3. ROCK & CORE ANALYSIS

3.1 GENERAL INTRODUCTION

This chapter consists of six parts. The section on mud logging describes the information that can be obtained during drilling. The second part on coring discusses the various methods to obtain an intact piece of the rock down hole and bring it to the surface for analysis. In the following section, the sampling and retrieval of reservoir fluids is covered. In part four relevant analysis techniques to define mineral characteristics, texture properties and fluid behaviour are explained. Part five reviews well logging and part six covers measurements with instruments embedded in the drill string.

3.2 ASPECTS OF MUDLOGGING

Important information can be obtained during the process of drilling a well by the analysis of :

- cuttings produced when the drilling bit grinds the rock to small pieces, which are carried to the surface by the mud when it is circulated through the hole.
- oil or gas shows in the mud stream.
- the rate of penetration of the drilling bit.

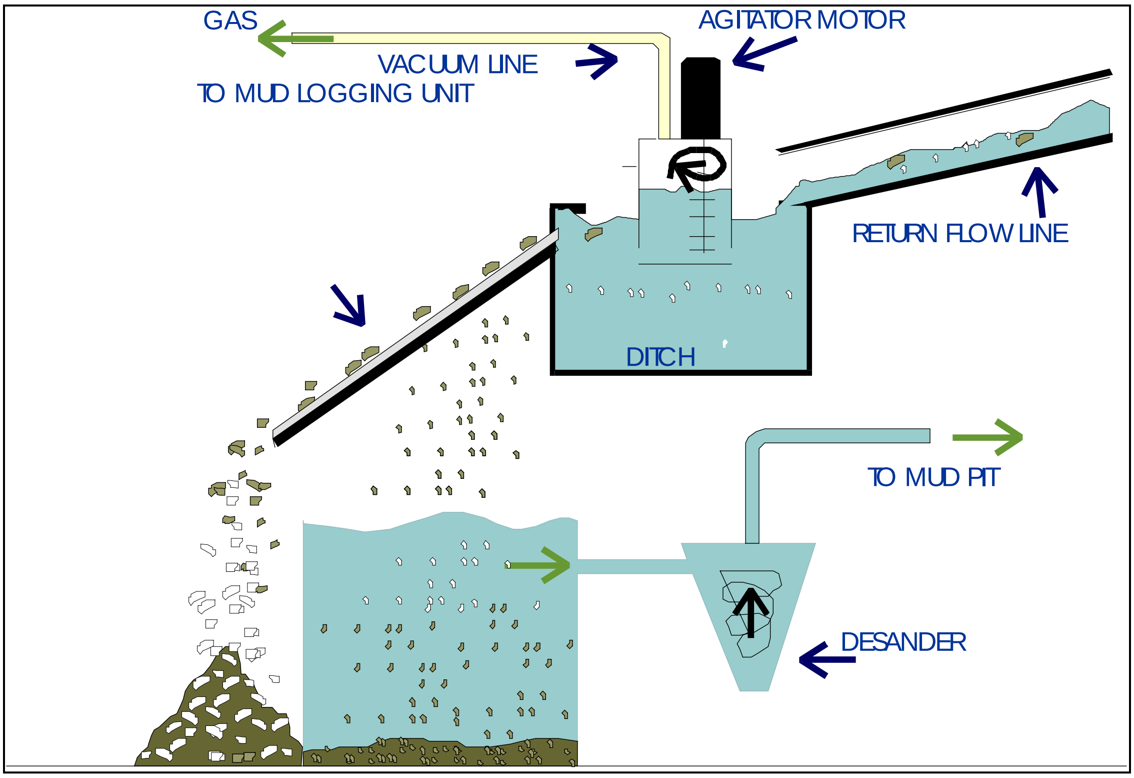

Figure 3. 1: Gas extraction at the ditch. (Revised after Exlog, 1985)

For the interpretation of the mud logging data it is important to know the time when and the place where the cuttings and gas were collected (Figure 3.1).

A mud logging unit on a large drilling rig used for oil exploration has the following facilities:

- Equipment for sieving, washing and drying of cuttings (figure 3.2)
- Laboratory set-up for chemical tests on cuttings and mud.
- Microscope and ultraviolet-light inspection chamber for the identification of oil and description of the lithology of the cuttings.
- Continuous recording of gas with recorders: hot wire analyser/thermal conductivity cell/gas chromatography/infrared analyser.

- Continuous recording of drilling parameters: pump rate, rate of penetration, weight on bit, rotary speed, drilling torque, standpipe and casing pressure.
- Mud properties at the flow-line and in the pit: density, conductivity, temperature, flow rate, mud pit level.

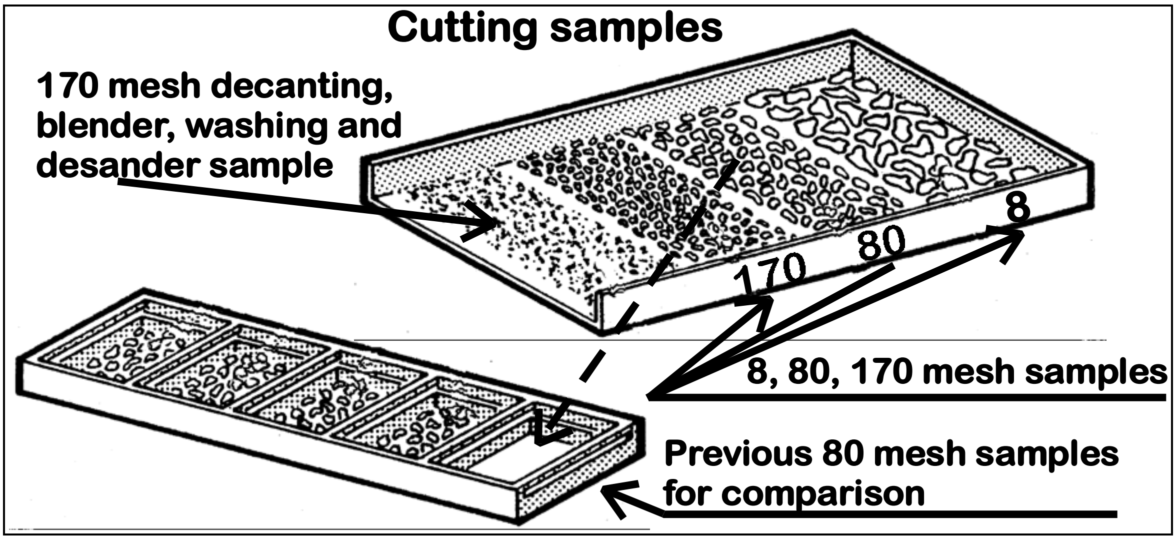

Figure 3. 2: Cutting samples for microscope analysis, X.R.D., X.R.F. and E.M.

