7. FLUID TESTING AND PRESSURE LOGS

7.1 Introduction

Formation fluid testing involves taking fluid samples from the formation and measuring their pressures. It gives information on the types and properties of fluids in the formation, indicates the presence of hydrocarbons, and provides information on the pressures of the fluids within the formation.

There are three generic types of test, the second of which will be examined in detail as it is a wireline method. The three measurement types are as follows, and are described in the order that they are performed, in their complexity, and therefore their cost.

Drillstem testing. This is carried out during the drilling of the well. A portion of perforated drill pipe and one or two devices for sealing the interval of the well of interest off (*packers*) are lowered down the well to the required depth. The packer is then expanded to make a seal between the borehole wall and the drill pipe. If the bottom of the well is being tested, only one packer is needed. If an interval further up the well is being tested, two packers are needed, one above the interval and one below. A valve is then opened to reduce the pressure within the drill stem and the packed-off interval to surface pressures. Fluids will flow from the formation into the packed-off interval and hence to the surface through the perforations in the drill pipe and up the pipe. These fluids may be sampled and analyzed. Note that this procedure is the equivalent of a temporary completion of the well. (Fig. 7.1).

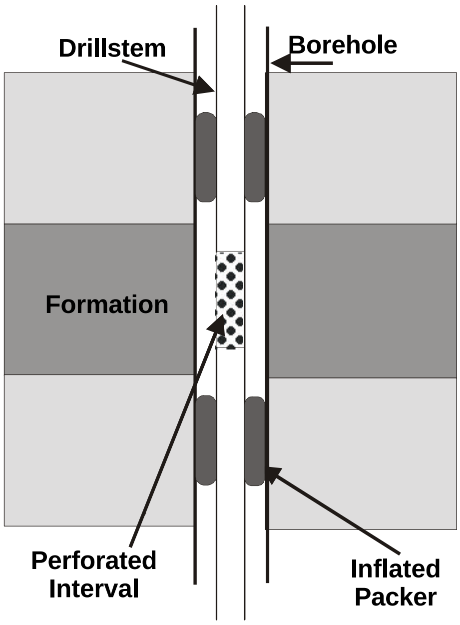

Figure 7.1 The drillstem test.

Wireline formation testing (*RFT*). This operation is carried out in an open hole during wireline logging operations. The wireline tool is lowered down the uncased hole to the point of interest. It is then jacked and sealed against the borehole wall. Samples of fluids and measurements of the fluid pressures are then taken. Note that this form of logging is not continuous, and is carried out at a few previously defined depths in the reservoir zone of the well only (Fig. 7.2).

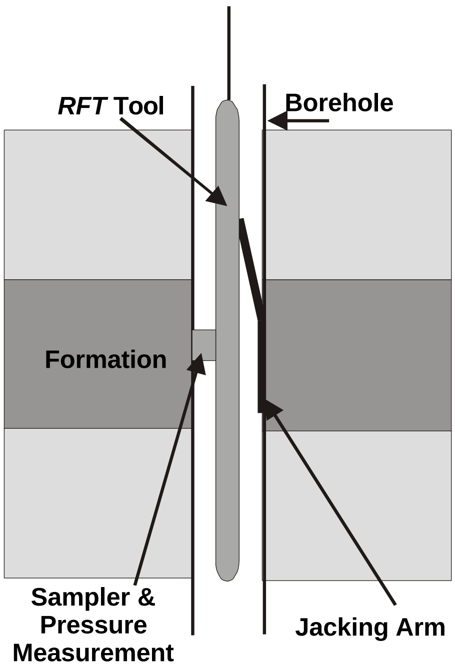

Figure 7.2 The RFT test.

Production Testing. This is carried out in a cased hole and completed hole with a packer that has been set in place and a production pipe. The casing is perforated using a wireline perforation gun. As the pressure inside the production pipe is held at a value that is lower than the formation pressure, the formation will produce fluids, which by this stage in the well completion, should be hydrocarbons. If the test produces sufficient hydrocarbons, the production may be allowed to continue as a fully completed well (Fig. 7.3).

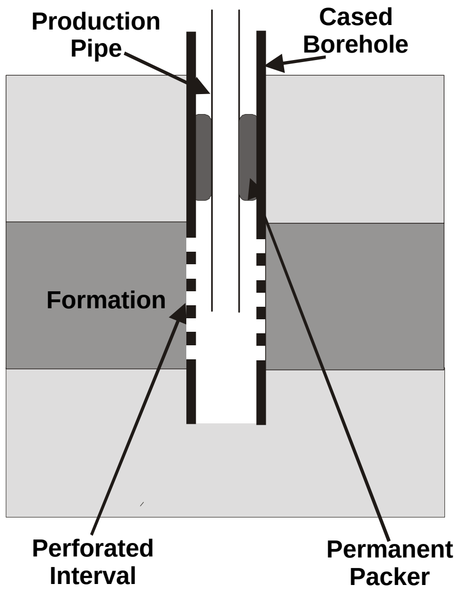

Figure 7.3 The production test.

