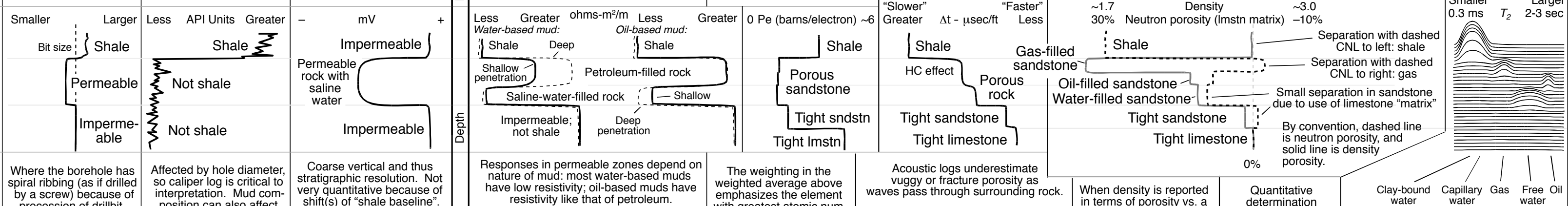
Characteristics of wireline well logs used in the petroleum industry

Railsback's *Petroleum Geoscience and Subsurface Geology*

	Caliper	Gamma ray	Spontaneous Potential (SP)		Resistivity	Photoelectric	Acoustic ("Sonic")	Density ("Gamma-Gamma")	Neutron Porosity	Nuclear Magnetic Resonance (NMR)
	Passive measurements				*Active measurements*					
	Log responses independent of formation fluids		*Log responses affected by formation fluids*							
			Electrical logs ("E-logs")			Porosity logs				
Name of log	**Caliper**	**Gamma ray**	**Spontaneous Potential (SP)**	Depth	**Resistivity**	**Photoelectric**	**Acoustic ("Sonic")**	**Density ("Gamma-Gamma")**	**Neutron Porosity**	**Nuclear Magnetic Resonance (NMR)**
Action of logging tool	Presses pads against sides of borehole	Scintillation counter detects gamma rays	Measures voltage between electrode pressed to borehole wall and electrode at land surface.		One electrode in borehole introduces current; current is measured at second (or second and third) electrode(s). (and see "Induction tool . .", below)	Source emits gamma rays; detector detects gamma rays resulting from ejection of electrons from formation atoms.	Transmitter emits pulse of sound and receiver at some spacing detects pulse.	Source emits gamma rays and detector detects scattered returning gamma rays	Source emits neutrons that collide with larger atomic nuclei with little energy loss but lose energy in collisions with H atoms, which are of roughly same mass as neutrons themselves.	Tool generates magnetic field that polarizes H atoms of fluids; detector measures decreasing resonance after field is released.
Characteristic measured	Width of borehole	Natural emission of γ rays by K (and U and Th) in the <12 inches of rock adjacent the borehole.	Permeability (because of charge in mobile fluids of permeable rocks - e.g. Cl^- moves out of saline formation water, giving negative SP in permeable rocks).	Depth	Electrical resistivity of entirety of formation (mineral and fluid, including adsorbed water and solutes)	Weighted average of atomic numbers of atoms in formation (mineral and fluids)	Interval transit time (slowness) of compressional waves (or shear waves)	Density of electrons and thus density of formation (mineral and fluids)	Concentration of hydrogen	Relaxation times (T_2) of H atoms in fluids
Applications	Where greater than width of drill bit, an indicator of caving (typically by shale) or dissolution/washout by salt. Where less than width of drill bit, an indicator of mud cake (an accumulation of solids from drilling fluid) in a permeable zone where mud invaded formation. (Swelling clays can also give hole diameter less than size of bit) Useful in determining hole volume for cementing casing.	Distinction between shale (radioactive with illitic K and adsorbed U and Th) vs. "clean" (clay-free and thus non-radioactive) lithologies. Also allows recognition of granitic arkoses (because of Kspar). Source rx commonly give large GR response because of redox segregation of U from seawater during dep'n. Because of high resolution vertically, useful in making well-to-well correlations. Spectral gamma ray logs (NGS or SGR) distinguish between K, Th, and U. Because GR can be run in cased holes, it is useful in workovers of old wells.	Recognition of permeable strata, including potentially exploitable reservoirs. Recognition of grain-size trends (and thus depositional environments) in sandstones. Can be used to calculate resistivity of formation water. Response is like that of GR in porous sands and sandstones and in shales, but not in limestones or cemented sandstones (where cement rather than clay controls permeability).	Depth	Determination of nature of and/or proportions of formation fluids (saline water has small R; petroleum has large R). Greater spacing of electrodes allows greater penetration into formation. Thus shorter spacing (typically solid curve) evaluates invaded zone; longer spacing or laterolog (typically dashed curve) better approximate uninvaded (natural/true) zone. Induction tool (typically dashed curve) uses coils instead of electrodes and sets up field to determine conductivity and thus resistivity; gives deep penetration to approximate R_t. Microlog and proximity log use short-spacing tools to characterize invaded zone and R_{xo}. Modern tools allow measurement of horizontal and vertical resistivity.	Determination of lithology of reservoir rocks (because calcite, dolomite, and quartz give have different values of Pe) In monomineralic rocks, determination of porosity (because values of Pe for limestones, dolostones, and sandstones differ even with varying effect of fluids in pores.	Determination of porosity, because waves pass faster through minerals than through liquids or gases. Determination of travel times through stratigraphic units (useful for conversion of seismic time data to distances) Lithologic identification (sensitivity to lithology makes it the least accurate porosity log but useful to identify lithology).	Determination of porosity, because fluids in pores decrease bulk density of formation. Because mudcake interferes with response, logs are commonly "compensated", as in FDC and CNL logs. Logs are commonly presented in porosity units, with assumption of a limestone (or sandstone) "matrix". The low density of gas yields excessively great apparent porosity in gas-bearing zones.	Determination of porosity, because (except in shale) hydrogen is in H_2O or hydrocarbons in pores. Shale appears porous because of OH^- in (and H_2O in or adsorbed on) clay minerals. The lesser abundance of H in gas than oil or H_2O gives less apparent porosity in gas-filled zones, opposite the trend in density porosity.	Determination of size of pores and of mobility of fluids (in smaller pores, greater proportion of fluid returns quickly to original spin because of proximity to pore walls). All logs to left present, for any one depth, one number, which is an average or bulk measurement. The NMR log instead presents, for any one depth, a *distribution* of values of T_2. Positions of peaks for larger pores can be related to fluid type. The NMR log is the most modern of the logs shown and the log that is most independent of lithology.

