The Wellsite Guide

An Introduction to Geological Wellsite Operations

Consulting Geologist
Jakarta, September 1995

What this text is about

This text addresses geologists who are going out to work as wellsite geologists in an offshore or onshore location for the first time. It gives instructions and a checklist-type overview over those wellsite operations which need geological input or supervision. THE WELLSITE GUIDE is not a sample description manual or geological data handbook. It is assumed that the wellsite candidate is - first of all - a geologist and knows, owns and is capable of using the basic tool kit of geological reference books, log charts and computer utilities, as far as they are of relevance for the work. Therefore no formulae, graphs or similar material has been incorporated into this text, they are better quoted from the original references.

THE WELLSITE GUIDE is rather meant as a briefing instruction to those geologists who are new to the trade or only occasionally wellsitting or, as a checklist for geologists who are changing from one operator or operating area to another, facing new concepts, routines and formats. It is also tried to introduce and illustrate modern or future developments that may be new to some "old hands" with no recent exposure to the actual work. However, owing to the fast development of techniques and methods, even this booklet will be outdated partly in very short time.

I thank Dr. Wolfgang Monninger for his critical review of an early version of this text and many constructive comments, most of which were incorporated. Thanks also to Mr. Richard Wells for his editing work on several chapters.

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1. The Job Description

The work of the wellsite geologist is defined in the following by one major operating oil company:

> "The wellsite geologist, as the source of all operational geologic information, is the most important link in the chain of communications between wellsite and management. The importance of the wellsite geologist to the overall successful termination of any project whose aim is to find hydrocarbons for exploration cannot be overstated. He is the exploration department's *man-on-the-spot* upon whose shoulders rests the responsibility for obtaining (of insuring that) every possible scrap of information which can be wrested from the earth and insuring that the data are transmitted to the office in a concise but comprehensive, coherent report.
>
> It is the wellsite geologist's duty to confer regularly with the company's wellsite drilling operations representative (company man) on location to forestall misunderstandings and to insure that the maximum information is obtained at the most economical price. Foresight, training and a working knowledge of drilling equipment, terminology and personnel are necessary to bring this to fruition.
>
> The wellsite geologist under the direction of the Company Operations Geologist[1] is responsible for *all* geology and geologically related administrative wellsite activity."

Depending on the company he is working for, the wellsite geologist may also be responsible for certain work in the company office, such as compiling reports, relaying routine reports to partners and maintaining contacts with various contractors.

[1]The position of an operations geologist may not be filled in a particular organization. The wellsite geologist reports in this case to the area geologist, the senior or chief geologist.

2. Getting Mobilized

2.1. Duties, Responsibilities and Authorities

Before you travel to the field, find out what your duties and responsibilities on location will be. As a wellsite-geologist, you should know exactly what is expected of you and how and when your reports to be submitted:

- Who is your supervisor? Whom do you report to? Make sure that you and your supervisor understand the relationship. It is very cumbersume to be on a rig and having different people calling and trying to tell you what to do.

- What sort of daily reports will be used for the project? What are the reporting deadlines? Some companies report at midnight so that the report is in the office at 6:00 AM in the morning. Others expect their reports to be up-to-date as of 6:00 AM, and expect an abridged update in the afternoon. Be certain that the requirements are clear before you head out to the rig. (See also page 49, daily reporting.)
  Check out the working schedule of the head office, when do thwe want to see their report.

- What is your work schedule? Will you be working a regular schedule or will your time on the rig depend on the well progress ("...stay until TD!") ? Typical on/off schedules are two weeks on - two weeks off or four weeks on - four weeks off. It depends mainly upon the logistical situation and the company policy. In some cases periods are required; however work periods which are too long will affect motivation and performance.

  Experience has shown that drilling operations tend to fall behind rather than move ahead of schedule. If your stay on the rig depends on the completion of certain steps (logging, casing, TD, testing, etc.) you are well advised to plan for the longest stay possible. Do not forget to inform your family (friends, or whomever) accordingly.

- Will you be picking casing points? If so, do you have to confirm with the base office in town?

- Will you be selecting coring points? If yes, do you have to contact your supervisor before you request a core ?

- Is it your responsibility to call wireline, velocity survey or other service companies so that they are on location on time, or will the office in town motify the contractors of the well's progress ?

- Do you have authority to sign service tickets for wireline logging, velocity surveys, mudlogging, MWD, wellsite biostratigraphy, etc.?

- Are you responsible for reporting movement and storage of radioactive or explosive substances used for logging, sidewall cores or perforating? Who has the formal responsibility for these matters ? The drilling department is responmsible for the safety of the drilling operation , they ordinarily are assigned responsibility for radioactives and explosives.

Regardless of other duties, you may assume that you will be supervising the mudlogging contractor on location. Whatever problems arise in the mudlogging unit will be your problems.

2.2. Office Preparation

- First of all, find out what this well is about. Is it an exploration well, a delineation or development project ? Get a copy of the well montage, the seismic line(s) through the well and

a copy of the drilling program. Read it carefully. What is the expected reservoir, what is known about it, what is the stratigraphic sequence above and below it. Collect and - if possible - copy refernce material of the regional geology. Of particular importance are descriptions and analysis of the rocks that will be drilled. Your job is to compare the findings in this well against data that exist already. Does this well confirm the understanding of the regional geology or is it a surprise ? You need to be able to comment or answer these questions at the wellsite.

- Get all the details about he well to be drilled. Is the well expected to be dangerous? Is it likely, or possible that there is shallow gas, overpressure, H_2S (see page 16), CO_2 ?

- Is the well to be straight or deviated ? Obtain a diagram of the well course from the drilling department.

- Are there special requirements for confidentiality? Will you encode part or all of your report? (See page 50)

- Will you be supervising or witnessing any wireline logging? Does your supervisor require a quick-look interpretation of wireline data? (See page 108, logging supervision for details.)

- Is electronic data transmission of log data planned ? (If so, Section 11.1 for data formats.)

- If you are responsible for supervision log acquisition, plan a session with the petrophysicist to get the basic information and instructions. Ask for parameters required for logging and preliminary interpretation. Get data on R_w and typical mineral composition of the area - if available.

- Will you be witnessing other operations which are not strictly the wellsite geologist's duty, such as perforating, testing or rig positioning?

- Will you be supervising a velocity survey or VSP ? If so, talk to the geophysicist for briefing. (More details on page 117, VSP.)

- Who are the contractors for mudlogging, wireline logging, well seismic, transport (helicopter, boating or land transport) biostratigraphy, geochemistry, etc? Get their addresses and/or contact numbers.

While you are in the office you should try to get as much information as possible about the project and make personal contact with the other exploration personnel involved. Meet the area geologist and geophysicist for special instructions. If you are new to the geological province try to get a familiarization session with the project geologist. This type of introduction is more valuable than reading heaps of literature.

- What are the sample collection requirements? Drill cuttings samples are taken routinely for analytical purposes and to satisfy the partners. Find out what type of samples, from what intervals and how many sets are to be taken. (See also page 44, sample types.)

- Will the operation and reporting be in metric or imperial units ?

- Assemble your collection of geological documents for the well (listed on page 12).

- As a courtesy, introduce yourself to the drilling manager. Ask his opinion of the prospect, which may be entirely different from that of the geologist.

- Discuss the mud program and possible changes to it. This may have some bearing on the wireline logging program. Will tracers (page 92f) be used?

- Try to identify and resolve any potential disagreements before going to the rig because you are likely to be at the center of any conflict between the various interests.

Find out from the drilling department or other sources of information what facilities are available on the rig.

- Telecommunications system: Is a telephone available? Is there a fax (facsimile) machine, and if so does it utilize telephone lines or shortwave radio? Is there a VHF or phone system connecting to the shore base or town office ?

- Computers: Will there be a computer at the wellsite, do you bring a laptop from the office or your own ? Are there any special programs, company specific software that should or must be used. Make sure that you have at least the same text processor and the same spreadsheet program that is considered company standard or fashionable in the office.

- Modems: Discuss the possibility and procedures of electronic data transmission (log data, see page 108). Find out what the modem settings are, which protocol software is in use and at which hours of the day the modem will be on and in receiving mode. Who is your partner to talk in the office in case something does not work (don't expect any help from the drilling department).

- Transport facilities: For personnel, samples and cores. Ships, crewboats, helicopter, fixed wing aircraft ? How will you get to location ? If you travel by helicopter, will you need a safety or survival certificate (page 15) ? Will you have to stay overnight somewhere, is there any support from an agent or a service company in the field ? Note the addresses in your notebook. Who buys and supplies airline tickets ?

- Shore base. Will you be going through a company base on shore (guest house, ware house, agent), does the company entertain a shore base ? If so, get the contact numbers.

- Medical facilities[2]: Is a doctor or medic on the rig? Who is responsible for emergency medical treatment? Where is the closest hospital?

Contact the service companies' base offices to introduce yourself. You may need to call them from the rig during operations (possibly even in the middle of the night) and it might be helpful if they know who you are in advance. The mudlogging and wireline logging contractors are particularly important in this regard.

- Find out the name of the wireline logging engineer(s), their suervisors, the base manger's name, and whether or not a second wireline engineer is available. Logging jobs may exceed 40 hours, and the safe handling of explosives and radioactive materials is essential.

- Confirm that all the wireline tools and downhole equipment are suitable for the anticipated temperature and pressure conditions. (See also page 107, logging supervision).

- Introduce yourself to the logistics man of your company and find out about the flows of material, transports of samples and cores and service company crew changes.

If you will be relieving another geologist who is already on location contact him (by telephone or radio) before you leave for the rig to ensure a smooth crew-change.

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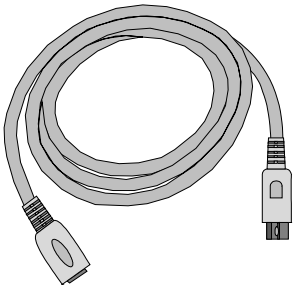
[2] Contingency planning for emergencies is the responsibility of the drilling department. On the other side, the wellsite geologist is the second company representative on the rig and should be advised about the particulars of emergency planning.

2.3. Materials and Equipment for the Wellsite Work

There are many things which might be useful at the wellsite, but it is preferable to minimize the number of things taken so as not to overload. Ordinarily there is laundry service on the rig or in camp, so that one change of clothes should be sufficient. Pack your belongings in a soft bag rather than in a sturdy suitcase, particularly if you will be travelling by helicopter. You may be mobilized with only a few hours notice, so you should you decide in advance what you will take along to the rig.

Minimum personal gear:



- Work clothes (coveralls), T-shirts and underwear. Wear one set and take another for changing.
- Safety shoes (required).
- Hard hat. Don't rely on the rig's supply as they may have visitors and run short.
- Safety goggles to protect your eyes against dust and aggressive mud chemicals.
- Select clothing with regard to the climate, and allow for unseasonably cold weather, if this is a possibility.
- Sandals, slippers or sport shoes to be worn inside the living quarters.
- Shaving kit, with the usual essential items.
- A sweat shirt or pullover may be needed *inside* their living quarters, which can be extremely cold on air-conditioned rigs.
- Spare glasses.
- ID card, company ID badge and passport.
- Money. Be sure to include some local currency if going to another country. You may need some to pay taxi fare, porters or airport fees. Do not take credit cards, checks or other valuables with you. They are useless on a drilling rig and prone to get lost.
- Cigarettes (if you are a smoker).
- Medicine, if you are under medication or usually take certain drugs. You may be suspected of carrying illegal drugs. Make sure your medicine is in the original package. Bring along your doctor's prescription if there could be any doubt or question.
- Watch and alarm clock. Make sure the alarm is loud enough to be heard over the usual background noise, and the batteries are still o.k.

Minimum working gear :

- Pencils and ballpoint pens.
- Notebook.
- Forms for sample and core descriptions, reports, routine communication, material shipment, transportation requests, etc. Take a collection of everything that might be useful. Take one form of each and photocopy on the rig, if possible.
- Blank master log forms[3], transparent preferred, in the appropriate units (metric or imperial).
- Calculator. (Preferably a programmable calculator for quick-look log analyses).
- Ruler.
- Rapidograph (or other) drafting pens (two or three, size 0.25, 0.35 and 0.5) and drafting ink.
- Colored pencils (just a few).
- Contact telephone numbers (including home phones, pagers etc.) and addresses of the supervisors and decision makers in the office and of the relevant service companies (mudlogging, wireline, freight agents, transportation contractors, etc.).

