5. WIRELINE LOGGING

5.1 What is a Wireline Log

A *log* is a continuous recording of a geophysical parameter along a borehole.

Wireline logging is a conventional form of logging that employs a measurement tool suspended on a cable or wire that suspends the tool and carries the data back to the surface. These logs are taken between drilling episodes and at the end of drilling. Recent developments also allow some measurements to be made during drilling. The tools required to make these measurements are attached to the drill string behind the bit, and do not use a wire relying instead on low band-width radio communication of data through the conductive drilling mud. Such data is called *MWD* (*measurement while drilling*) for simple drilling data, and *LWD* (*logging while drilling*) for measurements analogous to conventional wireline measurements. MWD and LWD will not be covered by this course, although the logs that are produced in this way have very similar characteristics, even though they have been obtained in a completely different way.

Figure 5.1 shows a typical wireline log. In this case it is a log that represents the natural gamma radioactivity of a formation. Note that depth is arranged vertically in feet or metres, and the header contains the name of the log curve and the range. This example shows a single *track* of data. Note also that no data symbols are shown on the curve. Symbols are retained to represent discrete core data by convention, while continuous measurements, such as logs, are represented by smooth curves. Figure 5.1 shows only 50 m of borehole, but real logs are often much longer (thousands of metres), and contain multiple curves on a single track such as this, and multiple tracks.