3.2.1 CUTTINGS

Investigation of cuttings under the microscope enables the petroleum engineer or the geologist at the well site to describe the various rock types that were penetrated by the bit. Useful information on porosity and permeability may also be obtained. When the cuttings originate from an oil bearing formation they will usually retain only a fraction of the oil that was present in the undisturbed rock. This severe reduction is due to flushing by the mud filtrate, and expansion of gas. This gas was first compressed or was dissolved in the oil, but is released and expands up to 200 times, when the pressure decreases from a few hundred atmospheres downhole to one atmosphere at the surface.

Note: The methods described in this chapter are also applicable to define the quality op asphalt (road-pavement) and coal maceral types.

3.2.2 FLUORESCENCE

Fluorescence occurs when a substance is exposed to ultraviolet radiation (Photo 3.1). Not all materials fluoresce. If the fluorescence caused by ultraviolet excitation is in the ultraviolet region, it cannot be observed by the human eye. Simple organic molecules like paraffin’s rarely fluoresce. Fortunately, a sufficient number of aromatics and naphthenes are present in most crude oils, which provide a distinctive fluorescence in the visible region (wavelength 4000-7800 Angstrom). Sometimes crude oil or diesel oil are added to the mud as a lubricant. In addition pipe dope or lubricants are used for connecting the drilling pipes. The presence of these refined rig oils makes the interpretation on hydro-

API	DENSITY(60 F)	COLOUR FLUORESCENCE
< 15	>0.96	brown
15-25	0.9 - 0.96	orange
25-35	0.85 - 0.9	yellow - cream
35-45	0.80 - 0.85	white
>45	<0.80	blue white - violet

Table 3. 1: Colour of fluorescence as a function of oil density.

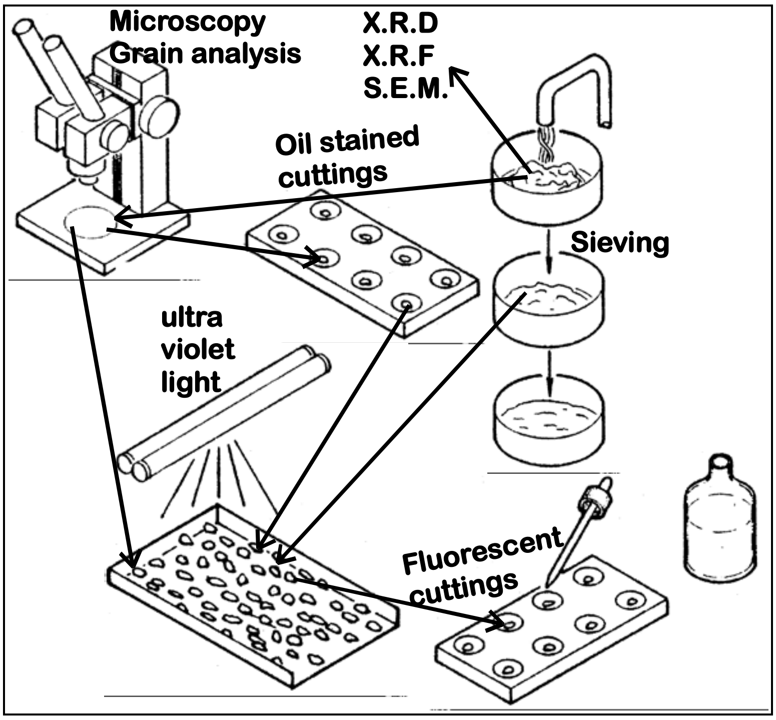

Figure 3. 3: Washed cuttings used for examination on rock type and pore fluid content (i.e. water, oil, drilling fluids)

carbons ambiguous. The colour of fluorescence is, normally characteristic for the gravity of the oil as shown in Table 3.1. Crude oil produces fluorescent light with characteristic colours which fortunately deviates from the fluorescence produced by diesel. In contrast the fluorescence from diesel and from condensates found in gas reservoirs can be very similar.

3.2.3 GAS ANALYSIS

In Figure 3.1 is shown how the agitator motor stirs the mud. The gas that escapes due to the stirring is transported via the vacuum line to the mud logging unit. The gas collected from the ditch is analysed in the mud logging unit. Coal layers can release methane, and trip gas released from the drilling mud when the drill pipes are pulled out of the hole should not be confused with gas from hydrocarbon reservoirs. Analysis of gas can be carried out with a number of methods:

1. **Hot Wire Analyser**
   The heart of the analyser is a Wheatstone bridge of which two resistors are replaced by a pair of matched platinum filaments. One is in a cell that is open to the atmosphere while the other is in a cell through which the sample gas is passed. The filaments are heated to high temperatures by passing a current through the bridge. The recorder reads zero when air is present in both the calibration cell and in the gas sample cell. When the sample contains hydrocarbons, catalytic oxidation of the hydrocarbon gases at the filament occurs. This causes an increase in the temperature of the filament and consequently an increase in its resistance. The recorder is roughly proportional to the amount of hydrocarbon gas in the sample.
2. **Thermal Conductivity Cell**
   This cell is similar to the hot wire analyser, but operates at a lower temperature (lower voltage). As a result there is no combustion of gas, and the temperature and resistance fluctuations of the filament depend solely on the rate of heat conduction. This conductivity depends on the thermal conductivity of the gas in the cell.
3. **Gas Chromatography**
   The two foregoing methods can only indicate the presence of hydrocarbon gases and give a very rough indication of the quantity. The gas chromatography is used to distinguish the various components (methane, ethane, propane) and to obtain a more accurate quantitative analysis. A sweep gas flows continuously through a small column, packed with an inert solid, coated with a non-volatile organic liquid.

At the inlet a small measured volume of the gas sample is injected into the sweep gas stream. The column separates the components by their different absorption characteristics. Methane is relatively insoluble in the column and passes quickly. The various components are identified by the length of time it takes to move through the column. These travel times can be determined for each component. The arrival times of the various components can then be determined by monitoring the passage of the individual components with a thermal conductivity cell at the exit of the separation column. The position of the peak in the time sequence identifies the compound and the area under the peak gives its quantity.

3.3 DRILLING SPEED AND CORING

3.3.1 PENETRATION RATE.

The penetration rate is based on the vertical movement of the Kelly or the swivel on top of the drill string. This movement is plotted as a function of time to produce a penetration log. Progress of the drill bit depends amongst others on the strength of the rock matrix and the porosity these rocks. Slow penetration is indicative for tight and hard rock, while fast penetration is obtained in soft, porous rock. A sonic log (porosity log), which is run later over the same interval, often correlates with the penetration rate. The effect of weight on bit, mud pressure, changing bits have to be taken into account, when the penetration rate is correlated with rock properties. An attempt to normalise the drilling parameters was made by the introduction of the “d” exponent. However like many geo-parameters the correlation often prove to be only valid for one field, one reservoir or even one layer.