7.2 Wireline Formation Testing

There are a range of wireline formation testing tools now available, such as the *Repeat Formation Tester* (*RFT*), *Repeat Formation Sampler* (*RFS*), shown in Fig. 7.4, and the *Formation Multi-Tester* (*FMT*). These tools are capable of taking multiple samples of fluids and pressure measurements in the borehole without withdrawal. These testers can mix the fluids sampled from several *settings* in one chamber, or take two separate samples and keep them separate. Fluids can be maintained at high pressure, which is important in some volatile oils as a sudden pressure drop causes a change in the composition of the oil. Time is saved by the tools incorporating a pre-test facility, where the seal between the probe and the rock formation is tested and an adequate flow of fluids for sampling is checked. If either of these is not the case, the tool can be reset at another depth for another try. This facility also enables the first part of the sample (mud filtrate) to be stored separately from the latter part of the fluid sample (reservoir fluids), or enable the first part to be ignored, so that the sample reliably samples only the reservoir fluid. The tools can cope with consolidated and unconsolidated formations, and provide very accurate fluid pressure readings. The tools also require very little time between runs for *re-dressing* the tool, i.e., unloading the sampled fluids and preparation for the next run.

By comparison, older tools (the *Formation Interval Testers, FIT*) had a range of problems including low pressure accuracy, bad sealing, mixed sampling of mud filtrate and reservoir fluids, were not operable in unconsolidated formations, and required one run per sample with a long re-dressing time between runs.

It should be noted that even with the newer tools, the RFT is expensive to use if many fluid samples are required, as only two separate samples can be obtained on each run. Hence, RFT fluid samples are expensive.

7.3 Operation

The tool is run into the well to the depth required, which is recognized by comparing the gamma ray readings from a gamma ray sensor attached to the tool with previously taken logs. In this way an accurate depth may be fixed. Initially the tool takes a reading of the drilling mud pressure. The tool is then attached securely to the wall of the borehole, by a jacking device known as a *back-shoe* on one side of the tool. Opposite the back-shoe is the measurement and sampling head. This consists of an annular seal or packer surrounding a sampling probe which contains a piston. Figure 7.5 shows details if the back-shoe and sampling head for the *RFT* device. A similar, although much more cleanly designed arrangement applies in the case of the *RFS* in Fig. 7.4. The packer seals the sampling head from the drilling mud and mud-cake surrounding the tool (Fig. 7.6a). The probe containing the piston is then pressed through the mud-cake into the formation (Fig. 7.6b). The piston is withdrawn, allowing fluids to pass from the formation into the tool (Fig. 7.6c). This fluid is made to enter a chamber (first pre-test chamber) through a special valve that limits the flow rate to about 60 cm^3/min. The sampling pressure is measured. When the first chamber is full, it is closed-off and a second pre-test chamber is filled at a higher rate (150 cm^3/min), while measuring the fluid pressure. When this chamber is full the flow-line fluids are at the same pressure as the fluids in the formation, and this pressure is measured. Figure 7.7 shows the internal piping of the tool.

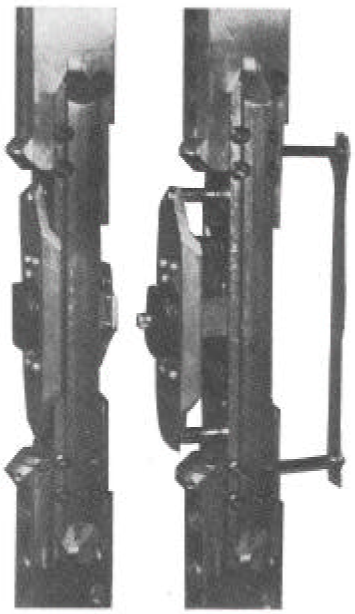

Figure 7.5 The *RFT* tool. (Courtesy of Schlumberger)