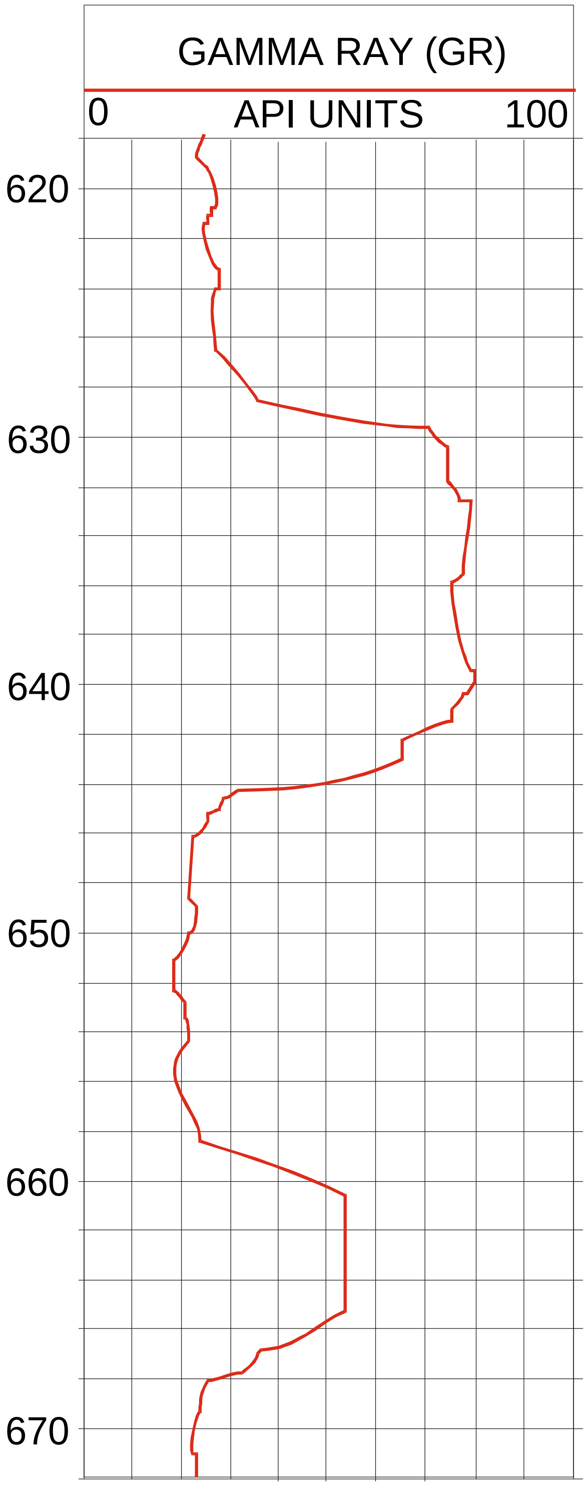

Fig. 5.1 Example of a Gamma Ray Log

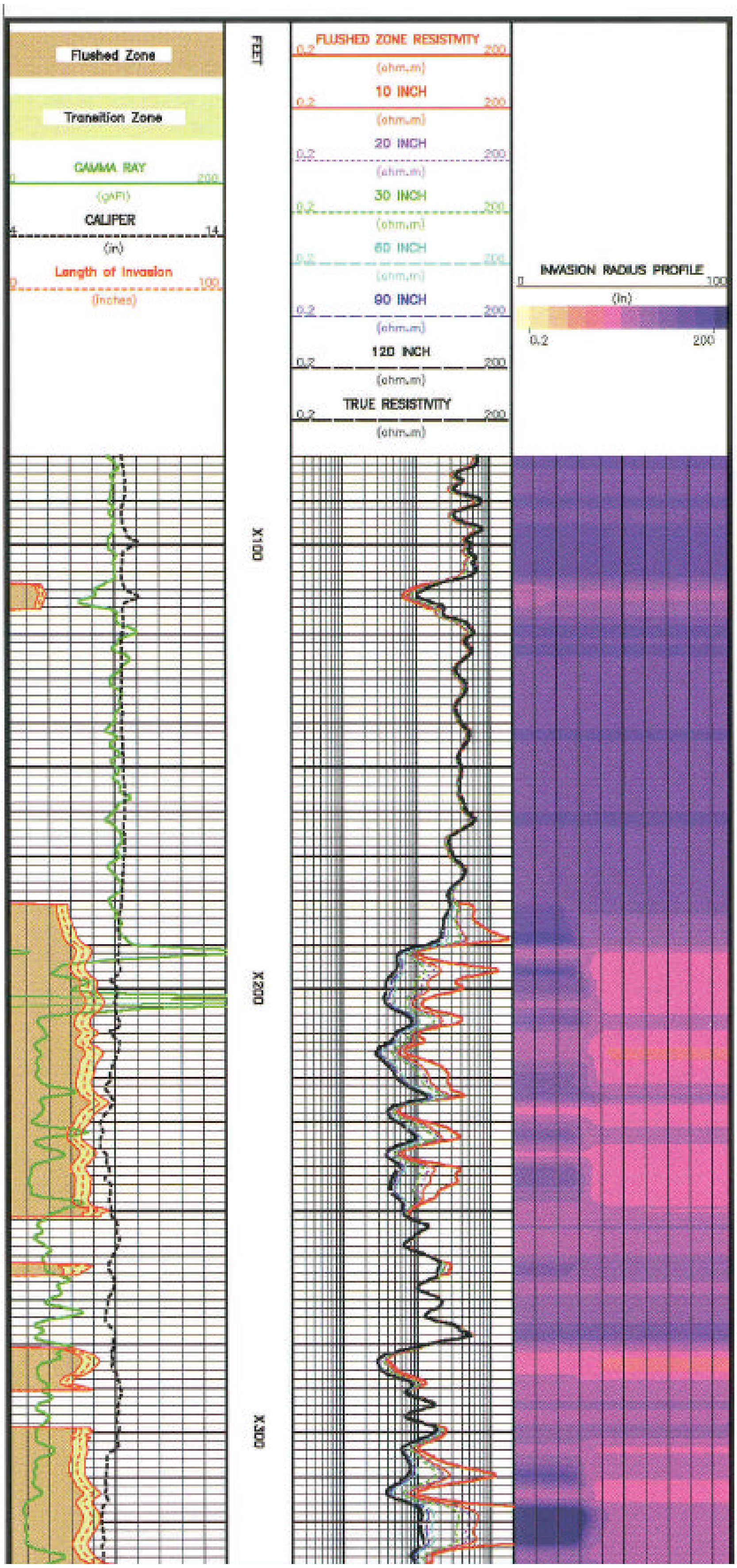

Figure 5.2 A typical log set

An example of a more usual log is given as Fig. 5.2. This log contains 3 tracks and many different sets of log data. There is a very large range of basic logs that can be run in a well, and an even greater number of derived logs, i.e., data that can be plotted in log form that is calculated from the basic logs.