3.3.2 CORING

All oil, coal, ground-water, mineral, and soil-mechanic logging activities have in common that log measurements have to be calibrated sooner or later with analyses results on formation samples. These rock samples are obtained by coring. The core is cut using a special hollow bit. The cylindrical core is usually split lengthways in at least two pieces. The first half is photographed in natural light for a detailed lithological description, and in ultra-violet light to detect residual oil. Small cylindrical samples are drilled from the other pieces and used to measure reservoir properties such as porosity, permeability and grain density. For proximate analysis of coal properties such as moisture and ash content larger samples are usually required. For soil mechanics undisturbed cores can often only be obtained in unconsolidated formations with a hollow probe. This probe penetrates the shallow subsurface like an apple bore.

3.3.3 CORING VIA THE DRILLSTRING

Two types of coring techniques are used with the drillstring. In the first, the standard in the oil industry, the hollow tube which receives the core remains in position during the coring operation. In the second the core barrel can be retrieved back to the surface, while the drillstring remains in the hole.

1. **Conventional Coring**

The coring assembly consists of the core head or bit and the core barrel. This technique utilises a hollow core bit which cuts the periphery of the hole while leaving a centre stub of rock. The barrel consists of two parts : the outer barrel for mechanical strength in the string and the inner light weight aluminium or fibreglass barrel to guide the core. This inner barrel does not rotate to avoid breakage and grinding of the core. Most common core diameters are 3 to 5 inch in diameter. The maximum length is 90 feet.

2. **Retrievable core barrel**

A disadvantage of the above coring method is that at least two additional round-trips are required. In the first all drill pipes are removed and unscrewed to get the core barrel to surface, the second to run a new barrel in the hole. The retrievable core barrel is similar to a conventional barrel with the exception that the inner barrel is connected to a wireline and can be run-in and pulled-out of the drillstring without tripping the drill pipes. It allows continuous coring over long intervals. Diameters range from 1½ to 3 inch. This method is particularly attractive for mining companies, because it is economic and provides immediately samples for proximate or ore grade analysis. It has been used by the mineral industry for several decades and was recently adapted to slim-hole drilling for the oil-industry. The risk of blow-out in the oil industry has hampered general acceptance.

3.3.4 SIDEWALL CORING & WIRELINE HARD ROCK CORING TOOLS

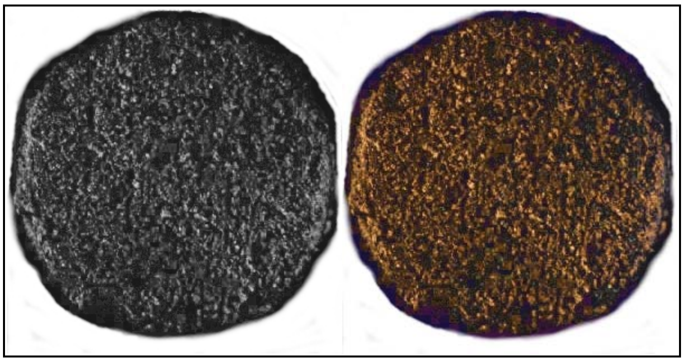

Photo 3. 1: Sidewall sample under microscope: left with plane light, right with fluorescing light (UV), giving a brown colour to the oil.

The side-wall sampler is an instrument run at the end of a logging cable. It can be positioned accurately by means of Spontaneous potential or Natural gamma-ray logging tools, that are run together with the sidewall sampler (see Chapters 8 and 9) . Hollow bullets (about 2 inches long and 1 inch diameter) are fired individually from the "gun" body by electrically ignited powder charges that are placed behind the bullets. The bullet cuts a cylindrical plug from the formation and remains attached to the gun by two heavy wires. After the sample has been cut, it is detached from the surrounding rock and recovered by an upward pull on the gun body. The standard gun carries 30 bullets.

The method is widely applied to sample clays and shales for palynological analysis. It is also used for positive identification of oil in fresh water sands. A disadvantage when sampling soft formations is that the impact of the bullet tends to compact the formation and thereby distort the porosity and permeability. Rock properties such as grainsize and sorting can still be obtained from disturbed samples. In hard formations the recovery can be very poor, due too lack of penetration and adhesion between sample and bullet. In the late eighties a wireline tool was developed with a small hollow rotary drilling bit, which can take small (2 cm x 2.5 cm) plugs from the borehole wall. After the plug is drilled the bit is retracted and the samples removed from the bit by a punch. Up to 20 plugs can be individually drilled and stored in the tool. The main advantage of this tool is its ability to function well in hard formations where the conventional sidewall sampler often fails. Moreover, the plugs are usually little disturbed and the porosity and permeability analysis performed on these rock samples can be very reliable.

3.3.5 COMPARISON OF CORING METHODS

A rough comparison between the three types of formation samples that is made in Table 3.2. Figures on costs must be used as a guide only, they mostly depend on the drilling location and the well depth. Table 3.3. indicates the capability of the three types of formation sampling techniques to assess the reservoir parameters for the requirements listed in the first column of the table. Here the recovery is one of the important aspects. The core recovery is the percentage of the core that has been recovered. When the recovery is poor the continuous record is poor and the thickness depth control is poor. Most striking is the common inability to provide saturation data as illustrated in Figure 3.4. At the bottom of the well the mudfiltrate can flush a part of the oil and water that was originally present in the pores of the rock. The oil in-situ contains dissolved gas because the pressure is above the bubble point. During pulling of the core barrel to the surface the pressure and temperature decrease and gas will escape from the oil which will expand and finally flush oil and

	Cuttings	Cores	Sidewall samples
Size rock	1-3 mm	70-100 mm	40-25 mm
Length	collected ~ each meter	9-27 m	Up to 72 SWS/trip
Acquisition Cost	none	3000$/m	250$/sample
Accuracy in depth	lagtime, slippage	depends on recovery	good

Table 3. 2 : Comparison methods to obtain formation samples

ITEMS	Cuttings	Cores	Sidewall samples
DEPTH CONTROL	POOR	FAIR (*)	EXCELLENT
CONTINUOUS RECORD	YES	GOOD(*)	NO
THICKNESS	POOR	GOOD(*)	NO
POROSITY	INDICATION	GOOD	POOR
PERMEABILITY	INDICATION	GOOD	POOR
SATURATION	NO	NO	NO
TIME CONSUMED	NO	YES	YES
EXPENSIVE	NO	YES	YES
HOLE RISK	NO	POSSIBLE	POSSIBLE