[3] It is very practical to use master log formats similar to wireline log displays. Transparents can be copied on fan-fold blue print paper available in the wireline logging unit and fit into the fax machine.

- Shipping addresses for samples and cores.
- Manuals and documentation (see page 12 for more details).

If there is any possibility that you may be coring, be sure to include the following:

- Hand lens (6x, 10x or combination 10x and 20x).
- Geologist's hammer to take rock chips from a core.
- Marker pens.
- Steel tape measure .

With this minimum gear you should be equipped to do your job on the wellsite. However, you may want to add a few items from the following list to your expedition baggage.

Additional personal gear :

- Rain coat (or rain coveralls).
- Radio, cassette or CD player.
- Pocket knife (always useful).
- Books, magazines for your leisure time. Be prepared for unexpected periods of down-time, which can come at any time.
- Camera and flashlight (batteries !).
- Padlocks (to protect company and private valuables).
- Torch (flashlight) with spare batteries (needed to check shakers, desander, desilter, etc. during the night.)

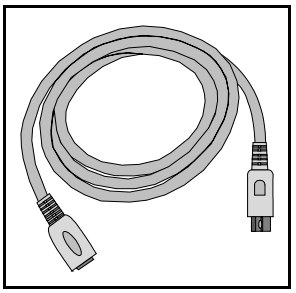
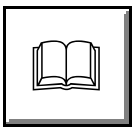


Figure 2: Think of power cables for the computer gear. Rig plugs may not have the same voltage or connector like in the office!

Let your selection be guided by the job you are going to, the expected length of your stay and the remoteness of the rig from your supply base or office. Depending on the these factors, you might bring anything from the bare minimum (see above) to a complete office, drafting room and petrological lab. A reasonable compromise might also include the following:

- Clip board.
- Laptop computer (with printer, modem, cables, etc.), loaded with text processor, spreadsheet, graphics program, log interpretation software etc. Don't forget the latest anti-virus software.
- Scaled ruler (1:200, 1:500, etc.).
- Rubber stamps with well name and location, company mailing address, etc.
- Writing pads, envelopes, white (address) stickers.
- Transparent paper, graph paper, etc.
- Correction fluid, white (to make the final corrections on fax reports).
- Scotch tape, stapler, hole puncher.
- File folders, files or something suitable to organize your work.
- Magnets (for displaying maps and montages on the wall. Warning: these must be packed and stored far from computer diskettes and magnetic tapes).
- Business cards.

- Manuals :



  - Wireline logging chart book.
  - Log interpretation handbooks.
  - Sample description manual[4].
  - Drilling data handbook.

[4] Swanson,R.G.: Sample Examination Manual .- *AAPG Methods in Exploration Series,* Tulsa, 1981

- Geological documentation :

    - Well proposal, well program, prospect montage.
    - Selected seismic lines.
    - Logs from offset wells for correlation and reference.
    - Seismic time/depth charts from control wells.
    - Directional well course diagram (if any).

- Programmable calculator, computer, programs, software manuals and batteries or 110 V adaptor with the proper adaptor plugs.

- If you will be using a computer, consider taking templates for spread sheet programs and diskettes with customized programs and report forms. The following items may be particularly useful:

  Diskettes:

  - Spread sheet with seismic velocities, interval velocities, of surface seismic and adjacent wells, pre-set graphics.
  - Spread sheet for quick-look log interpretation
  - Spread sheet for extrapolation of wireline well temperatures
  - Spread sheet for overpressure prediction (as questionable as the particular methods might be; see also page 63).
  - Other software (such as programs for log interpretation, report generation, communications, data base, word processor, - just to name a few).

- Company stickers (baseball hats, T-shirts). These give-away items are ideal for making friends and honouring people you work with for their cooperation, and as gifts for officials or visitors. Remember that you will be representing your company at the wellsite.
  If you are a consultant (free lance or self employed) it might pay to promote yourself. Have some lighters, pencils or other gadgetry made up with your contact number or address on them. This investment could provide valuable contacts for future work

2.4. Travelling and Arriving

The trip to the rig may be by car, supply boat or small motorboat, airplane, helicopter or any combination thereof. Even if your destination is only a short distance, you should expect to be delayed and have to spend the night somewhere enroute. You may be hoisted on the deck of the rig in a crew basket or you might be the last passenger on a fully loaded helicopter. Therefore, travel light. If your belongings weigh more than ten or fifteen kilograms and you are travelling by helicopter you should reduce it. It may be possible to transport part of your gear as cargo, particularly if you are carrying company materials, spare parts, etc.

If you travel by air, you must comply with air safety regulations (see also page 15 regarding helicopter safety). When flying over water you must wear a life vest. In cold areas, survival suits must be warn. These are insulated garments which keep you warm enouth to survive for a time in cold water. Follow the instructions given by the pilot or the dispatcher.

- Immediately upon arrival on the rig report to the radio operator who will add your name to the crew list (POB list) and assign your lifeboat station.

- Make sure, radio operator knows who you are, what your name and function is, and who you work for. He will receive the radio or telephone calls from your office and page you all over the rig. It is therefore important that he does not mistake you for a service company hand.

On some rigs you must also report to the safety officer, the liaison officer or (in certain countries) to the police or army representative on the rig. One of the above will direct you to the *camp boss* or *chief steward* who will show you to your room, shack or cabin and assign your bed. Find out where the galley is and when it is open. Most rigs provide four meals a day, every six hours. Coffee, tea and some kind of cookies are always available. Most rigs require, that you dress properly for the meals, i.e. wear clean working clothes.

Before beginning your work you should pay a *courtesy visit* to the *rig superintendent*[5] and to the *captain*, on a drillship or floating rig.

2.4.1. The Company Man

The drilling supervisor, colloquially referred to as the "*company man*" is the operator's representative on the rig. He is the person ultimately responsible for nearly all aspects of the operation, in particular the safety and operation of the rig. The wellsite geologist works in close cooperation with him but is not under his authority, does not report to the company man. If possible, introduce yourself to him before you start work. A good working relationship between the wellsite geologist and the company man is of paramount importance. He may be friendly and cooperative or a card carrying arsehole, but in any case you must work together with him.

Assume that the company man and his counterparts on the side of the drilling contractor (the "drillers") do have no or only a marginal understanding of the work of a geologist in general and even less appreciation of his work. They assume that he is only on location to look at drill cuttings and fill out a few blanks on the morning report. The position of a geologist is therefore considered much less important than the work of any service contractor.

3. On the Rig

3.1. Safety

The major safety hazards on offshore drilling rigs are well blow-outs, poison gas and storms. The ordinary safety hazards associated with any industrial or marine operation such as fire, falls, falling objects and electrical hazards are also important.

Safety is top priority on the rig. For the wellsite geologist this means being aware of potential hazards, knowing the how to prevent accidents and knowing the emergency procedures. Find your lifeboat station as soon as it is assigned to you. Familiarize yourself with your duties in emergencies. Most rig operators assign the geologist to "standby" in emergencies, meaning "keep out of the way".

The most significant contribution of the geologist to rig safety is in dealing with overpressured zones, particularly shallow gas sands. (See page 63, overpressure, for details.)

For your own personal safety:

- Wear a hard hat (helmet) and steel-toe boots whenever outside the living quarters.
- Do not smoke outside designated smoking areas.

[5] The rig superintendent or rig manager is the representative of the drilling contractor at the location

- Watch out above you when walking outside, particularly when near the pipe deck or wherever a crane or forklift may be operating.

- Familiarize yourself with the communication system (telephone, pager, alarms, etc.) on the rig. Check the location of the nearest phones relative to your different working areas and learn the most important phone numbers (rig floor, company man, mudlogging unit, radio room, etc.).

- Learn how to sound an alarm. Usually all alarms are directed to the driller on the rig floor because this position is always manned. The driller is familiar with the emergency procedures on the rig and trained to take the appropriate actions in an emergency. On big semisubmersible rigs, emergencies are managed from the control room, the place which controls engines, pumps and boats.

- Familiarize yourself with the locations and types of fire extinguishers in your working and living areas.

- It is good practice, even in warm countries, to wear long trousers or a coveralls rather than not shorts.

- In tropical onshore locations, always check your boots for bugs, scorpions, etc. before putting them on. Watch for snakes near the mud pits and mud pumps.

- When pulling cores, never allow anyone to put their hands beneath a core barrel. Core fragments on the rig floor should be retrieved with a hammer or other tools whenever the core barrel is still suspended.

3.1.1. Helicopter Safety

Many fatal accidents in context with oil field operations happen while travelling with helicopters. Therefore, many oil companies send their personnel to a helicopter survival training and require such certificates from their service company personnel or consultants. Other companies take the position that only *regular* personnel going to the rig requires such training, thus often excluding geologists.

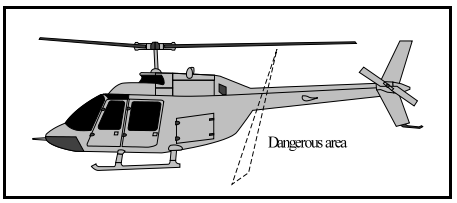


Figure 3: Beware of tail rotor. Always go to the side or front when boarding or leaving the helicopter.

- Attend the safety briefing prior to boarding and listen carefully to all instructions given by the helicopter crew.
- Wear your life jacket, and wear it correctly.
- Wear survival suits when supplied. These suits guarantee several minutes of extra (life-) time after ditching in cold water and may save you from hypothermia.
- Study the safety leaflet. Be familiar with the operation the life jackets, the position and operation of the emergency exits, and the location and operation of the life rafts.
- When approaching or leving the chopper, do not wear any hat, not even a hard hat. It will be blown away by the strong winds of the rotors and might create a dangerous situation for the bystanders.
- Do not approach or leave the helicopter from the rear. When landing on a slope, leave the helicopter towards the down-hill side.
- If you have to walk around the nose of the chopper, be aware that the rotor blades can be as low as 1.5 meters above the ground, in partcular when strong winds blow.
- Do not smoke when the "No Smoking" signs are lit, on the helideck or outside the terminal.
- Always keep your seat belt fastened.
- Be careful when loading and unloading material. best, leave the cargo handling to the ground crew, they are trained for it.

3.1.2. Hydrogen Sulfide, H_2S

H_2S or sour gas is extremely dangerous and toxic. It can cause sudden death, even in very small concentrations. H_2S is heavier than air, it is soluble in water and hydrocarbons and H_2S is explosive when mixed with air. If H_2S is coming to the surface the well should be shut in. In the event that H_2S is encountered you may need to remind the other crew members that this poison gas is heavier than air, and that they should move higher on the rig rather than lower to escape from it. H_2S tends to accumulate in low places such as in the substructure, near the shakers, the pit room, etc.

Effects of H_2S

ppm	Effects
5-10	Obvious odor of "rotten eggs".
20	Safe for about 8 hours exposure per day
100	Kills sense of smell in 3-15 minutes, may sting eyes and throat.
500	Reasoning impaired and dizziness. Breathing ceases after a few minutes. Prompt artificial respiration required.
700	Unconscious quickly. Brain damage/death will result if not rescued promptly.
1000	Unconscious at once. Brain damage/death after 4 minutes.

If you are on a land drilling site, find out where the evacuation areas are or could be. Some open, elevated place. Check out if or where a wind indicator is on the rig. Would the camp need to be evacuated ? If so, are there alarms in the camp or any method to alert the camp properly ?

Generally, find out what the H_2S alarm system consists of . Is it a sirene, a PA-speaker announcement? Then where to go ? Was there an H_2S safety briefing, do you have evacuation procedures ? Do you have your own, personal breather pack ? If you feel that you have no idea what *the plan* might be - ask the company man. he might answer himself or delegate you to his safety officer.

- Anyone who suspects the presence of H_2S *must* alarm the driller on the rig floor immediately. He will then instate an H_2S alarm and give the necessary instructions.