Examples of the basic physical parameters that can be measured down-hole with logs include (a) the size of the borehole, (b) the orientation of the borehole, (c) temperature, (d) pressure, (e) the natural radioactivity of the rocks, (f) the acoustic properties of the rocks, (g) the attenuation offered by the rocks to radioactivity generated from the tool, (h) the electrical properties of the rocks, (i) the NMR characteristics of the rocks, and so on.

Examples of derived logs include (a) porosity derived from the sonic or density log, (b) water saturation calculated from the porosity and the electrical logs.

5.2 Running a Wireline Log

Oil companies require log data to assess the reservoirs that they are interested in. As with drilling, the oil companies contract out the job of making the wireline measurements to specialist companies, and increasingly these companies also complete much of the processing of the measured data. The two largest wireline companies are Schlumberger and Halliburton, although there is a range of smaller specialist companies too.

Wireline logs are made when the drill-bit is removed from the borehole. This can be either between drilling episodes, before casing is laid, or at the end of drilling. Wireline logging can be done when the newly drilled rock formations form the wall of the borehole (*open-hole logs*) or after a concrete lining or casing has been inserted to stabilize the well bore (*cased-hole logs*). However, as may be guessed, the quality of data from the rock is best from open-hole logs, and some measurements cannot be done at all through casing. Cased-hole logging requires special tools to optimize measurement through the casing, and is a specialist subject not covered by this course.

A wireline logging set-up consists of the wireline tool, the wire itself, a winching gear, and a vehicle containing data analysis and recording equipment. The vehicle is usually a large lorry (Fig. 5.3) for land-based measurements, or a transportable cabin for use on rigs (Fig. 5.4). All data recording and processing is now done digitally using powerful computers and array processors (Fig. 5.5).

The required tool is attached to the wire and lowered into a cleaned and stable borehole from which the drill string and bit has been extracted. When it reaches the bottom of the interval to be logged, it is slowly withdrawn at a predetermined speed. Log measurements are made continually during this process. The wire is made from a bundle of cables, the outermost ones of which are steel and carry the load, and the innermost of which are insulated copper and carry the electrical signals. The wireline is winched up the borehole by a motorized drum at speeds between 0.3 to 1.8 km/hr (1000 to 6000 ft/hr). It should be noted that all logs except one are run during their withdrawal from the borehole. The exception is the temperature log, which must be run on the way into the borehole because its presence in the hole disturbs the temperature reading.

The tension in the wire and the speed of the wire is constantly monitored using magnetic markers attached to the wire so that intermittently stuck tools can be detected. This information is used together with knowledge about the natural elasticity of the wire that causes it to stretch under its own weight to calculate the instantaneous depth throughout the logging phase.

Figure 5.3 Land logging vehicle

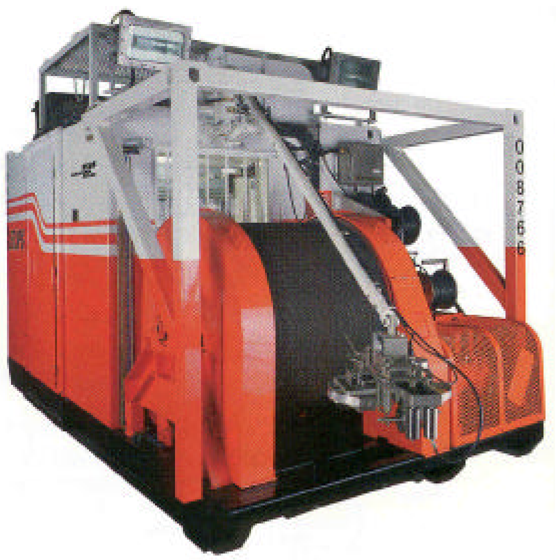

Figure 5.4 Offshore logging cabin

Figure 5.5 Inside the logging unit

Data is transmitted to the surface through the wire and recorded digitally. Modern tools sample the formation at intervals from 2.5 mm for the high definition imaging tools to about 15 cm for the simpler tools, so for a combination tool with several different logs, there may be as many as 100,000 individual measurements per metre over a log run of up to say 2000 m. Depending on the logging speed, data transmission rates may be as high as 200 kbits per second. This data is subjected immediately to a rudimentary analysis by powerful processors and displayed so that the quality of the measurements can be checked. The data is also recorded onto digital (DAT) tape and transmitted to the controlling office of the logging company by satellite for in-depth analysis.