Table 3. 3: Capabilities of the methods for obtaining formation samples

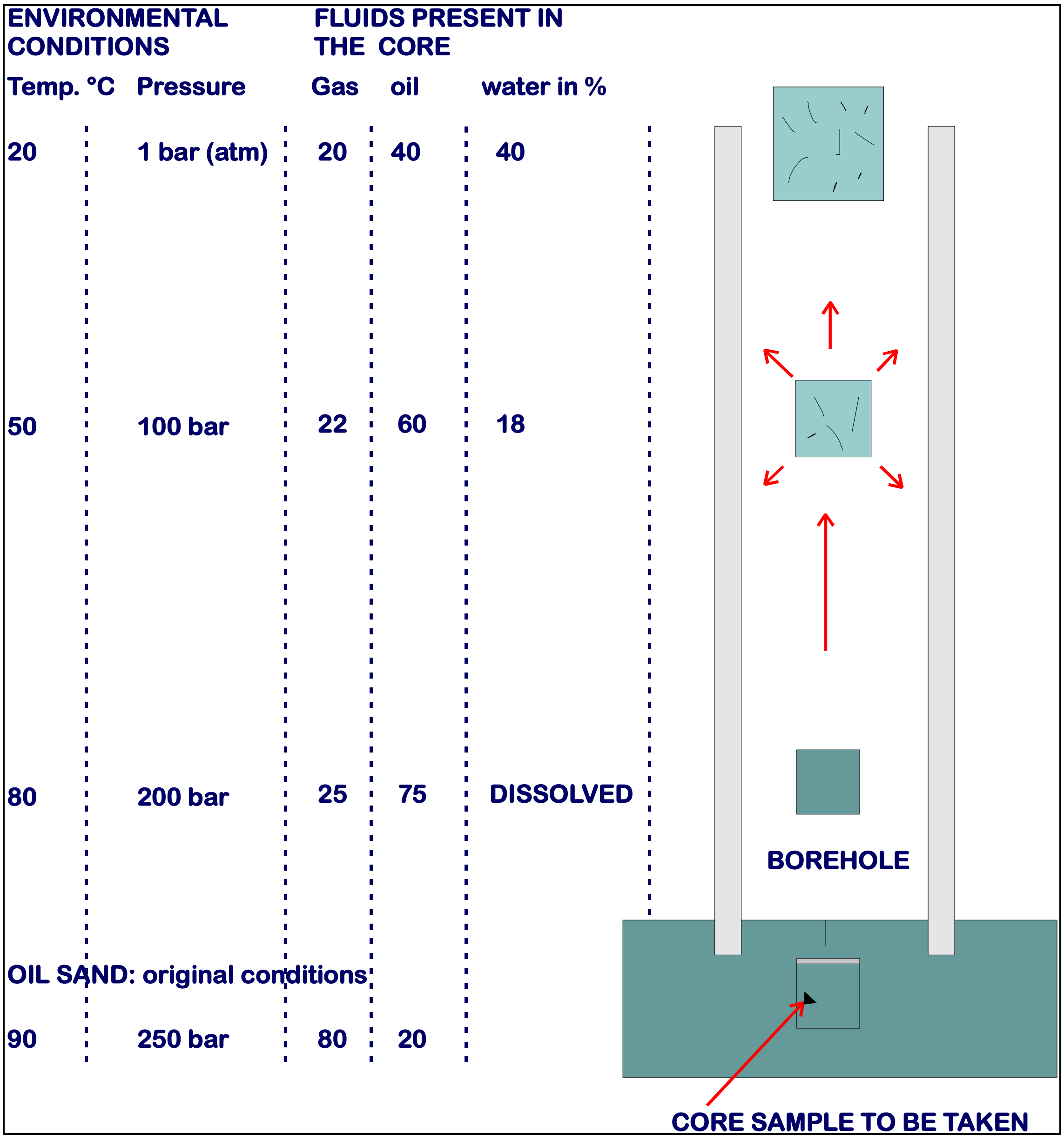

Figure 3. 4: The history of the core from in-situ conditions to atmospheric circumstances.

water from the pores. Hence the oil content at the surface is much lower than it originally was at in-situ conditions in the reservoir.

3.4 FORMATION FLUID TESTING

Information on the presence of hydrocarbons, their composition and ability to flow can be obtained by means of formation fluid testing. Three methods are available :

1. Drillstem testing
2. Production testing
3. Wireline formation testing

3.4.1 DRILLSTEM TESTING

This technique is applied with the drilling string augmented with hydraulic components. A valve, a packer and a length of perforated tail pipe is lowered on the end of drill pipe to the depth of the potential reservoir. The packer is expanded to fill the space between the borehole wall and the drill string, thus separating the test interval from the mud above. The drill string is only partly filled with fluid, hence when the valve is opened, the formation fluid pressure will be sufficient to produce reservoir fluids towards the surface. This technique is basically a temporary completion of the well.

3.4.2 PRODUCTION TESTING

This method is carried out in the cased hole, properly completed with a packer to isolate the reservoir interval that is tested, and with production tubing to conduct the fluid to the surface facilities. The casing opposite the reservoir interval is perforated using shaped explosive charges. If the test is positive, production may continue without any changes to the well design. This method is very reliable and accurate, and most of all safe and is therefore routinely applied in offshore exploration. It is also the most expensive technique from the point of view of elapsed time, material and manpower resources.

3.4.3 WIRELINE FORMATION TESTING

The third method of formation fluid testing is provided by wireline contractors. This technique inserts a nozzle surrounded by a rubber pad into the reservoir. After the pad is firmly pressed against the borehole wall the nozzle is opened and reservoir fluids can flow into a sample chamber in the tool (Fig.3.5). In the late eighties the modular formation tester (MDT) was introduced that contains several fluid sample chambers and up to three fluid entry ports.