- *Do not attempt to rescue a person who has been overcome by H_2S without a breathing apparatus.* There are two reasons for this precaution. The first is that the gas is probably still concentrated in the area and it can kill you, and the second is that the victim is probably beyond help. Remember, one breath of H2S can be fatal. *After you put on your breathing apparatus*, move the victim to fresh air and and keep him warm. If the victim is not breathing, artificial respiration must be administered immediately.

Note, that steel that comes in contact with H_2S becomes brittle. Drill pipe (see page 77) is particularly exposed to any H_2S. Drilling in H_2S prone areas requires casing and drill pipe made of special steel.

3.2. Working Space

As geologist you have many maps, logs, book, the computer, drafting material and other working gear. It is a classic problem to find and defend a desk in a reasonable working area. Depending on the design of the rig and the cooperation of the company man you should be able to find adequate space. (This is more of a problem on jack-up rigs than on semi-submersibles, which have more deck space.) In the worst case you still can work in the mudlogging unit, but this is often inappropriate from many points of view. It is commonly not spacious enough to put your maps and seismic sections to the wall, it is *always* busy, and you cannot keep sensitive data confidential in this place. (See page 50, confidentiality.) If you have a private cabin you might work in the living quarters, but you will need to carry your paperwork with you. Ideally there will be a separate office for the geologist near the company man's office, with an

unobstructed view of the drilling floor. It should be equipped with a remote video display (page 33) of the pertinent drilling data (provided by the mudlogging contractor).

3.3. Wellsite Psycho-hygiene

On most rigs you will meet all sort of characters, different nationalities and people with various different socio-cultural backgrounds. They have all one thing in common, which you share with them: Getting the job done and earning money. You have to work together (whether it is easy or not) and you have to live together. This does not mean that you have to be close friends with everyone, but it definitely means that you should adhere to the basic rules of civility and courtesy.

You may be working under psychological stress, often without a sufficient rest. Remember that many of the people working with you are in the same situation. You are literally "all in the same boat". You cannot escape this togetherness even during your leisure time. Your personal goal should be to avoid conflicts and handle any differences that may arise. The fact that you live very close together with no immediate alternative makes it essential to get along well with people. The following points may help you to develop your own personal conflict prevention and handling procedures:

- Get enough sleep. Drilling goes on round the clock but you cannot stay up around the clock and still do your job. Build your own daily schedule around the reporting deadlines.

- Do not take pills to sleep or pills to keep you awake. Their affects can be worse than not sleeping at all.

- Do some physical exercise every day. Some rigs have a "gymnasium" or workout room. If not, suggest it to the company man. There are probably others on board who would also enjoy using it. You can also go jogging around the helicopter deck. Physical exercise is an excellent method to release stress, improve your mental attitude and increase you appetite. Otherwise your bad moods may turn into conflicts with your colleagues.

- Be patient. Never get angry and excited. Be prepared to take more abuse than usual if necessary. The only survival mode on the rig is the mental attitude of an old elephant.

- Take something along to enjoy during your leisure time. This can be a radio[6], a book or a chess game, or even golf clubs or musical instruments (the generator room is a great place to play the trumpet). There is usually good fishing[7] and there may even be competition to grow the biggest sunflower or tomato on a rig (reported from the North Sea). Most offshore rigs also have a video room and a gymnasium for work out.

- There may be things happening on the rig which do not qualify for reporting. You might also get to know some of the details of your colleagues' personal lives. Whatever it may be, as long as it does not directly affect your work or safety, leave it on the rig. Do not bring gossip to town or to the office.

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[6] Radios do not work inside an offshore rig. The metal walls act as a Faraday Cage and inhibit radio reception. Only a few modern rigs have antenna outlets wired in the living quarters.

[7] Fishing is prohibited for safety reasons on some rigs and platforms. The fishing lines might cause trouble to the divers if left around the well head. Check with the rig superintendent or safety officer of the drilling contractor if fishing is allows on your rig.

- Venting and air conditioning: The mudlogging unit must be overpressured with fresh air taken in from a "safe" area. Check that the venting system works: open a door and observe the pressure drop. Check the location of the air intake: It should be in a safe area (ask the rig supervisor if in doubt). Any location near the shale shakers, the rig floor or the flare booms is *not* a safe area.

- Inside the logging unit: Is the place clean and tidy ? The area where samples are washed and packed is always *a bit* dirty, but the rest of the unit *can* be clean.

- Is the mudlogging crew complete ? Get the names of all mudloggers (day and night shift), and the name of the pressure engineer(s). Find out when the last crew change was and when the next crew change is scheduled.

- Make clear to the mudlogging crew - in particular in onshore locations - that you wish to be informed whenever a member of the crew leaves the location, irrespective if the man is on tour or not.

The actual crew change is usually arranged with and through the company man. He is the one who allows someone to leave the location. Nonetheless, a "well behaved" crew will tell their geologist who is coming and who is going.

Safety aspects :

- Is the unit pressurized and all doors kept shut ? This should prevent poisonous gases from entering into the unit.
- Is at least one fire extinguisher available ? Is it of the correct type ?
- Are H_2S masks available for everyone who works in the unit ? This point may not be applicable for operations where the absence of H_2S is definitely known such as basins in a mature stage of exploration or development drilling.
- Are life jackets available (marine operations only) ? There should be life jackets for the entire mudlogging crew in the unit, not only the jackets for the crew on duty.
- Are there flashlights ? Emergencies have a tendency to happen at night and proper lighting contributes to the safety while abandoning the unit.
- Are personal descend lines[9] available (marine operations only) ?
- Is the communication system (usually a telephone) working properly ?

Fineprint: The following points should be checked although they may not apply in every country and on every operation:

- Has the mudlogging unit been inspected recently ? Is there a copy of the inspection certificate ?
- Excessive noise in the unit ? Does it exceed safe working conditions ?
- If dangerous or toxic fluids and substances are handled in ther unit information should be displayed emergency procedures in case of spill or exposure.

Some cosmetics: If the unit is newly deployed to an operation in certain Middle-East countries, this may be the moment to take off the common oil field pin-ups. These can be a cause of misunderstanding and unnecessary trouble in such areas. At the sime time, have a look for possibly rude or otherwise inadequate displays and grafitty that should not come to the eyes of an official inspector. Clean the house.

[9] Descend lines are special ropes made of synthetic fiber and constructed in a way that every layman can use it like a mountaineer to lower himself into the sea or on deck a ship in case of emergency.

Geology related:

- Are all strip charts properly annotated with scale, time, depth and explanations of unusual readings and events ?

- If the mudlogging services are based on an electronic database, find out when and how the database is being backed up.

- If not already available, set up a *log book* for the mudlogging unit. This is a bound book with numbered pages. It is to record any instructions given to the mudloggers, calibrations and changes made to the equipment. The mudloggers are required to note all relevant events in the log book. It can be used as well to note any sample material transfer from the unit to other locations.

- Sample storage: Where are the samples of the last section drilled, the relating transmittals, how and where is the current lot of samples stored and packaged ?

The basic concept and idea of the wellsite geologist's work is data collection (see page 7, job description). Therefore it is important that you make sure that all data and samples are clearly documented, labelled, described and annotated, so that no questions or ambiguities arise once the material is reviewed in the distant future. Good quality work is orderly work, at least in this context. *As a fundamental concept of the geological science observations and facts are to be kept clearly apart from the interpretation*. Do not accept sloppiness in any respect.

Keep data and interpretation apart !

- Make sure the work is up-to-date. Even in times of very fast drilling, the mudlog must be updated at least every twelve (12) hours before crew change. If the workload is really too heavy, you, the wellsite geologist has to find a solution, or must step in and help. One of the ways to alleviate the work load on the mudloggers is to use ther services of a sample catcher, unskilled help to catch, wash and bag the sample material during times of fast drilling.

4.2. Consumables and Spare Parts

Consumables and spare part stock depends on the logistic situation of the drilling site. Stock on location should be enough for at least one week of normal drilling operation, two or three weeks if you are in a remote location. The list below gives only an overview of the materials that should be on location, without exception:

The basic tool set necessary to do geological work:

- Microscope (actually a binocular type microscope with 6-20x magnification).
- UV box (sometimes combined with the microscope).
- Sieves to wash the samples. The screen of the sieves must be made of metal. Typically stainless steel or some bronze or brass alloy is used. Reject plastic sieves ! (See page 51, for handling instructions)
- Sample trays.
- Tweezers and pins (preparation needles).
- Magnet (stud finder) to separate ferromagnetic material (such as metal shavings from the casing) from the cuttings.

Test agents :

- Clorethene for hydrocarbon solvent tests (cut). Check if the agent is contaminated with fluorescent substances (UV light).
- HCl (carbonate tests and etching of carbonate rock surfaces).
- BaCl for sulfide test.
- $AgNO_3$ for chloride test (important if you drill evaporites).
- Alizarin S for carbonate staining (dolomite and calcite determination).
- Phenolphthalein (staining agent for cement).
- Tetrabromethane (used for the distinction between gypsum and anhydride and shale density fluids, see page 43). Tetrabromethane is carcinogenic !

Clorethene is poisonous in high concentrations. Work only with good ventilation and use only small volumes. Clorethene is non-inflammable and therefore preferred over other solvents such as Acetone.

Other chemicals :

- $CaCO_3$ as calibration for the calcimetry test (page 42.) Hydrochloric acid should be available anyway. Check for sufficient stock if calcimetry is planned for all samples.
- Carbide for lag time check (see page 36)
- Calibration gas for the gas detectors.
- Biocide (to prevent bacterial growth in geochem samples).
- Desiccant for the gas dryer in the gas suction line.
- Ammonia (for blueprints).

Kits and tools :

- Shale density test kit (see page 43 for procedures).
- Calcimetry test kit (Autocalcimeter). This includes glassware (best a pipette) a precise balance which can accurately measure weight of one gram or so with at least 1/10g accuracy.
- Thermometer.
- Glassware for chemical tests (test tubes, hour-glasses, scaled glass tubes (1/10 cm^3 sub-scale, pipette, etc.).
- Soldering and electrical tools, multitester (for resistivity, voltage, etc.), small screwdrivers, tongues, spare cables and connectors, insulation tape, contact cleaning spray, etc.
- Hydraulic oil (required to fill pressure transducers)
- Spare light bulbs for the microscope illumination and the UV box.
- *Gas bladder*, a football-like rubber bladder to collect gas from the separator or RFT tool and transfer it to the chromatograph. To my knowledge, only one mudlogging company offers this equipment. Nevertheless, it should be on every location. The use of children balloons as a substitute is not satisfactory because they burst (irrespective of what other people tell you).
- Coffee kettle, not only to make a cup of coffee during hard times but also to provide hot water for the *hot water test* (see page 56) to evaluate oil shows.
- Grinding powder, glass plates, optically neutral resin, slides, heating plates, etc. (if it is planned to make thin sections).
- Blender.
- Basic mud test kit consisting of balance and funnel.

Stationary

- Spare rolls and pens for the strip charts.
- Blueprint paper.
- Report forms.
- Computer printer and plotter paper.

- Are the alarms for gas set properly, i.e. close enough ? The alarm should sound if the gas level reaches about twice the background level. This may need frequent adjustment when the background level fluctuates. Anyway, check every time you go to the mudlogging unit.

- Check the gas trap and the suction line at least once a day. Is the gas trap installed properly in the shaker feeder tank (possum belly)? Is the suction line straight without kinks that may obstruct the flow of gases ?

- *Notification procedures.* If the gas levels exceed a certain threshold, the mudlogging crew *must* report to the *company man and the geologist.* Some operating oil companies or rig operators require that gas readings over 50 or 100 units are announced all over the rig through the PA system so that hot work (welding, grinding, etc.) is paused. Note the valid procedures in the log book of the unit. Then there will be no excuse saying, we never did this that way before...

- If the mudlogging unit is operational during a drill stem test, the low pressure side of the separator should be connected to the chromatograph and the gas composition analyzed and recorded at regular intervals.

- See page 54 for interpretation of gas shows.

- Note also that on offshore operations, the long riser leading through cool sea water cools down the mud considerably. Onshore and offshore flowline temperatures are therefore not comparable.