A typical drilling and logging history for a well might be as shown in Table 5.1. Note that the logs are run in each section before casing takes place. When each log is run, the operator ensures that some measurements are included opposite the previously cased section above the log run as a test that the log tools are working correctly and to provide a local depth fixed point to help tie the depths for each tool together. Whenever a borehole is logged in sections the operator also ensures that there are overlap sections so that the logs can be tied together accurately, and repeat sections to check log quality and consistency.

Table 5.1 A typical drilling and logging history.

Procedure	**Drill Bit Size (inches)**	**Casing Diameter (inches)**	**Depth (m sub sea surface)**	**Tools**
Drill	25	-	300-400	
Case		20	300-400	
Drill	17.5	-	400-700	
Log	-	-	700-400	ISF-Sonic-GR/1
Case	-	13.375	300-690	
Drill	12.25	-	700-1400	
Log	-	-	1400-680	ISF-Sonic-GR/2
Log	-	-	1400-680	FDC-CNL/1
Log	-	-	1400-680	HDT/1
Case	-	9.625	690-1390	
Drill	8.5	-	1400-2100	
Log	-	-	2100-1380	ISF-Sonic-GR/3
Log	-	-	2100-1380	FDC-CNL/2
Log	-	-	2100-1380	HDT/2
Log	-	-	2100-1380	DLL/1

Note in Table 5.1 that the logs are recorded during the withdrawal of the tools from the well, that some tools were run several times at different depth intervals and that these runs have been coded consecutively, that there is an overlap of data, and that the lower log runs include part of the previous casing at their top. Note also that the most tools are run in the area that is expected to be of greatest interest (i.e., the reservoir). For tool codes see wireline operators manuals.

Efforts are made at all times to ensure that the logs are of the highest quality. Methods of ensuring that logging quality is high include (a) making repeat sections of log measurements over short sections that contain both low and high measured values, (b) making overlap measurements of the previous (shallower) run of the same tool, (c) making measurements opposite the casing at the top of the run, (d) local calibration of all logging tools both before and after the survey, and (e) ensuring that a 'master' calibration of the tools has been carried out recently at the wireline service company's workshop (particularly for sensitive and important 'porosity' tools).

5.3 The Presentation of Log Data

Conventionally, logs are presented on a standard grid defined by the American Petroleum Institute (API). This grid consists of 3 tracks and a depth column as shown in Fig. 5.6.

Track 1 on the leftmost side is always linear and is often reserved for drill bit size, caliper and gamma ray tool information.

Moving to the right, there is a depth column that may be in feet or metres. A range of depth scales are used depending upon the resolution required for a particular analysis. In Europe and The East scales of 1:1000 and 1:500 are often used for large scale correlations between wells, while 1:200 is optimum for petrophysical evaluation, 1:40 for correlation with core information, and 1:20 for detailed dipmeter analysis. In the USA they use 1:1200. 1:600 and 1:240. However, the digital recording of logs now ensures that they can be displayed and printed at any required scale.

Moving once more to the right, there are tracks 2 and 3, which may have either a linear or a logarithmic scale and may be combined into one. These tracks traditionally were reserved for density, porosity and electrical tool data.

All tracks can take multiple log curves, and the code for the curve, its style (i.e., green dashed line), and the scale units are given in a stack at the top of the log. The curves are arranged in such a way that they can wraparound (i.e., if the curve slips of the top of the scale it appears again at the bottom, and the reader must make the required scale adjustments to read the wrapped-around data).

The fundamental basis of the API standard is still used, but the advent of computer analysis has made the presentation of logs rather easier. The modern log data is not first presented as hardcopy, but will come to you on a tape or CD-ROM. The arrangement of this data in the form of logs on a display or a printout is now likely to have as many tracks as 8 (its up to you!). Each will be linear or logarithmic, or even use a core image or a coloured array to represent the data. However the depth track is usually retained between tracks 1 and 2.

Electrical data is almost always presented on a logarithmic track because it can vary over many orders of magnitude.