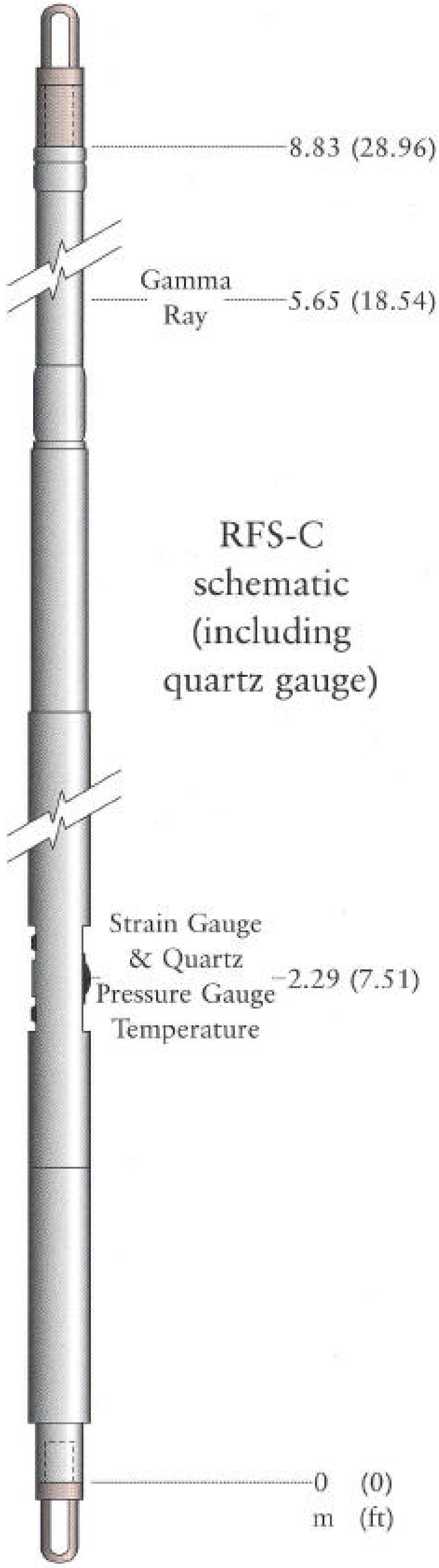

Figure 7.4 The *RFS* tool. (Courtesy of Reeves Wireline Ltd.)

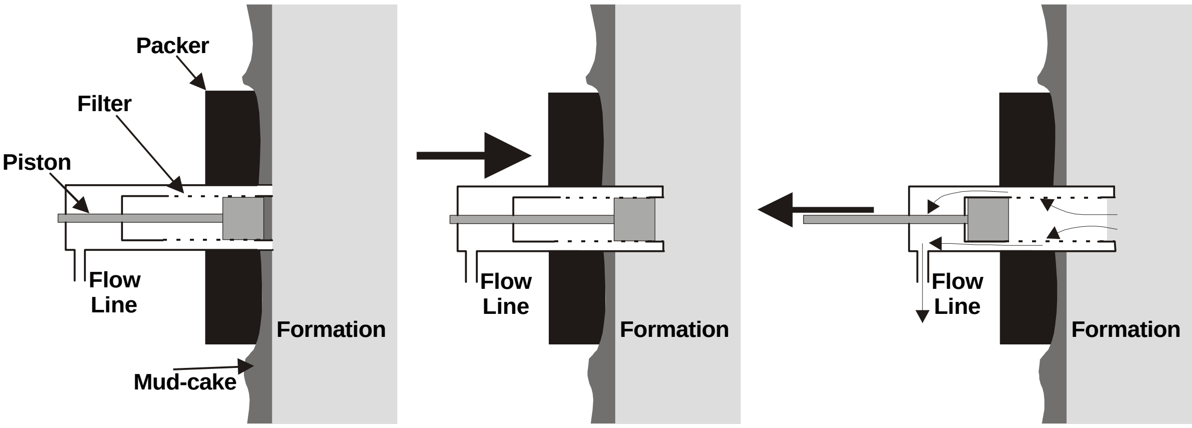

Figure 7.6 RFT operation.

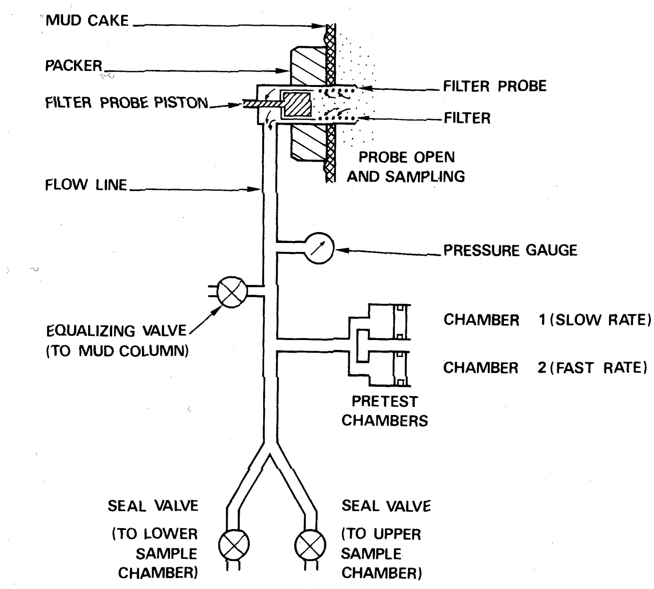

Figure 7.7 RFT internal piping.