4.3.2.10. Mud Density

A change in mud density, in particular a decrease of mud density indicates that the mud is diluted. This may be at surface when the drilling people reduce the mud weight for one or the other reason. A more severe situation is given when the mud is diluted with formation waters. This means also that the formation pressure exceeds the hydrostatic pressure of the mud column, - in other words - the well is not in balance. This is an alarm situation that must be reported immediately to the company man.

- Compare the reading of the mud density sensors (*in* and *out*) with a mud sample taken at the sensor point. Use the mud engineer's mud balance to verify. Accuracy should be better than 0.1 ppg.

- Of course, the mud density readings must agree with the mud weight reported by the mud engineer. Follow up if there are any discrepancies.

There are two different types of mud density sensors. One is a simple device based on the principles of buoyancy, the second, a nuclear density sensor. The latter works usually fine but the buoyancy sensor is sensitive to dirt and sometimes quite unreliable.

4.3.2.11. Standpipe Pressure

Principle: The pump pressure sensor consists of a diaphragm protector head and a pressure transducer. The head consists of a steel body with a thick rubber diaphragm inside. The inside of the rubber diaphragm is exposed to the mud pressure in the standpipe and transmits the pressure to the hydraulic fluid inside the body of the protector. This hydraulic pressure is then transmitted through the hose to the transducer assembly. The pressure sensor is a piezo-resistive Wheatstone-Bridge strain gauge with a signal conditioning circuit that produces a current output directly proportional to the pressure detected.

The standpipe pressue is of high interest to the driller but relatively unimportant for the geologist.

- A change of standpipe pressure can indicate washouts in the drill pipe, plugged bit nozzles, condition of the downhole motor (if used), etc. The standpipe pressure is recorded continuously on strip chart and - on modern logging units - on computer. This parameter is used to calculate several hydraulic parameters used to optimize drilling. There is little relevance in the standpipe pressure for the geological interpretation.

- When coring or when drilling with a downhole motor or turbine, the standpipe pressure gives an indication if the downholle gear is performing properly.

- Compare the read-out in the mudlogging unit with the gauge on the rig floor. Accuracy should be better than 5% and precision should allow the detection of pressure changes ±25 psi

Note also that changes in ambient temperature may introduce some variation in the apparent pressures recorded (diurnal base line shift) as the oil in the pressure transducers expands or contracts with temperature.

4.4. Mudlogging Procedures and their Checks

Despite the wide range of computer applications and automatization, the quality of the mudlogging services depends primarily on the skills and performance of the mudlogging crew. These non-automated routines are called procedures in the following:

4.4.1. The Mudlogger's Work Sheet

Before data are fed into the computer systems, they must be recorded on paper. The mudlogger keeps a tally book of the singles added to the drill string and copies this information to the work sheet. The work sheet list per depth increment (e.g. per meter) - at least - the following information:

- The pipe tally, i.e. lenght of single pipe added to the drill string and the total length of the drill string. The work sheet must show the exact depth of the well after the current pipe has been drilled down.
- Lag time and increment of lag time per unit of new hole, i.e. how many *more* pump strokes are necessary to lift the cuttings from the bottom to surface for every meter (or foot) of *new hole* drilled.
- ROP as worked out from the kelly height indicator, ("geolograph").
- Gas readings of the total gas recorder and the chromatograph.
- Lithology description of the cuttings samples.
- Oil and gas show descriptions.

This work sheet - if kept properly - is a complete documentation of the well history and the geology encountered. It should be up-to-date, with the last entries not older than exactly one depth increment (something in the range of five meters when drilling fast in top hole and about one meter when drilling deep hole slowly.

- Make sure that the work sheets are handed over to the geologist or another representative of the operating oil company. Reason: Confidentiality.

4.4.2. Chart Recorders and Charts

Even though nearly all modern mudlogging systems are based on a digital database and digital displays, the charts, i.e. the paper prints of the data are an important media of documentation and interpretation.

Charts are graphical recordings of sensor data on paper - directly or through a digital data system, which modifies, stores and then displays the data.

- All charts are to be marked every hour on a 24:00 hour basis including date (every 12:00 hours), including depth and well name.
- Any calibration must be recorded on chart and annotated.
- Carbide checks and calibrations must be marked clearly on the total gas and chromatograph chart. Mark also whenever the gas line is serviced or back-flushed.
- ROP chart: Each kelly down should be marked, as well as starting to make new hole (i.e. the position of the kelly height when the bit is on bottom with its full weight). Drilling breaks are to be marked (interval, top, bottom, etc.)
- Pit level charts: Any change of pit level must be explained on the chart.
- If a kick is suspected, note on the chart who was informed and when (time!). You may also record this situation in the log book of the mudlogging unit - *after* calling the driller and the company man

Explanations for a pit gain can be:

- Kick (formation fluids are entering the well bore).
- Mud is being transferred into the active system at surface.
- Water added at surface (diluting mud).
- Kick drill (see also page 40).

Explanations for a pit volume decrease can be:

- Mud loss to the formation.
- Mud transferred out of the active system at surface.
- Mud dumped (or part of the mud system disposed of, such as dumping the sand trap).
- Mud loss over the shakers. The shale shakers may be plugged with LCM materual or fine fraction drilling returns. Then the mud is lost over the shakes and does not flow back to the mud pits.

Complete rolls of charts should be marked clearly indicating the sensors recorded (name trace and color), well name, depth and time interval. they should be stored in the logging cabin until the end of the well and then transferred to the company office in town. One box should correspond to one recorder. Note that the charts are confidential data. Note, that the confidentiality also applies to the mudlogger's work sheet (see page 34).

4.4.3. The Mudlog

The presentation of the mudlog should be clean and tidy. Check for consistency and edit the geological descriptions if you feel it is necessary. The mudlog *must be up-to-date*, it can be expected, that the mudlogging crew completes their work on the log before they go for rest (e.g., after a 12 hour shift) so that the new crew starts with a clean desk (see also page 20).

- There are several ways to plot the ROP curve: feet per hour [ft/hr], minutes per foot[min/ft] and the same in metric units minutes per meter [min/m] and meters per hour [m/hr]. In any case, the ROP should be displayed in a way that the slow drilling intervals deflect to the right and the fast drilling intervals to the left of the track. This mimics the character of a gamma ray log: left = sand or limestone = fast drilling progress.

- If the mudlog is generated from a computer database, make sure that the mudlogging crew follow good practise and back-up their computer based data regularly, - best daily.

4.4.4. Daily Reports

The mudlogging crew has to prepare a daily report. This report consists of the mudlog and a text report (gas, show evaluation, formation description, etc.) covering the last 24 hours. This report is distributed to the geologist, the company man and the representative of the drilling company. If a pressure engineer (see page 63) is on location, their reports may be combined.

Some companies request also a *show evaluation report*. This report describes and evaluates hydrocarbon shows encountered within the reporting period.

- Note that the mudlogging report does not necessary cover the lithology down to the last foot or meter drilled in the reporting interval. If drilling continues, the report will cover the last *sample at surface* at the end of the reporting period[11].

4.4.5. Lag Time Calculation and Cuttings Transport

Lag time means the time in minutes or number of pump strokes necessary to move a sample (cuttings, oil or formation gas) from the bit to the surface. Other, related numbers are the *down time* the number of pump strokes or the time in minutes required to pump the fluid down the drillstring to the bit, and the *round time* the time required to pump the fluid down the drill string *and* up the annulus. The round time is the sum of down time and lag time.
The down time is usually only very few minutes wheras the lag time ranges between twenty minutes and more than two hours, in some cases.

Complications arise offshore. On floating rig, the riser is the biggest diameter pipe and annular velocities can therefore be very slow. It is common that the drillers line up an additional pump to the base of the riser to boost the velocity and improve the cuttings transport in this section. Of course, this additional pump output must be included in the lag time calculation. In this case calculate the riser as seperate hole section with different pump throughput and add this number to the lag time calculated for the cased and open hole section.

The mudloggers keep a calculation sheet with all the pipe diameters in the hole (casing, open hole, drill pipe, collars, etc) and their capacities. The lag time is updated automatically by the computer or by hand on the occasion of a new connection for the *hole take* and increased *lag time*. With every new meter drilled, the lag time increases and also additional volume of mud is required to keep the hole full.

Check the calculations and pipe volume parameters[12] used for the lag time calculations and compare with a carbide check.

- When a connection is made, carbide, wrapped in paper, is put into the drill pipe and pumped downhole as the circulation resumes. Carbide reacts with water and gives off acetylene, which can be detected by the total gas detector. Calculate the lag down (pump strokes to pump it down) and lag up (bottom to surface) and see if the artificial gas peak comes in correct. In cased hole, you can calculate the pump efficiency. With given pump efficiency, you can calculate the hole diameter over open hole sections, where you may suspect washouts. If no carbide is available on location, use rice(!) instead. Reduce the sample interval and find if the first rice grains come up with the right number of pump strokes.

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[11] Example: If the well has been drilled to 5000' at 6:00 hrs in the morning and the last sample seen at surface was from 4500' at 6:00, then the report will close with the lithological description down to 4500'.

[12] such as casing volume, open hole volume, displacement of tubulars like drill pipe, collars, tubing etc. Manuals of the cementing companies (DOWELL SCHLUMBERGER or HALLIBURTON) give answers to this questions. If such a manual is not available in the mudlogging unit (it should be!), try the company man's office or the cementer on location.

- If the first arrival of the carbide gas is not consistent with the lag time calculation, search for an explanation. In any case, the calculated and actual (carbide-) lag time should be recorded in the log book. If you have access to a small computer, make your own spreadsheet for lag time calculations to crosscheck the work of the mudlogging crew..

- Always use constant amounts of carbide (e.g. exactly hundred or two-hundred grams, - use a balance). The carbide peak measured should the be constant on the total gas detector, if not, this is an indication that something has changed downhole. It could be a washout, changes in mud properties, particular in mud weight.

- If the carbide is significantly too early and the peak small, consider also a wash out in the drill string.

- Always run a carbide test when drilling out casing shoe. At this time the entire mud circulation is within the casing the diameter of which is known precisely. The difference between the calculated and actual lag time can be attributed to pump efficiency. This pump efficiency (as factor or percentage) will then always be applied for the forthcoming open hole section. It is unlikely to change unless the drillers change the liner of the pump and/or its pistons.

  Note that this pump efficiency was calculated for one of the two pumps or both pumps running together. The pump efficiency needs to be established again if any of the relevant parameters (number of pumps running, speed, liner size, etc.) is changed. (See also page 82).

- In the open hole section, i.e. when drilling longer distances of new formation, the lag time (after correction for pump efficiency) gives an indication of possible hole wash outs, calculated as an increase in average hole size (**Figure 18**, **Figure 18**). Given the nominal lag time corrected for pump efficiency is available (that is why you should run a carbide check in casing) the lag time equation can be solved for the *average* open hole diameter.

The lag time is only the theoretical time (or number of pump strokes) hat cuttings and formation gas in the mud would need to come to surface and be sampled or detected. In practise, cutings will always be late realtive to the nominal lag time and gas *can* be early. The difference between the calculated lag time depends on cuttings size and density, the mud density and the annular velocity and type of flow (laminar or turbulent).

The following formulas put it into a mathematical background:

One widespread method in determining slip velocity of cuttings during drilling operations is Moore's correlcation. The correlation involves equating the annular frictional pressure-loss for the power-law and Newtonian fluid models and then solving for the apparent Newtonian viscosity.

The apparent Newtonian viscosity given by the first equation is then used in calculating particle reynolds number given in the second equation. The assumed perticle Reynolds number is checked by the calculated perticle Reynolds number given in the second equation.