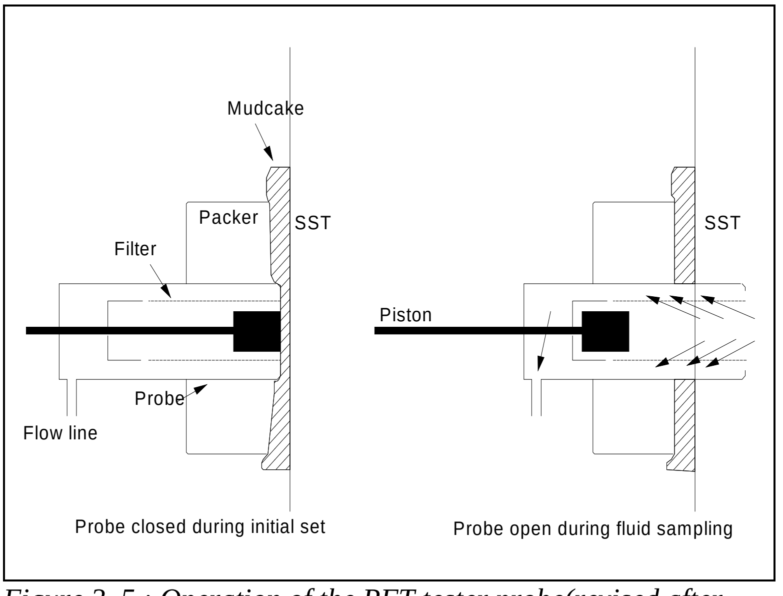

Figure 3. 5 : Operation of the RFT tester probe(revised after Schlumberger, 1984)

- **RFT Capabilities**
  The Repeat Formation Tester tool (RFT) has been designed to measure the formation pressures and t collect reservoir fluid samples
- **MDT Capabilities**
  The modular formation tester can, as indicated by the name, be assembled from several parts. The most extensive version contains 3 sample chambers and three different pads that each contain an extendible nozzle to communicate hydraulically with the reservoir. The pads can be arranged to carry out interference tests, which give indications on vertical permeability. The MDT is equipped with infrared and conductivity cells in the flow lines, which can be used to detect the onset of oil

production after the mudfiltrate has been removed. After switching of flow-lines a second chamber can then be filled with a virtually uncontaminated hydrocarbon sample. The contents of the sample chambers can be pumped out into the borehole, which gives the capability to take multiple fluid samples. A strain gauge pressure transducer located in the flow line monitors the pressure during the test. The application of the fluid and pressure data obtained with the wireline formation testers is further discussed during the course.

3.5 LABORATORY ANALYSIS METHODS

3.5.1 INTRODUCTION

Many information is already obtained during the drilling stage, both from the registration at the drill hole and from the cuttings. However, everyone, reservoir engineer, hydro-engineer, mining engineer, geologist and engineering geologist like to know more specific characteristics of profitable horizons on rock strength, porosity, permeability, mineral content, pore type, cementation, mineral weathering, fluid contents, etc. They want to put values obtained by microscope to implement in rock classification systems or to quantify engineering parameters for predictions.
A laboratory study has the following objectives:

- to identify the core damage from drilling and transport to the surface.
- to analyse the rock matrix: mineral content, texture and structure.
- to analyse the formation fluids still present and the penetrated drilling fluids.
- to analyse the basic physical properties, i.e. density, porosity and permeability.
- Indirect information on minerals & texture versus rock strength parameters.

Formation cores, samples of formation fluids and sometimes samples of the damaging material (organic deposit or scale) are required to perform a laboratory study. Various analyses are then performed on these samples to obtain the information necessary for designing a matrix treatment.

3.5.2 CORE ANALYSIS

Core analysis, including various flow tests, is an integral part of the laboratory study used to help design a matrix treatment, The various methods applied in the core analysis for the grain and pore characterisation are summarised in figure 3.6., and can be grouped as follows:

- Petrographic studies, including X-ray diffraction analysis, binocular lens observation, thin section examination under a polarising microscope and Scanning Electron Microscope observation.
- Petrophysics studies to determine the porosity and permeability of the sample.

Some widely used and novel techniques will be discussed in this section:

1. Microscopy,
2. Scanning Electron Microscopy (SEM and EDAX)
3. X-ray diffraction/X-ray fluorescence.
4. Image analysis as a quantitative tool

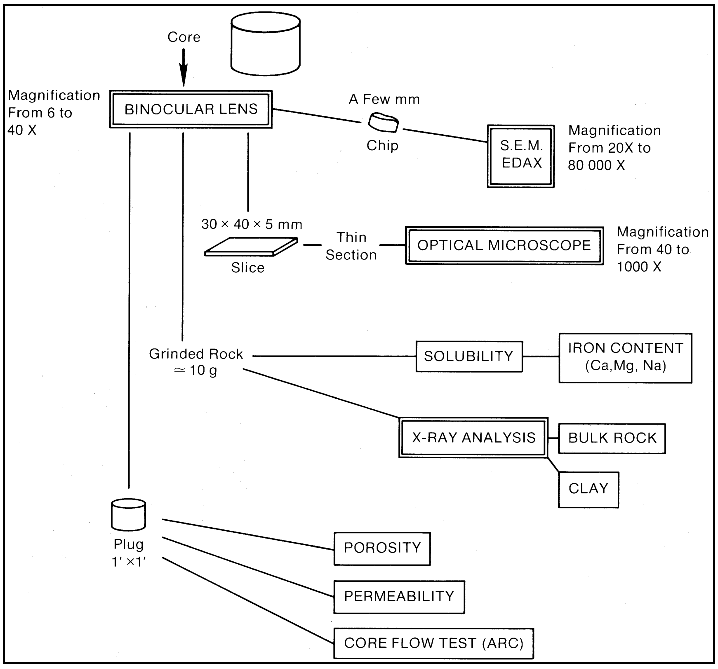

Figure 3. 6: Core analysis program, according to Dowel Schlumberger, 1986.

3.5.3 MICROSCOPY

Much is already explained in the first year and second year courses microscopy. Here we only summarise several methods that are used to define texture characteristics:

1. **Binocular microscope:**

Used for the analysis of cores and cuttings in grain size, sorting, and the larger sedimentary characteristics such as laminae, vugs, fracs, etc. Here geologists and hydrologist get an opportunity to define all textural parameters that are relevant for their specific questions on sedimentological maturity, weathering aspects and rock strength. Here some of the appearances, like grain size, mean, sorting, etc. can be defined in order to estimate a quick permeability, as defined in "de van Baaren-equation". This technique can be considered as a non-destructive technique. The sample is not damaged or prepared before or during the analyses.

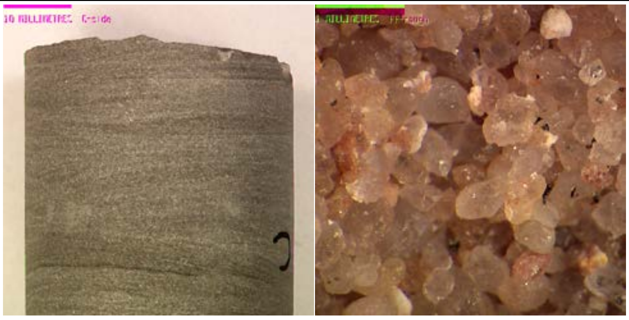

Photo 3. 2: Carboniferous cores and core surface of Bentheimer sandstone that can be described with the use of a binocular microscope.