Up to now, only pressures have been measured, and there are two pre-test samples in the pre-test chambers. The measured pressures give an indication of the productivity of fluids from the test depth. Since, there are only two main sampling chambers in the tool for operational samples, these samples are precious. It may therefore be decided that the tool should not take an operational sample, but move on to another depth. If this is the case, the pre-test chambers are emptied into the borehole, the back-shoe is retracted, the drilling mud pressure is re-recorded, and the tool moves on to another depth. If an operational sample is required, one of two valves to two chambers is opened so that fluid flows into a chamber. The fluid sample is commonly between 5 and 20 litres. Once the sampling chamber is full, the valve is closed. Note that the fluids are sealed in the sampling chamber at reservoir pressures. If another sample or more pressure data is required from further depths, the pre-test chambers are emptied and the tool progresses. Finally, the tool is removed with both its sampling chambers full, and having taken a number of pressure readings at sampled or unsampled depth points.

The samples are usually sent to a specialist laboratory where the compositions, physical properties and relative volumes of oil, gas, mud filtrate, and formation water can be measured.

7.4 Analysis of Pressure Measurements

A typical *RFT* recording of pressures from one depth is shown in Fig. 7.8.

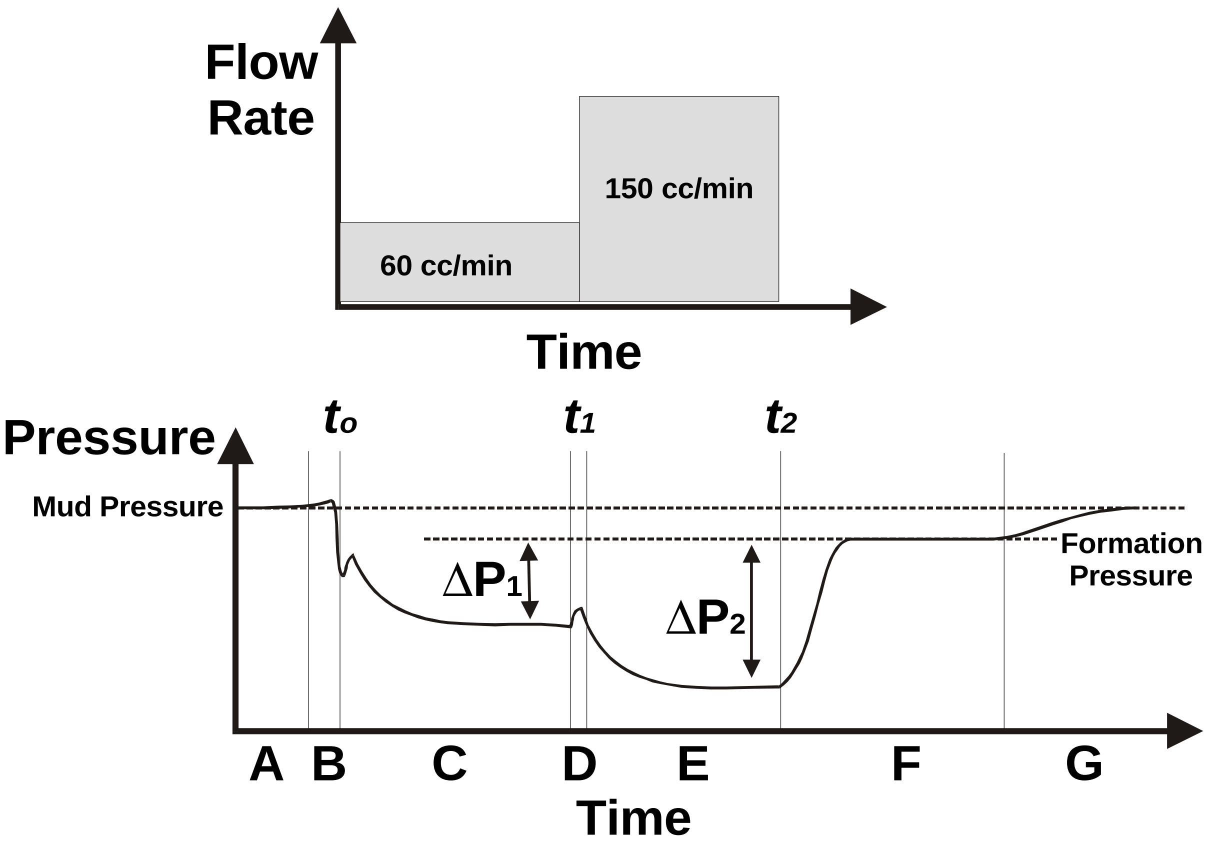

Figure 7.8 RFT pressure data.