μ_a	Apparent Newtonian viscosity
d_1	The outside diameter of the inner pipe (drillpipe, collars, etc.) in inches
d_2	Inside diameter of the outer pipe, the borehole diameter in inches
d_s	The cuttings diameter in inches
F_T	Transport ratio (dimensionless)
K	Consistency index of the fluid
n	Flow behavior index of the fluid
NR_p	Particle Reynolds number
V_a	Mean annlar velocity in feet per minute (fpm)
V_{sl}	Perticle slip velocity
ρ_s	Cuttings density in g/cm^3
ρ_f	Fluid or mud density in g/cm^3

Moore's correlation:

$$\mu_a = \frac{K}{144}\left(\frac{d_2 - d_1}{V_a}\right)^{1-n} \cdot \left(\frac{2 + 1/n}{0.0208}\right)^n \qquad NR_p = 928\,\frac{\rho_f \cdot V_{sl} \cdot d_s}{\mu_s}$$

$$V_{sl} = \frac{2.9\, d_s\, (\rho_s - \rho_f)^{0.667}}{\rho_{fl}^{0.333}\ \mu_a^{0.333}}\ , \qquad \textit{for } NR_p < 300$$

$$V_{sl} = 82.87\,\frac{d_s^2}{\mu_a}\,(\rho_s - \rho_f)\ , \qquad \textit{for } NR_p < 3$$

$$V_{sl} = 1.54\sqrt{d_s\,\frac{\rho_s - \rho_{fl}}{\rho_{fl}}}\ , \qquad \textit{for } NR_p > 300$$

The cuttings transport ratio is the ratio of the cuttings transport velocity over the divided by the mean annular velocity (V_a). A positive value of transport ratio means that cuttings are transported at the velocity of the mud stream.

To make things more difficult, we must bear in mind that the fluid velocity is not the same all across the diameter of the borehole: The mud moves slower near the borehole wall and near the drill pipe, provided it is in laminar flow. The situation becomes more complex and less predictabe if the flow conditions are turbulent. Figure **(7)** tries to illustrate this situation.

$$F_T = \frac{V_T}{V_a} = 1 - \frac{V_{s_l}}{V_a}$$

For practical purposes, we can assume that there is nearly no gravity separation of cuttings in the mud stream, but there *is* a separation of gas (even solution gas) and cuttings. Further, there is no significant delay for cuttings separated by different flow velocities in the mud stream - unless the mud used has extremely high viscosity.

- Be aware of differential lag times between cuttings, oil, and gas, although this aspect should not be overemphasized (see also above). These materials will travel up the annulus at different rates, depending on mud viscosity. Cuttings may be differentiated in correspondence with size and specific gravity. This is an application of STOKE'S LAW. Some mudlogging companies apply correcting algorithms in their lag-time calculations. Find out how the lag time is calculated and if corrections are applied. The differentiation of cuttings in the mud stream is also increased in deviated and horizontal wells.

- In strongly deviated wells cuttings tend to accumulate at the low side of the wellbore, thus leaving the mud stream until they are stirred up by the drill pipe touching on the bore hole wall. Expect longer "tails" of marker beds when working on deviated wells. This effect of settling cuttings has nothing to do with the theoretical transport velocities as discussed above.

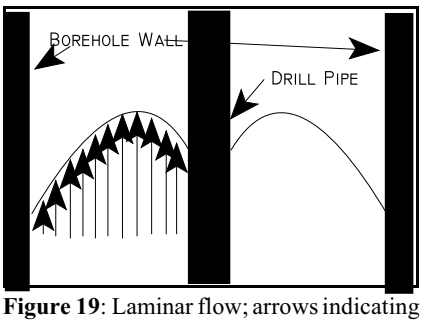


Figure 19: Laminar flow; arrows indicating relative velocity of the mud.

4.4.6. Hole Cleaning

One point, closely related to the cuttings transport is the efficiency of hole cleaning. Are you getting too much or not enough cuttings ? Are all cuttings removed from the well and brought to surface ? And, how could you tell ?

- Check the shale shakers every time you walk passed there. Is the volume of cuttings coming over the shakers in relation with the hole drilled ?

Big diameter holes (17½" and 12¼") produce more cuttings per foot or meter drilled than small diameter holes such as 8½" or even 6" diameter hole. The amount of cuttings coming over the shakers depends also on pump output. So, finding the *right* amount of cuttings that should come over the shakers is very much subjective. Therefore, check every time you walk past the shakers to build a feeling for what is normal and what may not be normal.

- *Too much cuttings*: That means that the hole is caving, there is more rock material coming from the hole than actally drilled up by the bit. The additional volume of rock material is caved from the side of the borehole wall. This situation is relatively easy to diagnose because the additional material, the cavings have a different shape than the cuttings. Cavings are usually much bigger than cuttings and can be indicative of overpressure (more on page 63). A rock type particularly prone to caving is coal, young tertiary coals in particular.

- Another reason for *too much cuttings* may be that cuttings have accumulated "somewhere" and are coming to surface. This "somewhere" may be in the possum belly itself, somewhere in the flow line or - more typical - at the base of the marine riser. The annulus increases abruptly at the base of the marine riser and above th cased hole section. Consequently, the ud velocity decreases sharply at this point and cuttings can settle out there. Most offshore rigs are constructed in way that an additional mud pump (the booster pump) can inject mud at the base of the riser to increase the annular velocity.

- *Not enough cuttings*. Cuttings remain in the hole. This is a dangerous situation because the cuttings will "choke" the circulation at one time. If cuttings remain in the wellbore, or even worse, in the open hole section, the cloud of cuttings may settle out when the pumps are switched off (to make a connection, for example) and can pack-off the stabilizers or the bit. A diagnostic indication is the occurrence of overpull when making a connection or when pulling out the first stands.

In either of the situations, consult with the company man, tell him his observation - and don't be surprised if he has another point of view. In any case, report !

4.4.6. Kick (Pit Volume) Drills

Loss and gain in mud volume can reflect loss to the formation or entrance of formation fluids into the wellbore, a kick leading in the worst case to a blow-out. Although the volume of the mud pits is also observed by the driller on the rig floor, the correct response of the mudlogging crew to pit level variations is essential.

- Most of the mud level changes may have other reasons. Water may be added to the mud (gain), new mud may be transferred from another pit (gain), mud may be dumped (loss), etc. Before such changes are made, the driller should call the mudlogger to inform him about his plans. If the driller does not adhere to this practice, he cannot expect the optimum cooperation with the mudloggers. In this case, tell the company man about the shortcomings.

- The pit level sensor system including the setting of alarms should be sensitive to changes in the range of ± one barrel. However, this does not mean that the alarms should be set to ±1 barrel.

- When the mud pumps are switched on, mud is taken from the pits and the surface system fills up, the pit volume will show an apparent loss for some minutes. On the contrary, when the pumps are stopped, mud flows from the shakers and the flowline back to the pits and shows an apparent pit gain. This fluctuation due to starting and stopping the pumps can be as small as 5 bbl on a very small slimhole rig or as much as 40 bbl on a big rig with a huge surface system.

- If unexplained changes in this range occur, the driller on the driller on the rig floor must be informed immediately. Any change in mud level (gain or loss) must be annotated and explained on the recorder chart (see page 34). No exceptions.

Check

- Go to the mud pits and lift up the sensor of the active pit, thus imitating a pit gain and see what happens. If the mudloggers call the rig floor immediately, everything is up to standard. Inform the driller and the company man before you make your exercise. The check is more difficult if an acoustic pit sounding system is used. You can put your hard-hat or a plank under the transducers to simulate a pit gain; however, the response of the indicators in the mudlogging unit are different. An experienced mudlogger will easily spot the nature of the exercise.

As a kick or loss of mud to the formation may also occur during a trip, proper monitoring of the mud level in the hole during a trip is extremely important. Due to the swab pressure applied while tripping out, the hydrostatic pressure on the formation is reduced. In fact, most kicks and blow-outs occur on when tripping out of the hole. The volume of mud gained or lost must be equivalent to the volume displaced by the drill pipe.

4.4.7. Sample Collection

Sample collection is the duty of the mudloggers. This duty is sometimes delegated to a sample catcher, a helper in the mudlogging shack. Most of the sample material is gathered at the shale shakers. But this is not sufficient. Even during routine drilling, you (or the mudloggers) have to check the desander and desilter outlet every time a sample is collected. Collect an additional sample from the desander and desilter and put it together with the cutting samples for inspection and bagging. It is indispensable that you check, that this practice is understood and followed by the mudloggers.

Samples should be caught by placing a wooden board across the front of the shakers, so as to catch a representative sample of cuttings. If different screens are used on a twin shaker use two boards and make the sample up from both piles. Normally the proportion should be approximately 50:50, however in sand sections the ratio needs to be changed so a more representative sample is caught.

- Make sure the roughneck who is on duty at the shakers during drilling does not change the planks, dumps the cuttings piles. Tell him what this construction is about and, also, not to mess with it.

- During fast drilling and in a big diameter hole, the board(s) will overload quickly, so the sample becomes non-representative. It is best in this case to bulk the sample using two separate collections, one at half, one at full lag time.

- During slow drilling, the same procedure may be need to be repeated several times in order to get a representative sample and to get enough quantity.

- Always wash the boards and the shakers down after collecting a sample.

- When a sample is missed for some reason, *never* bulk it up using the next depth. Put the relevant bag, *empty*, into the sample box or bag for shipment. Note the depth or depth interval missed on the work sheet and log book. Leave sample description sheet and mudlog blank for that interval. (See also page 41, bypassed shale shakers.)

- Whenever the desander or desilter is in use, always collect samples from the cyclones and describe on the work sheet. The sample recovered from the desander or desilter should be added to the sample collected from the shakers.

- During coring reference samples should be taken. As the sample material is not sufficient to fill the sample bags, add empty bags (page 46) as place-holders.

- Do not accept any sample material of unknown origin. If someone brings you a piece of something *throw it away*.

4.4.8. Cuttings Sampling and Sample Interval

Selecting an appropriate *sample interval* is the responsibility of the wellsite geologist. Select an interval that suits geological needs and that is feasible under given drilling progress. The sample interval usually decreases with depth or as the zones of interest are approached. At top hole the interval may be as wide as 50 feet (or about 25 meters) or even more. When the drilling rate slows down in deeper strata the sample spacing may be as close as 3 feet (or about 1 meter in round metric units).

- At times of fast drilling, in particular at the big-diameter tophole section, other factors influence the sample interval. The driller will pick up the bit and wipe up and down the hole for the full length of the kelly when making a connection. This mixes the cuttings samples in the annulus. Make your calculations of lag time and do not try to take closer samples than warranted by the actual resolution of the mud stream.

- As a guideline, try to adjust the sample interval so that there are not more than four to six samples per hour to be taken. For a short interval higher sample rates may be tolerated, however, be aware that the overall quality of the mudlogging services decreases if too many samples are to be taken within a given time.

The shale shakers may be bypassed for one or the other reason. If lost circulation material (LCM) is in the mud, it plugs the shaker screens. The drillers have a wide selection of materials to combat lost circulation: Mica (muscovite), walnut or peanut shells, processed sugar cane fibre, peanut shells, cellophane flakes, etc. When in use, the costly mud would then run over the shakers and be lost, moreover, the LCM material, which is added to the mud to do its job downhole would be filtered out. Therefore drilling people bypass the shale shakers on some occasions. Try to collect a sample with a

sieve from the mud stream (flowline). If the sample volume recovered is not sufficient, take frequent samples and lump the material together to fill the sample bags.

- For the sake of good practice intervals with no sample recovery (i.e. with empty sample bags) should be noted in the log book, reported on the daily report and noted on the transmittals sheets of sample shipments (see also page 41, missed sample).

4.4.9. Calcimetry

Calcimetry[13] is another geological tool particularly relevant in carbonate provinces. The principle is simple. A certain volume of cuttings substance (about one gram) is dissolved in hydrochloric acid in an enclosed test vessel and the pressure is recorded an a small strip chart. Calcite is dissolved very fast, dolomite slower, quartz, clay, etc. is insoluble in HCl. After calibration with clean $CaCO_3$, the recorded pressure curve can be translated into absolute values, whereby the first, almost immediate pressure peak is set equivalent to the calcite content of the sample. The increment to final pressure reading after three or four minutes is attributed to the dolomite content of the sample. Dolomite dissolves slower. The remaining difference between a formation (cuttings) sample and the $CaCO_3$ calibration sample is attributed to the weight of the insoluble residue. The whole process takes five to eight minutes, so don't expect the mudlogger in charge to produce more than one calcimetry measurement per ten minutes[14].

This description of the calcimetry process appears complicated, in fact once you see the apparatus, it is quite clear how it works - and where the weak points are:

- The calcimetry is very sensitive to any change in the environment controlling the reaction. Needless to say that a change in acid concentration changes the calibration, but be also aware that changes in ambient temperature may act in the same way.