2. **Polarisation microscopy:**

The original cores have to be damaged to prepare polished planes or thin sections. The rock can be filled with a special dye to define the pore space by straight colours (yellow, red, blue) or by fluorescence (yellow, green, red). Now many micro-textural aspects, such as grain-mineral content, 2-D pore sizes, grain shape, sorting, cementation, pressure solution, weathering, diagenetical features, grain damage, grain/porosity generation, can be studied to describe a rock history or burial history and to define the micro-values for geo-engineering purposes. The photos 3.3 show a good example of the different aspects, as mentioned before, that can be characterised. Note the presence of abundant nitre-particle porosity.

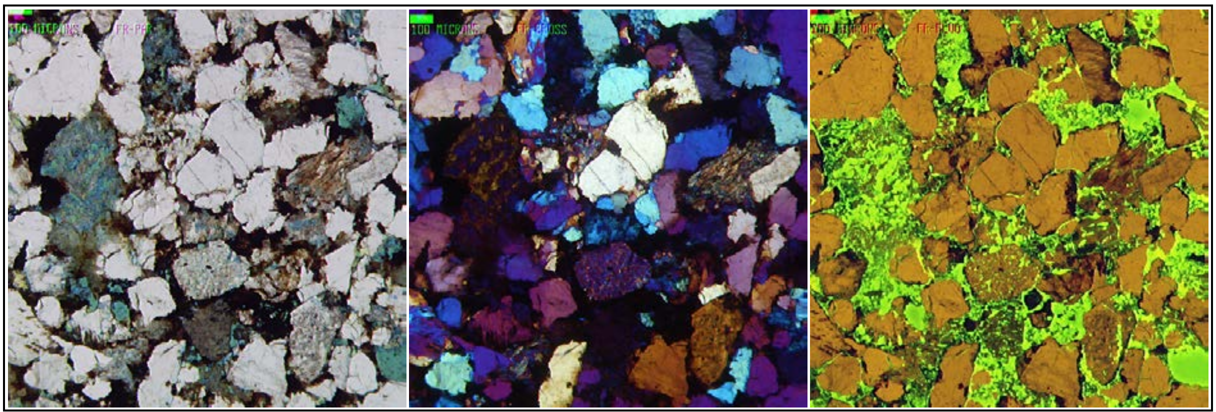

Photo 3. 3: Thin section of Felser sandstone: //-nicols, X-nicols and the fluorescing surface showing weathering (left), mineral content (middle) and pore space distribution (right).

3. **Scanning Electron Microscopy and Micro-probe.**

The basics of Electron Microscopy contain the use of an electron gun which produces a stream of electrons. This stream is accelerated at a voltage up to some 30 kV and bundled by some electromagnetic lenses. Then the bundle hits a rock specimen which reflects electrons; Back Scatter Electrons (BSE) and Low Energy Secondary Electrons (SE). Emission of electromagnetic radiation from the specimen produces visible light (cathode-luminiscensce) and X-rays. The BSE and SE are caught in a scintillator. Here several main types are used:

A. SEM:
The photographic options, in which a pseudo 3-D image is constructed. At a size of less than 1 micro-meter it is possible to characterise textural aspects. This option only shows shapes and no chemical content (photo 3.4).

B. Micro-probe:
The photographic options, in which a 2-D image is constructed from a polished section. At high accuracies of less than 0.25 micro-meter, a reflecting electron bundle is detecting reflection densities. These densities are translated to grey-tones which give a map with density-differences of the present elements.

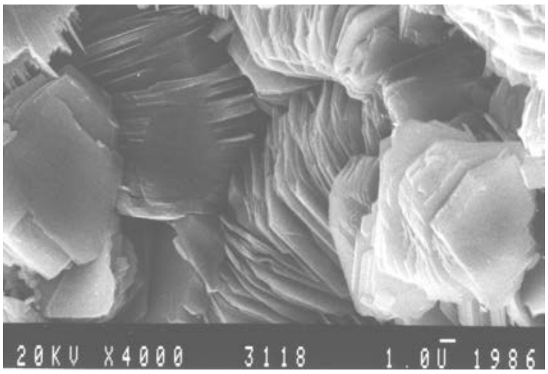

Photo 3. 4: S.E.M.-photograph of kaolinite; Whitby, Jurassic, Dogger hardground.

C: EDS:
An Energy Dispersive X-ray analysis system. Here spot analysis are made of areas of 1 square micrometer. The reflecting waves are giving a product of various wavelengths and amplitudes or intensities, which can be related to element specific wavelengths. In this way it is possible to analyse a certain spot on element distribution and quantity. When combined with option B, one can map large areas on the density of a specific element. For example Si, Al, Fe, Mn, Ti, Mg, Ca, Na, K as the main elements of sedimentary rocks (photo 3.5).

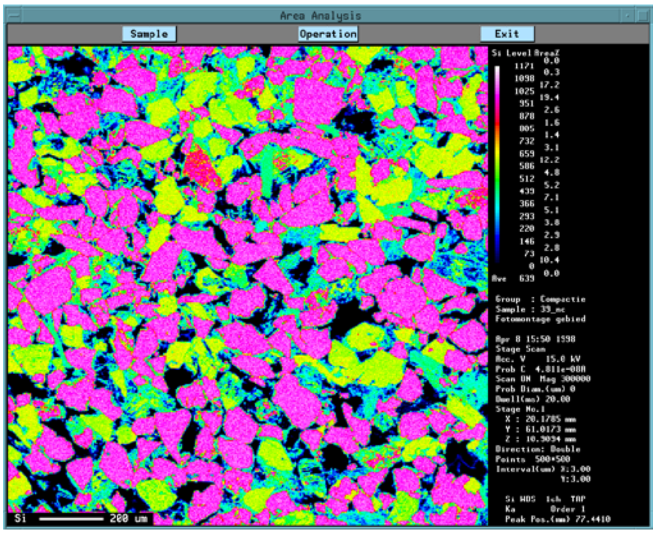

Photo 3. 5: Microprobe scan on the Si-component of a Jurassic reservoir. Dark colours quartz, lighter colours feldspar, clays, etc.

4. **X-ray diffraction** (XRD):
This method is commonly used to get a whole rock analysis of the matrix minerals, as found in regular cores. A Röntgen X-ray tube provides radiation , and preferably monochromatic radiation, that is sent to a sample consisting fine powdered matrix mineral matter. For this radiation preferably $K\alpha,\beta$ radiation is used. The X-ray beams meet the powdered sample, creating a reflective radiation due to collision at the different mineral planes. At specific angles a detector counts the reflecting electron, which results in the registration of an angle and the intensity. According to Braggs' law a whole number (n) of wavelengths (λ) represents the distance in a crystal lattice (d), at specific refraction angles (α) or: $n.\lambda = 2d.\sin(\alpha)$. The output from the detector is a film that shows the angles (α) and peeks at a specific wavelength (λ). Now the d can be used to define the different mineral/crystal types. In this destructive way the qualitative and semi-quantitative mineral content of a matrix can be defined. Unfortunately the samples have to be destroyed.