The hydrostatic pressure is that of the drilling mud, and is recorded while the tool is at the required depth, but has not been pressed against the wall by the packer (A). This is constant for a given depth in the borehole, and depends upon the weight of the column of mud above it. As the mud density is generally known, this value can be calculated and compared with the measured value.

When the probe penetrates the mud-cake, some mud is compressed between the probe and the formation wall, leading to a transient pressure increase (B).

The piston is open, and fluid flows into pre-test chamber 1 at 60 cm^3/min. The pressure drops because an additional volume has been added to the system (the chamber). The pressure pushing the fluid into the chamber is ΔP_1 (C). There may be some variation in the pressure behaviour here as the flowing fluid is a mixture of mud-cake particles, mud filtrate, and formation fluids of different flow characteristics. When the chamber is approaching full the measured pressure begins to increase towards the formation pressure again (D).

However, the second chamber is opened up, and the pressure once again drops because fluid now flows at 150 cm^3/min into the second chamber. The pressure pushing the fluid into the chamber is ΔP_2 (E).

When both chambers are full the measured pressure increases towards the formation pressure, which may take some time for low permeability formations (F).

After the pressure measurement, the back-shoe is retracted and the mud pressure is measured again (G).

Note that the pre-test chambers have a low volume (about 20 cm^3). Hence, the fluid flowing into these chambers is most likely mud filtrate. However, the pressure that is recorded is the true formation pressures, as this is the pressure driving the mud filtrate into the chambers.

Several problems may occur. The most common are:

A Tight Test. If the sample is very impermeable the sampling pressure drops to near zero. In this case it will take too long to obtain a pressure reading and the tool may stick in the borehole.

Stuck Tool. Usually when the tool has been set at a given depth for some time.

Plugging. Sand grains from the formation may enter the tool and block the flow lines, especially in unconsolidated samples. This problem is reduced by the filter in the sampling probe, but fine grains may still get through.

Seal Failure. If the packer fails, the drilling mud will be sampled and the mud pressure will be recorded.

7.5 Log Presentation

The pressures are given in analogue and digital form. Track 1 usually contains the analogue pressure data. Tracks 3 and 4 are divided into 4 sub-tracks that contain the pressure data in exploded form:

Subtrack 1. Pressures from 0 to 10000 psi in 1000 psi increments.
Subtrack 2. Pressures from 0 to 1000 psi in 100 psi increments.
Subtrack 3. Pressures from 0 to 100 psi in 10 psi increments.
Subtrack 4. Pressures from 0 to 10 psi in 1 psi increments.

The sum of all four digital tracks is the same as the analogue data. A typical RFT log for one depth is given as Fig. 7.9. Note that the vertical scale is in TIME not in DEPTH.