There are numerous little markers and 'grace notes' present on logs that require to be learnt. The majority of these will be described with their particular log type. However, one general mark is that which records the time on the log. On Schlumberger logs, the right-hand margin of track 1 will often be seen to be punctuated by gaps. The distance between these gaps represents one minute and indirectly allows you to tell the logging speed. If these gaps are of uniform spacing, the logging speed is constant. If there is a non-uniformity, then there is a problem such as a temporarily stuck tool that could affect the data quality. Other companies use ticks or spikes along the margin as a time marker.

The main section of logs will have a comprehensive header sheet that contains a plethora of information about how the log was run. Some of this information also appears at the end of the logs, together with repeat or overlap sections and information on tool calibration.

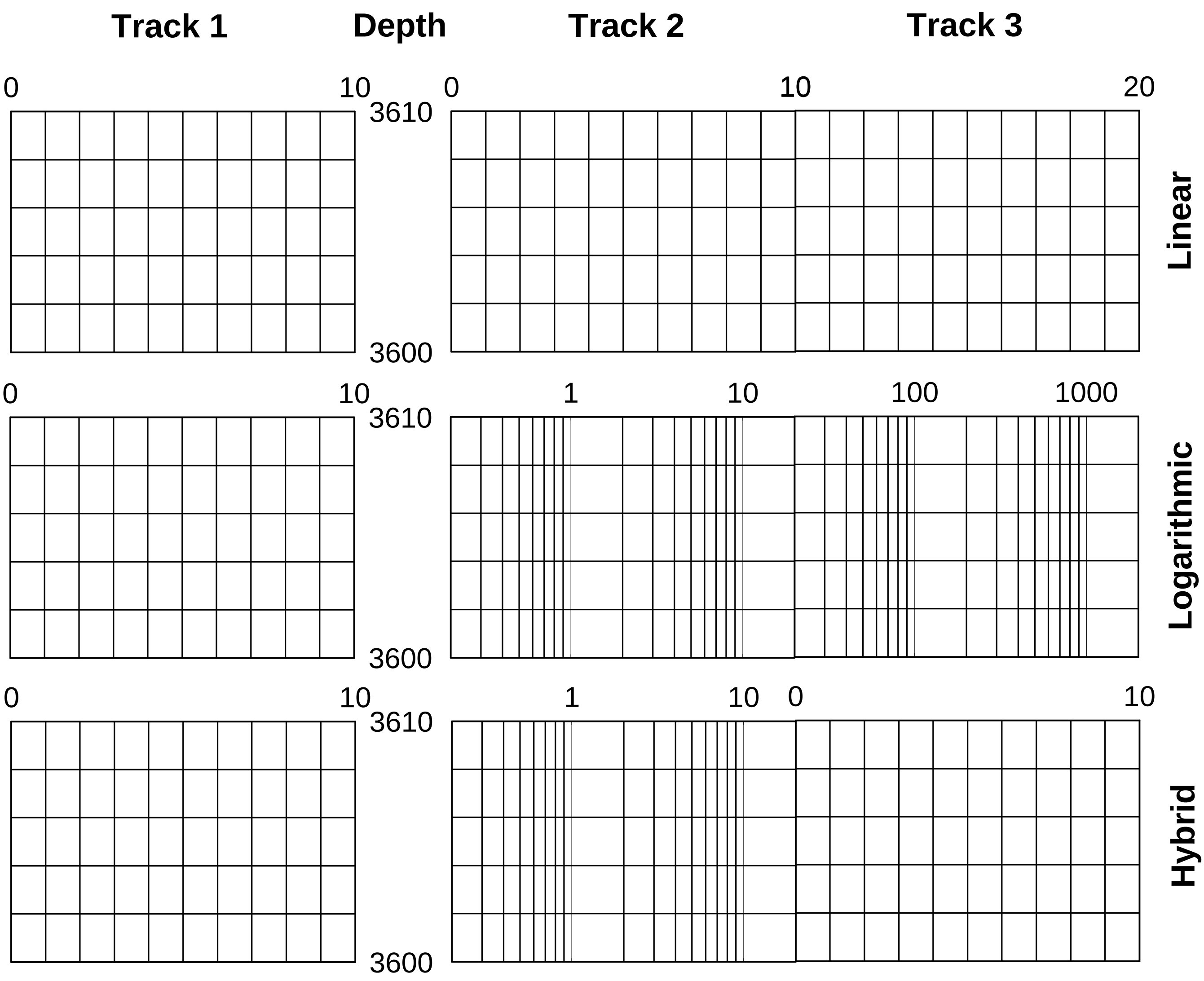

Figure 5.6 Log presentation grids. Note that the API format defines particular dimensions for each track, and an overall width of 8.25 inches.