Extremely generalized patterns in very common and straight-forward rocks



	Caliper	Gamma ray	Spontaneous Potential (SP)		Resistivity	Photoelectric	Acoustic ("Sonic")	Density ("Gamma-Gamma")	Neutron Porosity	Nuclear Magnetic Resonance (NMR)
Limitations or other concerns	Where the borehole has spiral ribbing (as if drilled by a screw) because of precession of drillbit, rotation of tool leads to excessive estimate of borehole diameter.	Affected by hole diameter, so caliper log is critical to interpretation. Mud composition can also affect response. Kaolinitic shales give low GR response. Micaceous sandstones give high GR response, as do some evaporites. U is mobile in diagenesis and can be enriched in dolostones.	Coarse vertical and thus stratigraphic resolution. Not very quantitative because of shift(s) of "shale baseline". Magnitude of response depends on contrast between more saline formation water and less saline mud; thus response is reversed where formation water is freshwater. Not usable in non-conductive drilling muds, such as diesel-based mud.	Depth	Responses in permeable zones depend on nature of mud: most water-based muds have low resistivity; oil-based muds have resistivity like that of petroleum. Distance of penetration of mud filtrate (of invasion) varies with permeability and with mud type. Strata that are thin relative to spacing of electrodes can give counter-intuitive responses.	The weighting in the weighted average above emphasizes the element with greatest atomic number. For example, calcite and quartz have the same average atomic number (10), but Ca (20) in calcite compared to Si (14) in quartz results in much greater Pe in calcite than in quartz.	Acoustic logs underestimate vuggy or fracture porosity as waves pass through surrounding rock. Hydrocarbons increase travel time and thus cause overestimation of porosity unless a correction is made. Because the shape of the hole influences passage of sound, Borehole-Compensated (BHC) logs are useful. In shales, Δt is greater near the borehole than farther away.	When density is reported in terms of porosity vs. a limestone matrix, tight sandstone shows some porosity and tight dolostone reports negative porosity, because of their densities. Against a sandstone matrix, both tight limestone and dolostone have negative porosity.	Quantitative determination of porosity from the CNL log involves a correction for lithology that is unique for each logging company and specific tool.	Some notes about presentation: • The order of this table from left to right mimics the order of presentation on most logs. • For most logs, the response to shale is a shift toward the central depth column of the presentation. • For logs to the left of the depth column, the response to more permeable rocks is a shift to the left.
Abbreviations	CAL	GR, NGS, SGR	SP		SN, RXO, LLS, SFL, SFLU, LL3, LL7, ILM, ILD, DIL, LLD, DLL	PE, Pe, PEF	LSS, BHC, DSI	FDC, DPHI, LDT	GNT, SNP, CNL, NPHI	NMR, MRIL, CMR
First use		1938	1931		1927 (the first wireline log in a petroleum well) (first commercial induction logging 1956)	1970s	1957	1957 (first compensated in 1962)	1938 (first commercial log in 1945; first compensated in 1966)	First developed in 1958; only useful later

Sources: Bjørlykke (2010), Assaad (2008), *Schlumberger Oilfield Glossary* (2000s), *Crain's Petrophysical Handbook* (2000s), Glover's *Petrophysique* (2000s), Asquith and Krygowski (2004), Baker-Hughes *Atlas of Log Responses* (2002), Selley (1998), Schlumberger *Log Interpretation Principles/Applications* (1987), and Wikipedia.

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