5. **X-ray fluorescence** (XRF):
This method is used to define the bulk element weight percentage of the present elements. It has more or less the same background of operation as the micro-probe. However, this method is very destructive. The sample is powdered and fused with a borate to a homogeneous and isotropic glass pellet. This method gives the best bulk element analysis and is used for igneous rock, metamorphic rock and sedimentary rocks.

3.5.4 AN INTRODUCTION TO IMAGE ANALYSIS AS A QUANTITATIVE TOOL

Preface

Quantitative Image Analysis is a technique used already for many years in:

- astronomy and space travel, for processing and enhancement of satellite and radio telescope images from space
- industry, for control of production processes and quality control of products
- administration, for recognition of handwriting
- science, for visualization and measurements of experiments

The aim of Quantitative Image Analysis is generally spoken the processing and eventually enhancement of images with the use of a computer and the measurement of properties in these images.

The **enhancement** is necessary to suppress or put emphasis on certain properties. It is used to make an image more easily readable or measurable, to recognize patterns or to reconstruct unreadable images.

Measurement of many object parameters are possible, to name: area, length, brightness, shape. Visual properties are in this way changed to numerical values.

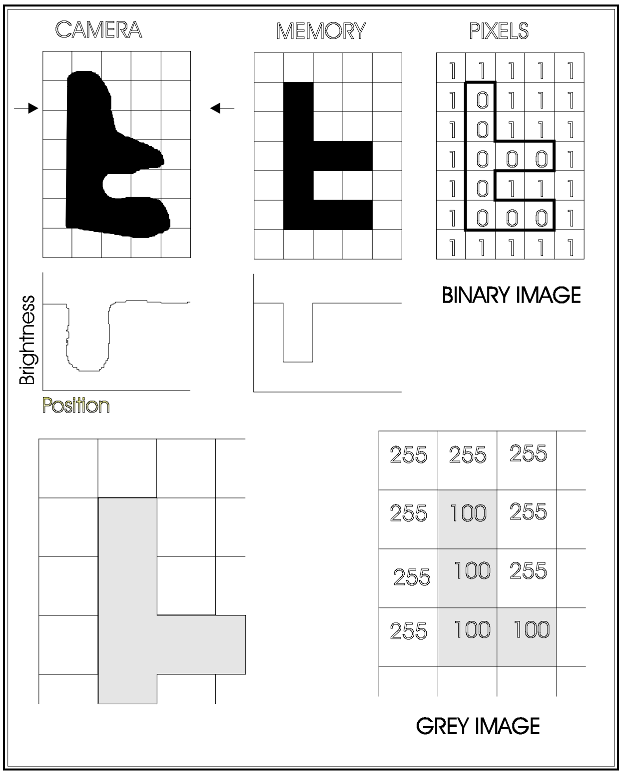

Figure 3. 7: Visualization of the concepts of a binary image and a grey image.

Methods of image acquisition

An image is acquired with the use of a videocamera. In the camera, changes in optical brightness are transformed to analog electrical signal fluctuations. But a computer can only handle two different states: high (5 V) or low (0 V) or - in an other way - 1 and 0 (digits). That is why it is necessary to transform images to a digital format before they can be processed in a computer. This is called *digitizing* - the image is divided into single picture elements (*pixels*). The brightness (*greylevel*) of each pixel is stored as a code of 8 zeros and ones (8 *bits* = 1 *byte*). In one byte of information 256 grey-levels are stored, from 00000000 = black, to 11111111 = white. Hence, a digitized image consists of a matrix of pixels each with a code for its individual brightness.

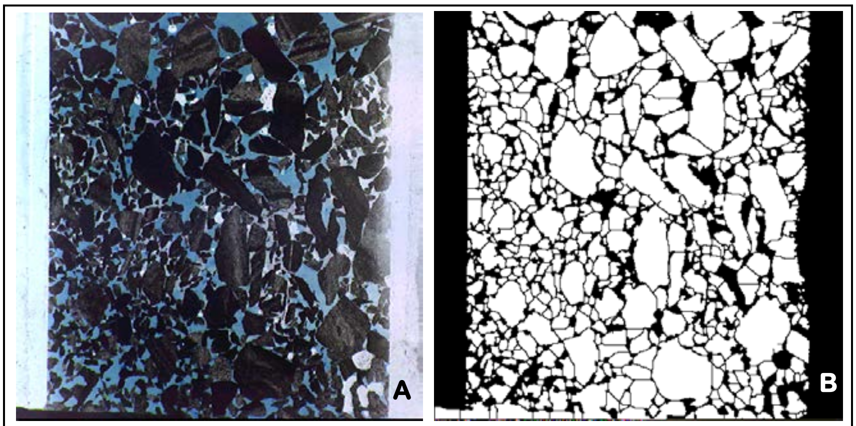

Photo 3. 6: fig.A. shows a color digitized thin section with the black parts as the grains and the remainder as pore space. Figure B. shows a binary image after detection of the grains (white, pixel value 1) and pores (black, pixel value 0). The grains are automatically separated for detection puroses.

To digitize a colour representation, (photo 3.6) a possibility is to split the picture into three images, each representing the relative amount of red, green and blue (*RGB format*) in the original image. So the colour information of a single pixel is stored in 3x8 = 24 bits. After digitizing, an image is in fact a file that can be processed and stored in a computer. An image analysis system like *Quantimet* (a dedicated computer system) or *Qwin* (a program that can be run on a PC under Windows) can handle the file for processing and measurement. Here, a colour image of 512x512 pixels (each image in the posters) will be stored as a file with a size of 512x512x24 = 6291456 bits or 6291456/8 = 786432 bytes.