5.4 Tools

There are a plethora of logging tools now available in the oil industry. There can be split into the following types:

- **Standard open-hole tools (diameter 3 to 4 inches)**
  These range from the simplest caliper tool to the sophisticated imaging and NMR tools and have vertical resolutions from 2.5 mm to over 30 cm.
- **Slim hole tools (diameter 1.6875 to 2 inches)**
  These are slimmer versions of the standard tools, and are used where standard tools are too thick. Applications of these tools are in specialist logging through drill-pipe or coiled tubing, and in small scale holes used in the water industry.

- **Cement-logging tools**
  These are special versions of those tools that work through cement casing that are optimized to work under these conditions.
- **Production tools**
  These are specialist tools for running during the production of hydrocarbons for measuring pressure and flow rate, and are always of the slim-hole variety to facilitate their insertion into a producing well.
- **LWD tools**
  These tools are designed to connect into the drill string and communicate data to the surface through the drilling mud.

A summary of some of the main standard open-hole tools is given in Table 5.2.

Drilling rigs are expensive and can often amount to almost 10% of the total drilling costs. The time required to run wireline logs effectively delays the drilling operation leading to greater expense. To minimize this expense tools are bolted together for lowering down the borehole. All wireline tools are designed to be combined in this way and there are many possible combinations, some which are as long as 30 m. Each tool in the combination has its own measurement-sensitive region, which measures a given formation at a specific depth at different offset times. The data has to be depth shifted to account for this. This is done in the data acquisition vehicle with information about the instantaneous speed and dimensions of the tool combination. Even using combinations, it is common for as many as three log runs to be made in the same section of the borehole with different combinations of tools. If this is the case, one tool is included in all combinations to act as a reference to which the others might be compared for depth matching purposes. This tool is commonly the gamma ray tool (GR).

Figure 5.7 shows an example standard open-hole logging tool. Note that it is a neutron porosity tool, which is combined with a gamma ray tool. The loops at each end cover screw threads to enable it to be combined with other tools of similar design.

On land, where the general geology is well known and drilling is cheaper, only a few logs may be run. This is because expense can be spared as information concerning the subsurface is not hard to come by. However, and perhaps counter-intuitively, offshore a full set of logs is often carried out even when there are no hydrocarbon shows. This is because drilling is so expensive that relatively fewer wells will be drilled, and hence the maximum data must be squeezed out of each well regardless almost of the cost. If there are no hydrocarbon shows, the well data will still be very useful for correlation with other wells that do show hydrocarbons, will help to constrain the extent of neighbouring reservoirs, as well as adding to the information about the general geological structure of the area.