- Variations within the range of 5 % (weight) are fully within the variation of the system and acceptable.

- Check when the last calibration was made (it should be noted in the mudlogging unit's log book). A calibration run per day or better one per shift is not asking too much. Re-calibration is due also whenever a new bottle of acid or a new bag of calibration $CaCO_3$ is begun.

- Have a look (with the microscope, of course) on the insoluble residue left after calcimetry. There are interesting things to find (- from a geologist's point of view).

[13] This device is also called *Autocalcimeter*, despite its low degree of automatization.

[14] If drilling is too fast to keep up with the calcimetry you have to instruct the mudloggers to analyze only every second or third sample.

4.4.10. Shale Density

Shale density can be measured in three different ways:

- Several large test tubes are filled with various density liquids produced by mixing differing amounts of tetrabromethane and trichorethane. Some contractors use water solutions of calcium bromine. These tubes are individually calibrated with a hydrometer. Then it is a matter of finding which density tube allows the shale cutting to "hover", i.e. neither float or sink.

> **Important**: *Tetrabromethane and calcium bromine are carcinogenic fluids*. Handle as little of the fluid as possible. Clean and dry equipment - if any possible - outside.

- A development of the method above is a large graduated cylinder carefully filled with tetrabromethane and trichlorethane so that the fluid is more dense at the base and less dense near the surface. The tube is calibrated by placing colored beads of known density and plotting their position on graph paper. The shale cutting is placed (with a piece of wire, shaped like a long spoon) into the tube. Its "hovering" position indicates its density.

Note that the density of the test fluids changes with time owing to evaporation. Also, the second method (graded test tube) is sensitive to vibration which disturbs the delicate equilibrium of fluids. The calibration graph should therefore be checked once a day and the fluid changed with new fluid about once a week.

- The best method is the shale bulk density, which can be measured by filling a mud balance with cuttings until it balances at 8.33 ppg. The cup is then filled with water and the total weight (W) measured. To convert to metric units use the following equation:

$$\varrho_b = \frac{8.33}{16.66 - W}$$

A number of problems and limitations is common to all three methods:

- Drying of the cuttings for the two density fluid methods is critical. Cuttings should be dipped in Acetone and allowed to stand for a few seconds in air.

- Cavings must be avoided.

- Shale composition and accessories (especially carbonates and pyrite) affect the density.

5. Sample Material

5.1. Routine Samples

There are three different basic types of cutting samples (besides core and sidewall core samples) collected at the wellsite:

- *Wet samples*. These are drill cuttings, which are bagged in cloth or plastic sample bags. The sample material is *not washed* or rinsed to clean the material from mud contamination. This is bulk sample material used mainly for paleontology.
  Cloth sample bags should no longer be used. Unless the sample material is perfectly dry, the bags will mildew or foul and disintegrate within weeks, leaving you or the poor lab technician with a big mess of unidentifyable samples. More recently, plastic / aluminum sample bags have become available. These bags, similar to those used for vacuum packed coffee, need to be sealed with a special electrical tongue, much like plastic bags for the freezer.

- *Washed and dried samples.* Drill cuttings are washed with water over a set of sieves. The mud contamination is washed away. If too much washing is done, soft shales will be washed away also. The sample material is dried, packed in paper envelopes or small self-sealing plastic bags (size about 6.5 x 12 centimeters) and shipped in cardboard boxes. The washed and dried samples are used for quick lithological reference. They are of little use for micropaleontological purposes because some of the clay fraction containing microfossils is at least partially washed away.

- *Geochem samples* are unwashed samples collected in cans. The cans are filled with tap water to about 1 inch (1-2 cm) below their top. One drop of biocide is added to prevent bacterial growth. Put the lid on carefully. The cans should be gas tight and not leak. Store upside down. The cans become corroded by the drilling mud within days or weeks. Fast transport to town is indicated. The geochemist in town will first punch a small hole in the cans to take the headspace gas for chromatographic analysis. The cutting material is used to extract organic compounds for chromatography and kerogen determination (done on polished mounted cuttings). The chromatographical analysis is very sensitive to organic contaminants in the mud. Note any possible organic contaminant (like diesel oil, organic mud additives etc.) on the transmittal note and include a separate sample of the contaminant (see also page 45).

  If no headspace gas analysis is required (some geochemists think it is "good money for old rope" anyway), geochem samples may be collected like wet samples and dried. Another technique is to collect wet samples and geochem samples in strong plastic sample bags (actually a bag consisting of two plastic and one aluminum layer) which are sealed. This method is relatively expensive but has obvious advantages.

5.2. Other Sample Material

- *Hot shot* samples are cuttings (or sidewall cores) sent to town for paleontological analysis on a rush basis. This is done to find out if a certain horizon or marker has been penetrated. (See also page 67, wellsite biostratigraphy.)

- *Bit Samples* on trips. Try to collect a sample from the drilling bit every time the drill string is tripped to the surface. Here you get sample material from a given depth. You do not rely on lag time calculations. Do not take your sample from the stabilizers. If you get anything, you will get a selection of all lithologies of the open hole section with an over-representation of tight spots and sticky clays.

Apart from rock samples other samples may be necessary or requested from time to time :

- *Water samples* from the formation (coming from RFT or DST) or a water sample from the drill water used to mix the mud. Use the geochem cans or a glass jar, not plastic containers.

- *Oil samples*. The oil may come from a DST or RFT, or even a producing well nearby. Collect fluid in glass or metal container. Do not use a plastic container. Be aware that this sample is not a complete oil sample as it may be required for technical oil analysis (required for refinery purposes) and not a reservoir sample, on which PVT analysis could be done. It may be sufficient for geochemical purposes (source rock to oil correlation, etc.)

- *Pressurized fluid sample*. It is collected from DSTs at the separator or the wellhead under pressure and stored in a pressure sample bottle, a ½ gallon steel container. The sample is needed to study the phase behavior under reservoir conditions (i.e., under different pressure and temperature conditions; therefore called PVT sample). The containers for pressured samples are available on a rental basis from the well testing contractors. Shipment of pressured sample containers has to comply with regulations for dangerous goods. Contact the freight agent or the materials and logistics department of your company for details.

- *Contaminant sample.* You often need to take a sample of mud contaminants or other substances of interest (Diesel oil, organic mud additives). Use the appropriate container. Label properly (including date, batch number and sample point). See also page 46).

- *Small gas sample, non-pressurized.* If you need a small volume gas sample for compositional or carbon isotope analysis, use pre-evacuated glass tubes for sampling. These tubes are available from agents for medical supplies. The tubes are sealed with a rubber diaphragm. A double pointed hypodermic needle comes with it. To take the sample, stick the needle into the sample point (rubber hose from the separator or RFT tool), then push the other end of the needle into the diaphragm of the glass tube. The vacuum "sucks" the gas into the tube. Shipment as dangerous goods is not necessary because the tubes are normally pressured.

- *Environmental Samples* are strictly non-geological samples. Such samples are taken to document the effect of the drilling operation on the environment or the toxity of chemicals used in the operation. Environmental samples can be water, soil, rock, plant, mud etc.

5.3. Sample Shipment

Before shipment, make sure that the samples (in particular the wet sample bags) are reasonably clean, dry and closed properly.

- Tie groups of ten sample bags together with a cardboard tag.

- If no samples were recovered over an interval (because of bypassed shakers, lost circulation, etc.), label empty bags and put them together with the samples recovered in the shipment container. The technician who receives the shipment and selects samples for analysis will know then that no sample has been recovered at a certain depth an he will not have to search the whole bag for a particular sample.

- Label every box, sack or sample container with :
  Shipping address (Company address or the address of the analytical contractor).
  Well name or number.
  Depth interval[15].

- Inform your company, supervisor or the receiver of the sample material *in writing* about time, means and content of shipment. Ideally, you would fax a copy of the transmittal to town.

- Keep a record of the sample material that has left the location. Best in the log book (page 20) of the mudlogging unit. The wellsite geologist is always made responsible for the proper documentation of sample shipments.

- Keep one set of washed and dried samples at location until drilling is completed. This is for reference, in case you want to review a certain interval later.

Follow-through the sample shipment as closely as possible. Find out by which means and over which route the samples are transported. This puts *you* in the position to find out where the shipment might have become stuck if it does not arrive in time at its destination.

[15] Very unlike cores, which are taken at points of interest only, cutting samples are taken over the entire well section. Rules of confidentiality are therefore not violated if the depth interval is written on the shipment containers of cuttings samples. See also page 62.

6. Wellsite Geologist's Routines

Now, as you have convinced yourself that the sensors work properly and the mudlogging crew is up to standards, you have to show some action yourself. There are a number of routine and non-routine duties that the wellsite geologist has to take care of himself and cannot be delegated to the mudloggers or anybody else.

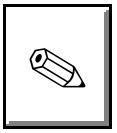
Special reference is made to the job description of the wellsite geologist on page 7 of this book. The main objective is to collect, document and interpret *geological* data. It is not the objective to help the drillng people, the company man, or someone else. However, it *is* part of the job to keep them informed about all geological aspects. In practise, this means that whenever you may be trapped between different priorities of your work, follow this sequence:

- Safety first, then geology, finally drilling aspects.

As an example, if the driller or company man tells you to watch the pit volume during a trip, be aware that he is delegating one of his tasks. Or, when you are asked to help counting casing, only help if there are no other geological duties on priority - and there will always be something more important (page 122 of this book gives several examples).

One of the duties, actually the main reason for your presence on the rig, is to monitor the operation, which means to be around and to know what is going on and represent the standpoint of the geology department on the rig.

Awareness The geologist should know at least and constantly be aware of:



- Where are you ? Your present best guess in which strata the bit is drilling at this moment. How far away (both in depth and in operating time) are casing points, expected reservoirs and TD?

- How is the hole condition ? Any drilling problems, indications of overpressure, sticky hole or indications of lost circulation ?

- What type of bit is run, how long will it drill (approximately) and when is the next trip expected. Have a look at the worn bit when it comes to surface. This gives a "feeling" as to what the mechanical properties of the formation may be (hard, sticky, abrasive...).

- What sort of bottom hole assembly is run (slick, stiff, pendulum, directional, etc.) and why ? The bottom hole assembly is a matter of drilling engineering. There is not much a geologist can contribute to drilling techniques, however, he should have a clear idea *why* things are done the way they are. Are we following the drilling program or is there any deviation from it ? If you don't know - *ask* !

- What type of mud is in the hole, what are the basic parameters (weight, viscosity, water loss, salinity, special additives used like diesel oil, etc.) ?

- Is your crew and equipment complete ? Are you waiting for personnel (service companies, etc.) or equipment (logging tools, spare parts, etc.) ? If so, have you reported the situation before and/or requested your supervisors action ? When ?

Be discerning that you should *know only* many things but by no means should you ever comment or in any way, be it formal or informal, report anything about these particulars. This is solely the job and responsibility of the drilling people and the company man.

6.1. Reporting

The second-most important task of the wellsite geologist is to report his findings to his supervisor in town or the base office. He is judged by the quality and punctuality of the reports he turns in. There are as many different reporting formats and procedures as there are operating oil companies. Nevertheless, your report should always be made up in such a way that it conveys the message as clearly, simply and completely as possible. Just imagine that you are in the office, receiving a report from a well that you never heard of before. Could you figure out from the report given what is going on out there?

Point out the different levels of reliability of statements in a report. There are tentative sample tops on one side and there are firm easy to pick marker horizons, for example. So stick to the good old principle to keep observation and interpretation apart. Make clear in you report where the interpretation begins. Report if your interpretation is based on poor data quality. Note "poor sample quality", or "based on color change..." or "interpreted from ROP..." or any other explanation, that may be relevant to judge the quality and reliability of the interpretation given.

6.1.1. The Master Log

The wellsite geologist has to prepare some kind of graphical presentation (log) of the lithological sequence drilled. On some occasions, this can be done using computer programs that draw logs and serve as a small data base. To differentiate your product from the *mudlog*, that is prepared by the mudlogging contractor, it is called the *master log*[16] or strip log. This master log is to a certain degree a duplication[17] of the work done by the mudlogging contractor, but in a way it should be more of an interpretative summary, while the mudlog is more descriptive. Modern computer based systems may change this situation in the near future. Database systems have become available, which enable the geologist and the mudloggers to work with the same data. Geological data files can be merged with technical parameters recorded in the mudlogging unit (ROP, gas etc.) and a graphical combination with wireline log data and MWD displays is possible. The daily report would then be a computer file transmission to the office, or, the office could directly access the actual and up-to-date data files on the rig.