Image processsing

Changes in the image can be performed by replacing each pixel value with another, say 2 times the original value = 2 times brighter. This is called *pointprocessing*. An other option is making the new value depending on the values of the surrounding pixels: *neighbourhood processing* (figure 3.8,3.9) This is a very sophisticated and powerful technique used in two important image processing applications:

- *Mathematical Morphology*
  There is a relatively simple mathematical relation between the processed and the surrounding pixels. The processing speed is high and can be controlled well. Basic processes are *erosion* and *dilation*. In erosion the pixel value is decreased and in dilation increased according to that of the neighbors.
- *Convolution*
  There is a more complex mathematical relation between the processed and the surrounding pixels. This technique is often applied in the enhancement of fuzzy (unfocussed) images and in geophysical signal processing methods like Laplace and Gauss filters (figure 3.9)

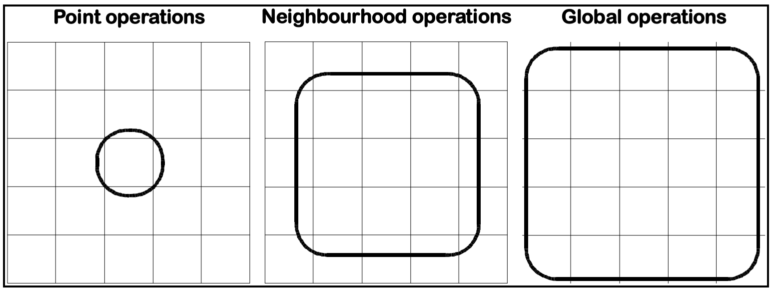

Figure 3. 8: Three kinds of mathematical operations that can be applied to pixelvalues.

Also the whole picture can be considered as a set of data. In *Fourier Analysis* this set is processed as a whole, filtered and 'translated' backwards. Using this technique certain signal frequencies in the set can be located and suppressed or intensified (*highpass* and *lowpass* filters). Applications for suppressing image noise and interference jam.

Image Analysis

Image properties can be analyzed at two levels:

- ***Grey level***
  Grey values are measured directly in the original image.
- ***Binary level***
  In the grey image, pixels within a certain brightness range are '*detected*' and stored in a separate image. This subimage is called *binary* because each pixel in this image satisfies the brightness criterion (=1) or not (=0). So the image consists only of pixels with values 0 or 1. Also this image can be processed in the usual way.

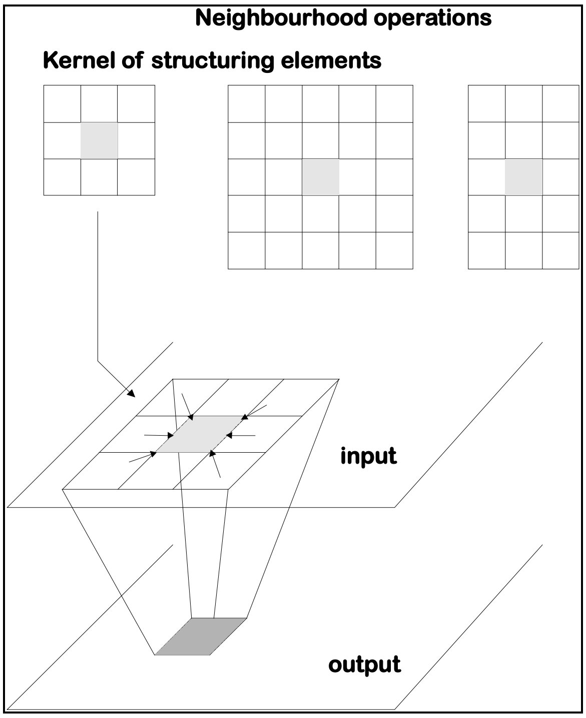

Figure 3. 9: Visualization of an operation on a pixel value and its neigbours, as discussed.

3.5.5 IMAGE ANALYSIS APPLICATIONS FOR STUDENTS DURING THEIR STUDY

- ***Geophysics***: Image improvement in seismics, Ground Penetrating Radar
- ***Engineering Geology***: Satellite images, surface geology, groundwater, rock engineering characteristics
- ***Reservoir Engineering***: porosity/permeability relations, rock engineering characteristics
- ***Raw Material Section***: ore or material distribution, liberation analysis
- ***Mining Engineering***:Coal vitrinite/ore – reflectometry, fracture analysis
- ***Petroleum Geology***: Mineralogy, petrography, reservoir characteristics.

3.6 WELL LOGGING

As discussed in the introductory chapter, well logs are records of physical properties as a function of depth. Many physical phenomena can nowadays be measured in the borehole ranging from simple spontaneous electric potentials, obtained with only one electrode, to gamma-ray spectrometers, which require the equivalent of a Pentium PC to be incorporated in the tools, to cope with the huge amount of data. The electronics is able to operate at temperatures up to 200 °C and pressures as high as 1,500 bar, but still fits into sondes with a diameter of only 3 5/8” or 92 mm. One can measure on the formations after drilling; open hole logging or cased hole logging, or during drilling, called measure while drilling.

3.6.1 OPEN HOLE LOGGING

In the oil industry a standard cable for open hole logging consists of 7 insulated conductors inside flexible steel armour. Its diameter is about 0.5 inch. A mono-conductor is normally used for logging in cased holes, where both the tools and the cables have a smaller diameter (1 11/16”or 43 mm) to pass through the production tubing. The data transmission rate of the cables is limited to 200 - 500 Kbytes, which imposes restrictions on the spectrometer and imaging tools due to the very high data rates. For mineral and ground-water logging both open and cased hole logging is almost exclusively carried out with small diameter, so called slimline tools (1 11/16”, 43 mm). The reason is that most exploration wells in these industries have a diameter of less than 5” in which tools with the standard oil industry size of 3 5/8” (92 mm) cannot be run. The same counts for conventional mining. In these cases the tools are used sub-surface in long walls and tunnels for (sub) horizontal laterals exploration. It is clear that in narrow spaces bulky and weighty equipment is preferably avoided.

3.6.2 MEASUREMENTS WHILE DRILLING (LOGGING WHILE DRILLING)

Till the seventies measurements with instruments that were embedded into the drillpipes were limited to weight on the bit with strain-gauges, and directional data with magnetic devices. These two were later augmented with a simple geiger-müller gamma-ray counter. The need to measure resistivity, density and neutron porosity during drilling became acute when highly deviated and horizontal wells were drilled in large numbers. In these wells it is usually very difficult and often impossible to run wireline tools into the hole, due to the lack of the pull of gravity. Running tools at the end of the drillpipe is a costly, time consuming and often unsafe. Measurement while drilling (MWD) was therefore an attractive alternative. During the eighties equivalent MWD versions of the gamma-gamma density; the neutron scattering porosity; and simple lateral resistivity wireline tools were developed, which could be inserted in recesses in the drill pipes. Moreover new tools like the electromagnetic wave propagation resistivity, and bit resistivity tools were developed that have no wireline equivalent. The instruments are either powered by a generator connected to the mud-motor, or by batteries. The measurements are either stored in a memory downhole or transmitted via pressure pulses in the mud to the surface. The most advanced instruments use sensors placed on or immediately behind the bit, and EM signals are used to bypass the mud motor.

The receivers above the mud motor convert the EM signals to mud pulses which are transmitted through the mud to the surface.