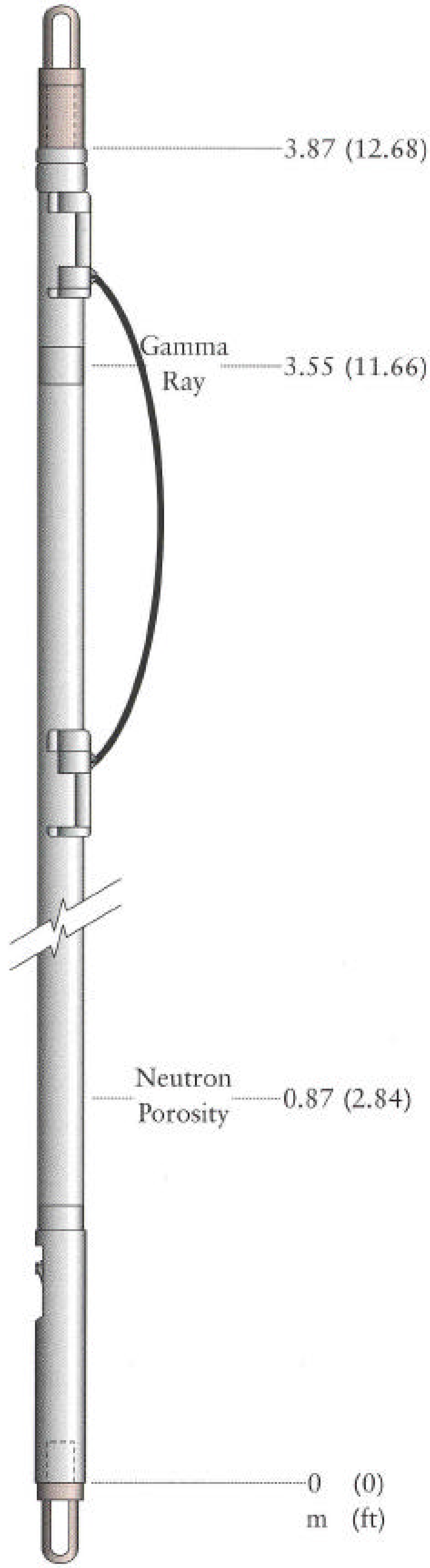

Figure 5.7 A Compensated Neutron Sonde (CNS)

Length	3.87 m (12.68 ft)
Diameter	95 mm (3.74 in)
Weight in air	109 kg (240 lb)
Range	-3 to 100 lpu
f Resolution	Better than 0.05 pu at 20 pu
Vert. Resolution	750 mm (30 in)
Investigation Depth	260 mm (10.2 in)

Table 5.2 Common open-hole tools and their uses

Tool	Physical Measurement	Use	Comments
Logging conditions			
Temperature (BHT)	Temperature	Borehole temperature for resistivity calculations.	Corrected with Horner plot
Pressure (PRESS)	Fluid pressure	Fluid pressure for formation volume factor calculations.	Incorporated in RFT
Caliper (CAL)	Borehole diameter	Data quality, in situ stress tensor, lithology and permeability indicator	Available in 2, 4, or multi-arm versions.
Lithology			
Gamma Ray (GR)	Natural radioactivity of the formation.	Shale indicator and depth matching	Can read through casing.
Spontaneous Potential (SP)	Sand/shale interface potential.	Permeable beds Resistivity of formation water	Does not work in conductive muds, or offshore.
Porosity			
Sonic (BHC, LSS)	Velocity of an elastic wave in the formation.	Effective (connected) porosity	Compaction, gas and vugs, calibration of seismic data.
Density (FDC, LDT)	Bulk density of the formation.	Total porosity	Used to calculate synthetic seismograms.
Neutron (SNP, CNL)	Hydrogen concentration in the formation.	Total porosity (shale increases measured porosity, gas reduces measured porosity)	Can read through casing.
Resistivity			
Simple electric log (SN, LN, Lat)	Resistivity of flushed, shallow and deep zones respectively.	Used in water saturation calculations.	Now obsolete, not focussed, can't be used in oil based muds, prone to invasion.
Induction Logs (IES, ISF, DIL, DISF, ILm, ILd)	Conductivity of the formation.	Conductivity and resistivity in oil based muds, and hence calculation of water saturation.	Focussed devices. Use in oil based and fresh water muds. Range of depths of investigation. (Vertical resolution 5-10 ft.)
Laterologs (LL3, LL7, DLL, LLs, LLd)	Resistivity of the formation.	Resistivity in water based muds, and hence calculation of water saturation.	Focussed devices. Use in salt water based muds. Range of depths of investigation. (Vertical resolution 2-4 ft.)
Microlog (ML)	Resistivity of mudcake and flushed zone.	Indicator of permeability. Detector of thin beds.	(vertical resolution about 1 ft.)
Micro-laterolog (MLL)	Resistivity of flushed zone.	Measures R_{XO}	Not good with thick mudcakes.
Proximity Log (PL)	Resistivity of flushed zone.	Measures R_{XO}	Not good if invasion is small.
Micro-spherically focussed log (MSFL)	Resistivity of flushed zone.	Measures R_{XO}	Part of DLL-R_{XO} tool.
Imaging Logs There is a range of imaging logs based upon sonic, visual, electrical and NMR measurements that are beyond the scope of this course.			