There are two basic concepts as to how to produce a lithological log: The *percentage log* and the *interpretative lithology log*. The percentage log records the lithology of the cutting samples as observed. Only obvious alien material such as cement is disregarded and the lithology of cuttings is described, using percentage values to describe the composition of the cuttings sample. The interpretative log, in contrast, seeks to zone lithologies, that occur together in one sample relative to the rate of penetration (ROP), gas occurrance and any other observation of relevance. For example, a coal streak of a few feet thickness which caves in over the following hundreds of feet will be recorded as only one streak (if recognized as such) in the interpretative log. On the percentage log it will show as a high percentage of coal cuttings fading away over the interval, still, being described as "trace" near the end of the interval.

[16] Some other operators call this presentation *sample log*.

[17] You can actually judge the quality of the reporting procedures of your outfit by the degree the both logs are duplications or complementing each other.

6.1.2. The Daily Report

Depending upon the set-up, the routines within your company, the daily geological report is either sent by alone or combined with the drilling report as an integral part thereof. It may be sent by telex, fax, e-mail, file transfer or read out on the phone or radio. Any type and format of a daily geological report should contain at least the following information:

- Well name and/or number.
- Depth at reporting deadline (usually midnight or 06:00 hrs local time in the morning).
- Date report sent, and date of reporting period.
- Footage drilled and summary of operations. Make sure you have exactly the same details on your report like the company man. Often, the midnight depth is rounded or slightly changed by the driller or company man and then entered into the reports. Check with the company man what he puts on his report. In case of differences, the daily IADC report of the drilling contractor is the ultimate authority.
- Interpreted lithology, hydrocarbon shows and stratigraphy.
- Hydrocarbon show evaluation as complete as it is available at the reporting deadline.
- Graphical presentation (the "log"). Send a copy of your log, or the mudlog, if technically possible by fax or electronic mail.

Do *not* delay the report only because you want to include something, which you think is important. (If you had a drilling break just at reporting deadline, report only what you know for certain. You still can send an update. Beside, the people from the office will call you anyway.)

Report in intervals. That means group similar lithologies together, add rate of penetration, hydrocarbon shows etc for the interval under consideration. A good report will always read "from" and "to", giving an interval.

Make sure to send the geological report *every day*, even if there is no geological activity such as when casing is run and cemented. Make up the standard form with a remark "no geology to report" or "no drilling" or whatever is appropriate in the given situation. This habit keeps up the routine of paper flow and evades the silly question from the town office, "why did you not send a report today ...?"

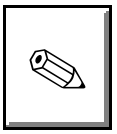
6.1.3. Ad-hoc Reports

Be prepared at any time, 24 hours a day, for your supervisor to call you on the rig and ask for an update of the last report. You may just have gone to bed and have no idea what is going on so *do not answer the phone or radio unless you know the basic data:*

- What is the current operation ?
- What is the present depth ?
- Any shows or other interesting things to report?
- Markers reached, change of formation ?
- What is the present average drilling progress (ROP) ?
- Background gas reading ?

If you don't know wht'a going on, do not commit to any statement if you do not have the correct answer. Ask for a few minutes time and find out, even if it appears embarrassing at the moment. It is better this way. The people in the office could base important decisions on the answers you give.

Again, a well kept notebook can be an important help. Note down the important parameters (depth, progress, gas, etc.) every time you leave the logging unit. When you are called to the phone or radio you can call the mudlogging unit for a short update.



6.1.4. Contribution to the Final Well Report

Regardless of whether you will compile the final well report later, or not, prepare and file your data in a format that is similar to the format used for the final well report. Many data are easily collected during operations at the wellsite but almost irretrievable from the files. (Page 109, the circulation time prior to logging is an excellent example). Make your notes and keep your notebook. This notebook, if properly kept and annotated can be a treasure of information.

- If you have a computer on location, it may be a good idea to merge the lithological descriptions every day into one file. This document needs to be edited when sidewall cores and lab results become available before it can be used as contribution to the final well report.

- Keep a file logging the daily operations (check the daily drilling report) and another document in which you type the body of the final well report, interpretation and results of analyses if they become available from town office.

6.1.5. Data Security and Confidentiality

Treat all data as confidential and unique. That means lock you report and log file away if possible and make sure nobody makes copies of your work - don't forget you computerized data, original data or interpretation without your permission. Think also of your waste paper and make sure is shreddered or at least torn up and disposed off properly. Think also of the confidential value of your notebook, diskettes used and data that may be filed on the hard disk of a shared computer on the rig.

The mudlogging and wireline logging contractors have always access to the most sensitive data are but are committed to confidentiality by their work- or service contracts. Assume that they adhere to professional standards of confidentiality. There is usuially no problem, if you share data and sensitive information with them; however, do not divulge any information to them which is beyond the scope of their work.

If you mail data to the office, make sure that a back-up copy, a duplicate, is kept on the rig, in case the mail is lost during transport. This applies in particular for transparencies (mudlog, etc.) and magnetic tapes or diskettes with mudlogging data.

For some operations such as testing, special rules of confidentiality apply. It may be requested by the operator not to report in open language, which means you have to encode your report (see also page 9). This may be necessary in particular if you report by short wave radio. (See also page 62 for aspects of confidentiality for packed sample material.)

Special reference is made also to *strip charts* and *work sheets* (page 34 and page 34). This data may appear out-dated , superseded or even useless when the well is completed. Nevertheless it can tell the whole story of the well. It is absolutely essential that this data is transferred to the office of the operating oil company. If the operations geologist should decide to destroy this data it's his business.

6.2. Working with Cuttings Samples

6.2.1. Sample Preparation

Samples taken from the shakers (see page 40, sample collection) must be prepared, washed, sieved, prior to description and packaging. Sample preparation is the duty of the mudloggers. Supervise and see if the following procedures are implemented:

- Both fresh water and sea water are acceptable to wash the samples.
- The raw wet sample should be put in the top tray of the sieve column, preferably 5mm screen size, and washed with a high pressure single jet applied in an angle to the sample. the action should be to slice the sample so that it breaks up and falls through the large sieve. The aim is *not* to pulverize the individual sample chips. After the raw sample has been jetted into the lower sieves, a spray should be used to disintegrate the remaining sample.
- You must have a complete set of sample sieves in *good condition*. During casing jobs or rig moves, the sieves should be thoroughly washed and dried in the sample oven to inhibit deterioration. Special care should be taken when there is salt in either the mud or the sample washing water (sea water). Do not be tempted to help preserve the sieves with oil as it will contaminate your next samples.
- Care should be taken not to wash away the clay fraction. When in doubt, reduce the amount of washing. Use a squeezed sponge underneath the finest sieve to remove excess water, and transfer to a stainless steel sample tray.
- During washing, look out for an oil skim on the water after it has passed over the sample.
- Note the proportion of obvious spalled cavings retained on the uppermost sieve.

6.2.2. Sample Description

The general lithologic description of rock samples is in principle the same as the description of outcrop samples. However, owing to the nature of cuttings, the description of sedimentary structures is nearly never possible. *This guidebook is not another sample description manual* ! The author recommends using the sample description manual of the operating company, or, alternatively, the AAPG sample examination manual, (SWANSON, 1981) which originates from SHELL, a reputable operator.

Only a few points, which apply particularly to cuttings rather than outcrop samples, are made here.

- Describe samples when they are wet ! No exception. If the sample material is dry, wet the surface with water. Structures and colors are much clearer visible when the sample is wet.
- Claystones and shales need special attention. Usually shales arrive in the cuttings tray as soft, or even soluble, whereas sidewall core samples from the same shales show a hard, splintery lithology. This is due to the effect of the mud on shales, its alkalinity and its temperature. Claystones and shales can be altered significantly being exposed to relatively high bottom hole temperatures in conjunction with high pH.

The lithological description should follow this sequence:

- Rock type (main lithology).
- Color.

- Texture, including grain size, roundness, etc.
- Cement and/or matrix.
- Fossils and mineral accessories.
- Sedimentary structures (if possible to describe).
- Porosity and oil shows (visual inspection).

Using this descriptive sequence and commonly accepted abbreviations allows to describe even fairly complicated lithologies correctly using a minimum of text.

Even within the given framework of a sample description manual or company guidelines for sample description, it is a common fact, that two geologists will describe the very same sample with a different wording. The same may apply for the graphical presentation of geological data, a hand-drawn mudlog in particular. *Never mind !*

- If you crew change with another geologist and tie into his previous work, have a look at his last samples and how he described them, but then *make your own description*. Later you will possibly have to defend your description, but nobody will give you credit for a mistake or error in judgement that you may have taken over from someone else just for the sake of continuity.

On the other side you may even repeat your own sample description differently under different circumstances. A different microscope, another UV box, or just a variation of ambient lighting may change at least your color description or, even more your characterization of stain and cut colors.

Sample description is rather a subjective matter of art and than a science. Exact and quantitative data, like grain size, porosity etc. are made in the lab in town, not at the wellsite.

6.2.2.1. Tricks and Pitfalls

There are many things that can go wrong with a sample decription. If you have been trapped in one of the pitfalls - *don't cover up*. As embarassing as it may be at the moment, use the next best situation to rectify your report. A good opportunity is the daily report of the following day. Don't worry, mistakes happen and can happen to everybody.

Cement contamination:

- When drilling closely below cemented casing, or, if cement plugs have been set recently, check every sample for cement contamination with Phenolphthalein. This agent gives a purple stain to the cement particles and leaves the rock cuttings unstained. Cement looks similar to a gray fine mudstone or siltsone sometimes with black grains. Even the most seasoned wellsite geologist can be sometimes in doubt. Cement looks strikingly similar to a fine sand- or siltstone.

Mud additives (in particular soluble organics like lignosulfonate) may come up undissolved and as pieces, thus sieved out over the shale shaker screens and lost for the further process.

- Gelly "fish-eyes" are one typical indication of undissolved mud additives of the starch group. They do not do any harm to samples or analysis. Gelly fish eyes are often seen in the cuttings after a high viscosity sweep pill ("hi-vis pill") has been pumped to clean the hole.

- Lignosufonate, another mud additive, can easily be mistaken for low rank coal. Lignosulfonate is usually in one characteristic grain size fraction whereas coal tends to cave and appear blocky, often in very coarse pieces. Linosulfonate is also much softer than coal, except coals, lignites which come from very shallow levels (low rank coals).

- Some material used to combat lost circulation (LCM) looks strikingly similar to low rank coal or some basaltic rocks. This material ("Nutplug") is made from nut shells and black. If in doubt, try to burn it.

- Other mud additives (such as Baranex®) are strikingly similar to amber.

- Barite can be mistaken for fine sand. If in doubt, compare with the original material from the mud room or tank. Check the specific gravity with density fluids. Barite will sink whereas quartz sand will float in tetrabromethane.

- *Mica* is used as LCM material. If you find loose mica (muscovite) in the samples, assume first that this is LCM material added to the mud. Only if the mica is associated with an igneous lithology you may interpret differently. Mica is very pervasive and is found in the mud system even if no such material has been added for days or even the duration of the well you are on.

- *Plastic based LCM*: Another group of LCM is plugging material made from plastic flakes (polyethylene or - less common - polyester). Some of these materials flouresce similar colors like real oil shows.

- *Pipe dope*, grease used to treat the pipe connections. It flouresces. Pipe dope contains lead or other metal particles which can be identified under the microscope if the substance is rubbed between the fingers or over a piece of paper. Some other pipe dope may have a copper or bronze colour.

- Other *grease* may look even more misleading. Sand and other rock particles may be mixed with the grease which gives a very "authentic" impression. If in doubt, ask the mechanic on location if he he knows what it is.

- *Paint particles* sometimes make their way into the sample tray. These colorful flakes cannot be mistaken for a mineral but still may be confusing.