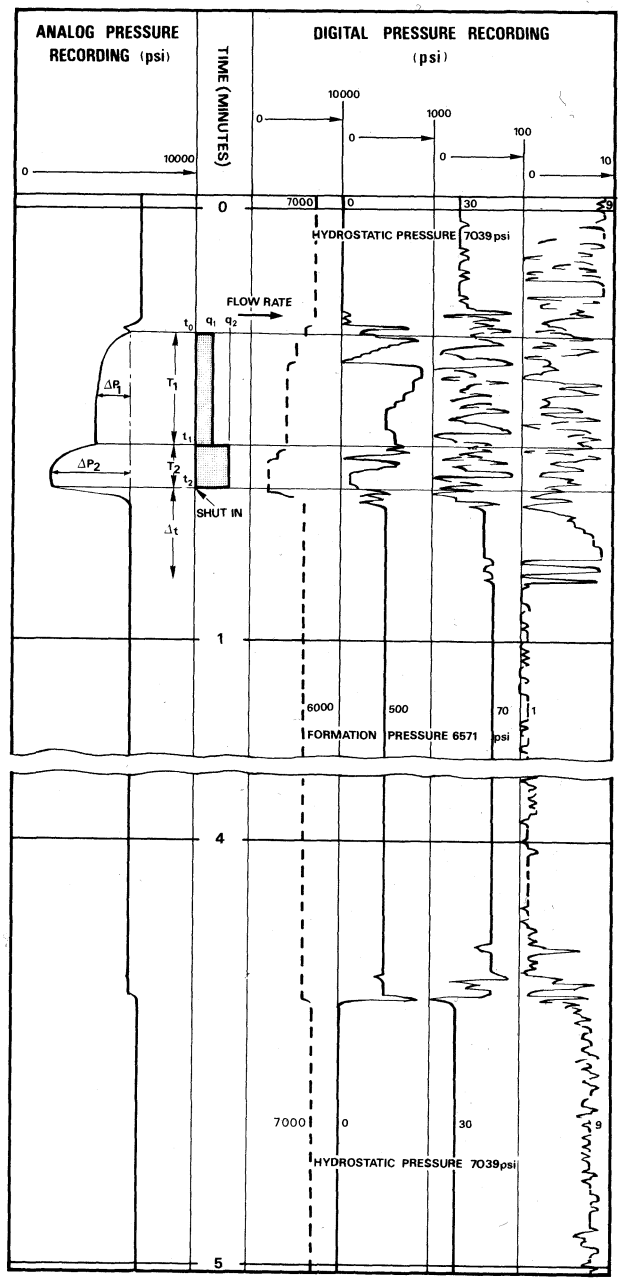

Figure 7.9 An example RFT pressure log. (Courtesy of Schlumberger.)

7.6 *RFT* Data Interpretation

The pressure data obtained from *RFT*s are very useful as they enable judgements to be made about the position of the free water level (*FWL*), oil-water contact (*OWC*), and the gas-oil contact (*GOC*). Additionally, it gives information about compartmentalization, or whether the various fluids in a reservoir are separated physically by an impermeable barrier.

If we have several (>4 say) fluid pressure measurements at different depths in an fluid-bearing sand, where the fluid is in good connection throughout the interval, we can calculate the pressure gradient in the formation fluid. All the pressures should lie on the straight line which defines the pressure at a given depth as a function of the depth and the density of the fluid.

$$P = P_o + \rho_{fluid}\, g\,(z - z_o) \qquad \textbf{(7.1)}$$

where: P_o = the fluid pressure at depth z_o
P = the fluid pressure at depth z
ρ_{fluid} = the density of the fluid
g = the acceleration due to gravity.

This is applicable to all fluids (gas, oil or water) providing that the fluid in question is continuously connected throughout the interval.

A plot of pressure on the *x*-axis against depth on the *y*-axis is used to interpret reservoir pressures as shown in the following sections. This simple equation and the pressure versus depth plot allows us to examine a large range of possibilities that might occur in a reservoir. It can be seen from the pressure depth plot that the gradient of the line $G = 1/\rho_{fluid}\, g$, hence the density of the fluid represented by a line $\rho_{fluid}=1/(9.81\times G)$.

7.6.1 Oil and Water

Referring to Fig. 7.10, the four oil pressures in Sand A determine the oil pressure line according to Eq. (7.1), and by fitting this equation to this pressure depth data, we can calculate the density of the oil.

The six water pressures in Sand B determine the water pressure line according to Eq. (7.1), and by fitting this equation to this pressure depth data, we can calculate the density of the water.

Note that the gradient of the lines is steeper for fluids of lower density. If one has pressure data, but does not know the type of fluid, then one may infer it from the relative gradients on the pressure/depth plot, or calculate the densities (gas very low, oil 0.5 to 0.9 g/cm^3, water about 1 g/cm^3). The intersection of the two lines is the likely free water level, providing Sand A and Sand B are connected. Sand B may be oil-bearing up-dip.

7.6.2 Gas, Oil and Water

Referring to Fig. 7.11, the four gas pressures in Sand A determine the gas pressure line according to Eq. (7.1), and by fitting this equation to this pressure depth data, we can calculate the density of the gas.

The data in Sand B do not form one straight line, but two. The higher is for oil and the lower for water. The densities of each can be calculated as above. The intersection of the water and oil lines is the free water level, as in the previous example. Note that this is about 2.5 m below the known oil water contact *OWC*.

If Sand A and Sand B are in communication, the intersection of the gas line with the oil line gives the gas oil contact (*GOC*). If they are not in communication, the *GOC* is controlled by the impermeable barrier, and might be anywhere between the two sands.

