISION825(LWD),

Seismic

ASI, CIS, VSI, SeismicVISION

Caliper

Mechanical Caliper (using arm of other tool)

HRMS(Part of Platform Express), TLD(part of Platform Express), LDS(Part of IPLT), HLDS(Part of Xtreme), FMI

Ultrasonic Caliper

adnVISION(LWD)

Others

CDN(LWD), arcVISION (LWD), geoVISION (LWD)

Combination Tools

- Platform Express

  (HGNS(GR, Porosity) + HRMS(Density, Litho-Density, Caliper, Micro resistivity) + HALS(Laterolog) or AIT(Induction resistivity))

- SlimAccess

  STGC(GR) + SCNT(Porosity) + SLDT(Density, Litho-Density, Density, Caliper) + SSLT (Sonic) + SAIT(Resistivity)

- SlimXtreme
  QAIT(Resistivity) + QSLT(Sonic) + QLDT(Density, Litho-Density, Density, Caliper) + QCNT(Porosity) + QTGC(GR)
- Xtreme
  HPHT (HTGC(GR) + HNGS(Spectral GR) + HAPS(Porosity) + HLDS(Density) + HSLT(Sonic) + HIT(Resistivity))
- IPLT(Integrated Porosity Lithology tool)
  (HNGS(Spectral GR) + APS(Porosity) + LDS(Density))

LWD Tools

- adnVISION (Porosity, Density, Litho-Density)
- CDN (Porosity, Density, Litho-Density , Ultrasonic Caliper)
- arcVISION (Resistivity, GR)
- geoVISION (Resistivity, Resistivity imaging, GR)
- sonicVISION (Sonic)
- proVISION (NMR)
- SeismicVISION (Seismic)
- EcoScope (GR, resistivity, ultrasonic, density, Litho-Density, porosity)

return