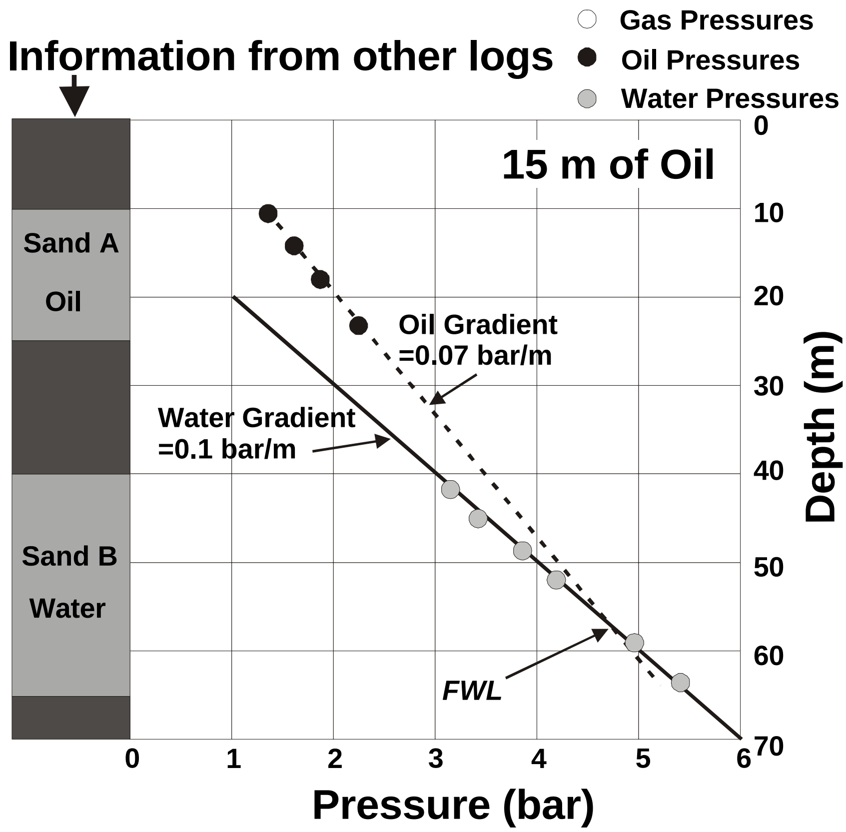

Figure 7.10 Pressure versus depth plot 1.

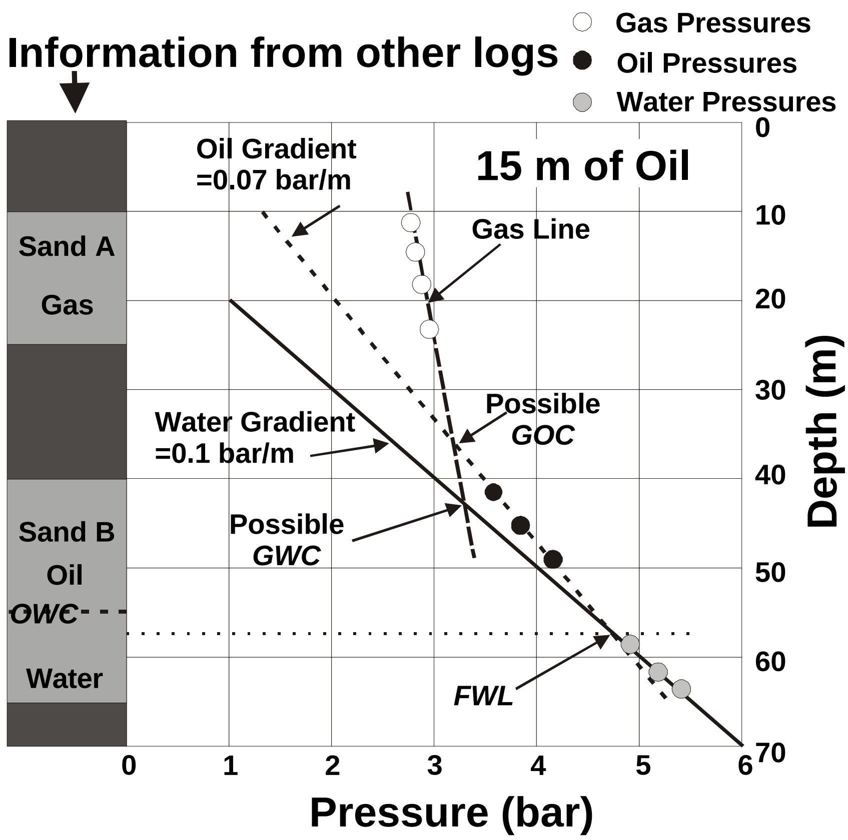

Figure 7.11 Pressure versus depth plot 2.

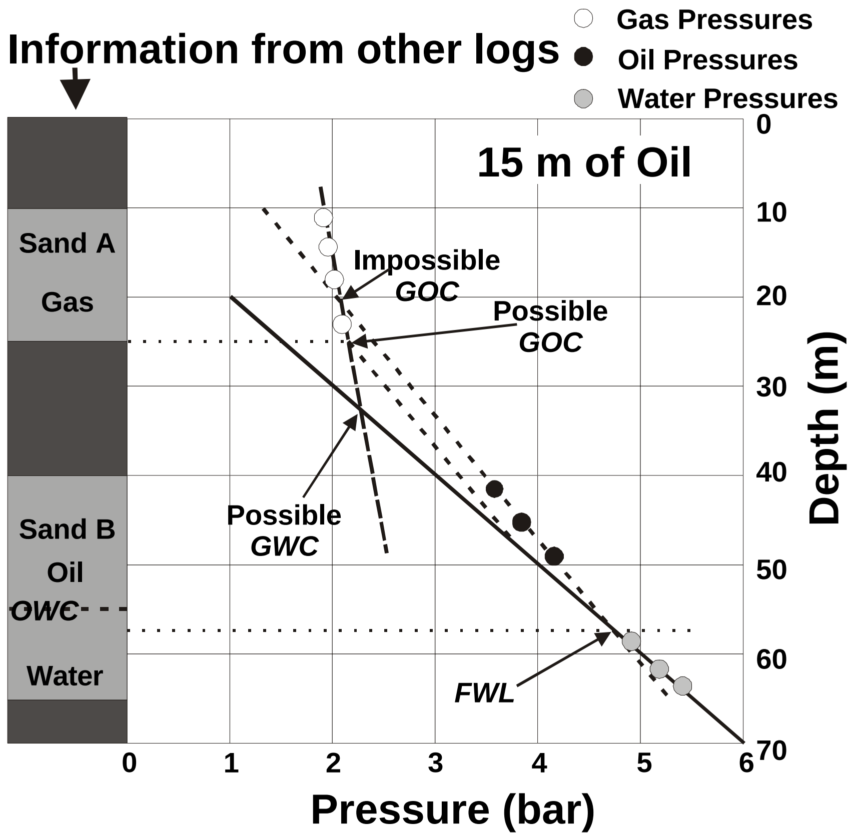

Figure 7.12 Pressure versus depth plot 3.

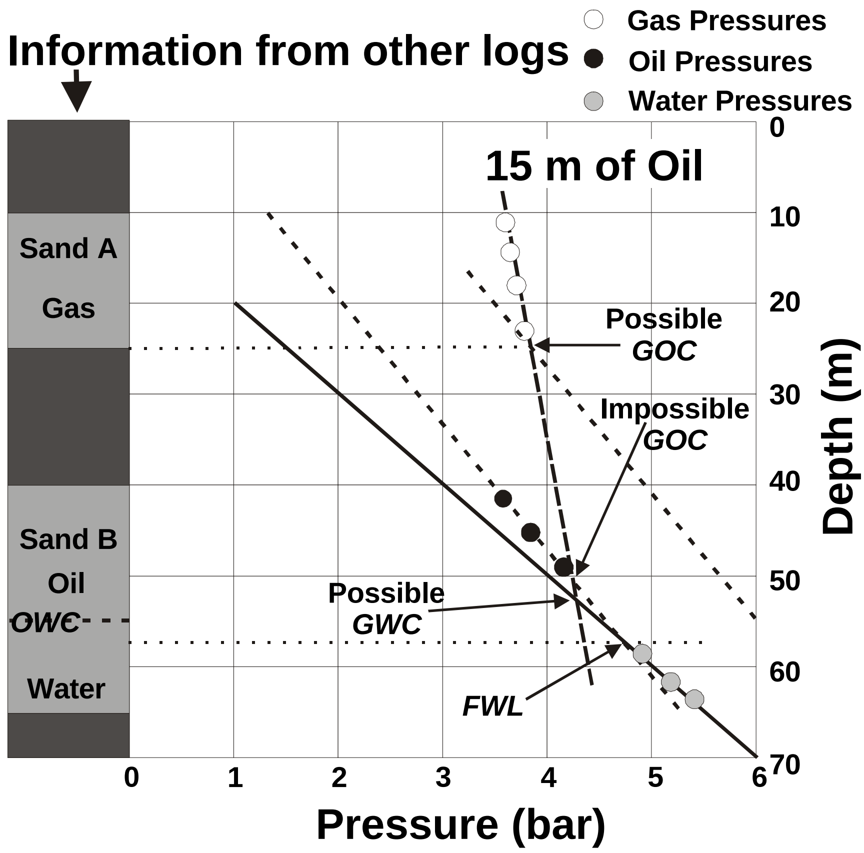

Figure 7.13 Pressure versus depth plot 4.

If oil is missing in the column, then the likely gas water contact (*GWC*) would be where the gas and the water lines intersect, again providing there is good communication between the two sands.

If the recorded gas pressures are lower (Fig. 7.12), the assumption that the sands are in communication implies a *GOC* in Sand A, which is contrary to the log evaluation shown on the left of the figure. Hence, the sands are not in communication.

If the recorded gas pressures are higher (Fig. 7.13), the assumption that the sands are in communication implies a *GOC* in Sand B, which again is contrary to the log evaluation shown on the left of the figure. Hence, the sands are not in communication.