- *Pipe scale*. Rosty pieces from inside the drill pipe may occur in the samples, inparticular when the pipe has not been used for weeks or monhts. Pipe scale is magnetic but still has a resemblance to limonitic shales.

When describing samples, look also for material which does apparently *not* come from the formation. This can be cement from the last casing point or mud additives, which are not soluble or have not been dissolved yet, or metal chips:

- If you find significant volumes of *metal chips or metals shavings*, tell the company man. This material has a fresh metal luster and is long, curly and different from pipe scale. The bit may be drilling on metal junk in the hole or the drill pipe may be wearing the casing, with the risk of cutting a hole into it if the situation persists. Use a magnet to fish the steel cuttings from the tray. Some companies also put a magnet into the flow line or the possum belly and check daily, if magnetic material has been accumulated (see also page 83).

6.2.3. Hydrocarbon Show Detection and Description

Hydrocarbon show detection and description is the key task of the wellsite geologist and of the mudlogging crew. However, despite the importance of hydrocarbon detection, nearly all of the tests and indications of a hydrocarbon show are weak, depend on experience or special situations and are far away from conclusiveness. Only petrophysical analysis will give the conclusive determination of the presence of commercial quantities of oil or gas.

The color and intensity of stain, fluorescence, cut, cut fluorescence and residual cut fluorescence will vary with each hydrocarbon accumulation. The ageing of the shows owing to a volatile hydrocarbon fraction evaporating quickly, and flushing by drilling fluids tend to mask the evidence of hydrocarbons, sometimes beyond recognition.

- Be aware that not all indications may be present when a hydrocarbon accumulation is penetrated.
- Believe and be sure of your own observation. In many situations the geologist tends to revise his interpretation under the pressure of questions such as "...are you really sure ?"

Some general points pertaining to hydrocarbon detection are listed below. The more specific tests are described in the following chapters.

- Lack of fluorescence is not conclusive proof of the absence of hydrocarbons.
- Real hydrocarbon shows will usually give cut fluorescence. Light hydrocarbons (i.e. condensate) often give fluorescence, may or may not give a residual cut but are likely to give negative results with other detection methods.

6.2.3.1. Gas Chart Interpretation and Gas Shows

Many aspects of gas show recognition depend on the lag time. This can give a good indication from where the gas is coming, in particular if there is some doubt, that it is really formation gas. Well kept and annotated charts are a great help in such situations.

Definitions:

- *Zero Gas:* The detector reading when circulating in a clean, balanced hole section, pipe rotating but not on bottom, no vertical movement. This reading should be above the zero of the chart because there is always minor volumes of gas in almost any formation; there should be a difference on the chart between zero gas and no gas at all (e.g. when circulation stops). Check the equipment if absolutely no gas is recorded.
- *Background Gas:* When drilling in a consistent lithology, it is common that a consistent gas value is recorded. This gas level may fluctuate considerably, but it is always above zero gas.
- *Gas Show:* Any deviation in amount or composition above established background. All gas reporting refers to values above background. The background gas (and its fluctuation) is reported and marked on the log.
- *Trip Gas:* If a trip is made, circulation stops, of course. During this time gas can migrate from the formation into the static mud. When circulation resumes, a gas peak is observed. This gas peak arrives at calculated lag time or earlier. Trip gas does not constitute a gas show, but should be reported if it clearly exceeds background.
- *Connection Gas*: Originates like trip gas from situations when circulation has stopped for a few minutes to add a new single of drill pipe. Connection gas is seen as constant peaks every 10 to 20 minutes (depending how long it takes to drill one single pipe length). Clear indications of connection gas on the chart are typically a sign of increasing formation pressure. Inform the company man !
- *Recycled Gas:* Not all of the gas in the mud will be removed by the surface equipment, some will be re-circulated back into the hole. Due to the dilution in the mud tanks and turbulence in the hole, any patch of mud containing gas will be diluted. The subsequent peak seen on the surface

gas detectors will be more diffuse. On the long term, background gas will show an apparent increase. This situation must not be allowed. Constant and high gas levels are masking any further shows. Also, the risk of fire near the mud pits increases. Drilling people have the option to run a mud degasser or circulate and increase the mud weight until the situation is cured. *Inform the company man* !

- Do not use the term *gas kick* for increased gas levels. A kick is - by definition - an uncontrolled influx into the well bore.

So what is a *gas show* ? No clear answer ! Any gas that comes from the formation in quantities above the background level may be as gas show. It may be indicative of a gas reservoir if the level introducing gas as into the formation is porous. The difference between a gas reservoir and an oil reservoir can be seen only in the composition of the chromatograph gas while drilling. Gas bearing zones are richer in lower alkanes (C_1, C_2, methane, ethane). However, only wireline logging, in particular the response of the neutron tool can give a conclusive answer.

6.2.3.2. Oil Show Detection

6.2.3.2.1. Odor

Odor is often described as one of the indications for live oil encountered. It is the author's experience that odor is just another observation, by far not precise enough to derive any conclusion from it. The presence of an oil odor or its absence does not have any impact on the general oil show evaluation.

Other authors go as far as instructing the company geologist to report "oil odor or condensate odor" and to check the shale shakers and the possum belly area (probably sniffing around there?) every 15 minutes.

- The only use of an oil odor (-test) is the application on a freshly broken rock surface in the absence of any, paint, fuel, fume smell. This situation may be reached in an outcrop but rarely on a core surface on a drilling rig.

6.2.3.2.2. Stain and Bleeding

The amount by which cuttings and cores will be flushed on their way to the surface is largely a function of their permeability. In very permeable rocks only very small amounts of oil are retained in the cuttings. Often bleeding oil and gas (noticed as bubbles) may be observed in cores and drill cuttings from relatively tight formations.

The amount of oil staining on cuttings samples and cores is primarily a function of the distribution of the porosity and the oil distribution within the pores. The color of the stain is related to oil gravity:

- Heavy oil stains tend to be dark brown while light oil stains tend to be paler. Report the color and distribution of the stain (is it uniform, patchy, spotty, along joints or veins, etc.)

6.2.3.2.3. Acid Test

The acid test works only in carbonate reservoir lithologies. Carbon dioxide, CO_2 is formed by the addition of HCl to any carbonate material. The surface tension of any oil present will cause lasting iridescent bubbles to form which are large enough to lift the cutting in the acid. If there is no oil present, the bubbles cannot become large enough to float the fragment.

- Note that this test is overly sensitive to the slightest trace of oil. Even carbonaceous and calcareous shales and even more oil contaminants in the mud may cause a positive test. Use the results of the acid test only in conjunction with a valid fluorescence test.

6.2.3.2.4. Hot Water Test

The hot water test is a very simple but efficient method to check for oil in cuttings samples. Take about a big spoonful of cuttings from the shakers and put the unwashed sample into a any suitable container. The pour boiling hot water over the sample and agitate before putting the container under UV light. If oil is present in the mud or cuttings, it will come to the surface like "fat in the soup" and can be easily detected by its fluorescence.

6.2.3.2.5. Fluorescence

Fluorescence is the light emission of material exposed to light of a shorter wave length, higher energy. Hydrocarbon benzol rings fluoresce when hit by ultraviolet light. This effect is used in hydrocarbon detection. Organic compounds without benzol ring compounds will not fluoresce.

Examination of mud, drill cuttings and cores for hydrocarbon fluorescence under ultraviolet light can indicate oil in small amounts, or colorless oils which might not be detected by any other means except chromatography. On the wellsite, all samples should be checked for fluorescence.

- Colors of fluorescence range from brown to green, gold orange blue, yellow or white. Typically lighter oils have lighter fluorescence. The distribution of the fluorescence may be eve, spotted, patchy or dotty. The intensity may range from bright over dull and pale to faint.

- Beware of mineral fluorescence. Calcite, for example, has a light white-blue fluorescence whereas hydrocarbon fluorescence shades more to warmer colors.

There are a few crude oils that do not fluoresce under ultraviolet light. They are usually of heavy gravity and are biodegraded. The biodegradation forms a double bonded molecule that for some reason does not fluoresce. However, on the addition of a solvent the bond is broken and an instant bright cut fluorescence is obtained.

- Biodegraded oil are usually first noticed as an ordinary oil stain without fluorescence. A solvent cut test (see chapter below) should be made of any suspected oil stain regardless if it fluoresces or not.

6.2.3.2.6. Cut and Solvent Tests

Cut is property of a cuttings to produce an extract soluble in an organic solvent. The most common solvent are Trichlorethene, Petroleum Ether and Acetone. Carbon Tetrachloride is poisonous and carcinogenic and should therefore not be used.

- Check solvent routinely for fluorescence (blind test) under UV light. Of course, it should not fluoresce.

To test cuttings or core chips, a few grains or - if possible - a single cutting, that was fluorescing and picked in the UV box and put into a porcelain spot tray. A few drop of solvent are added and the result is observed under UV light. If the material contains hydrocarbons, they will dissolve and give a fluorescence of the solvent.

- The result of the cut test is also observed in ordinary white light. The white-light-cut color varies from colorless over pale straw, dark straw, light amber to very dark brown or opaque. Colors are dhfficult to describe in a text, fluorescence in particular. If you have never seen oil fluorescence before, try to imagine the cuttings in the UV box are charcoal pieces on a barbecue and some of the coals glow from fire. Then, whenever you get hold of a UV box, try it out using any diesel, industrial oil, or if possible cuttings from an oil well to get an idea. Do not hesitate to put these descriptive terms on your report.

- The relative darkness of the cut described in white light should not be taken as an indication of the amount of hydrocarbons in the cuttings.

- A faint residual cut (the residual *ring*) is sometimes seen in the spot tray as an amber ring remaining after complete evaporation of the solvent.

- Failure of fluorescence should not be taken as decisive evidence of lack of hydrocarbons. All samples suspected of containing hydrocarbons should be treated with a solvent.

The color of the cut in plain white light and under ultraviolet light is an indication for the gravity of the crude. As a rule of thumb, the lighter the color, the light the crude. The cut fluorescence shades to bluish-white or milky white color when light oils are tested. Heavier crudes will show a more yellowish or greenish tint.

The most reliable test for hydrocarbons is the *cut fluorescence* or *wet cut* test. In this test the effect of the solvent on the sample is observed under ultraviolet light. The sample should be thoroughly dried before applying the solvent - although this may not always be possible in practice, in particular when time is pressing. If hydrocarbons are present, fluorescent streamers or clouds will emanate from the cuttings sample. If a sample fluoresces but does not give a cut, try to crush the cutting in the solvent and observe any cut fluorescence. This situation is called *crush cut*.

Some shows will not give noticeable streaming effect but will leave a fluorescent ring or residue in the dish after the solvent has evaporated. This is termed *residual cut*.

Heavy oils may not fluoresce but will cut a very dark brown and their cut fluorescence may range from milky white to dark orange. An alternate method involves picking out a number of fragments and dropping them into a clear 10 cm^3 flask or bottle. Solvent is poured until the bottle is about half full. It is then stoppered and shaken, oil present in the sample is extracted and colors the solvent. If the color of the solvent is very light, hold the bottle against a white background. If there is only a slight cut, it may come to rest as a colored meniscus on the solvent.

6.2.3.2.7. Acetone - Water Test

If the presence of oil or condensate is suspected, and provided no carbonaceous matter is present in the rock sample, the acetone-water test may be used. Proceed as follows: Crush the rock and place it in a test tube with acetone. After shaking it vigorously the liquid phase is decanted or better filtered into another *clean* test tube. Add an excess of water and shake again. When hydrocarbons are present, they form a milky white dispersion, being insoluble in water, whereas acetone and water are miscible.

6.3. Coring

6.3.1. Selecting Coring Points

Coring points (or conditions where coring is indicated) are defined in the well proposal and/or drilling program or directed during drilling from the company office. When you are at the wellsite and ready to core (as per program), call your supervisor to confirm, unless you have discussed this very core point just recently with him.

There are two procedures to actually *pick* a coring point. If you are in a well known area, in particular in limestone sections, try to establish a correlation between the ROP plot of your well and logs of the relevant neighboring wells. Try to correlate the ROP to the GR, SP, sonic or any other log parameter. Whatever makes a reliable correlation is valid. You may need a few hundred feet (100 meter or more) to build confidence in the correlation. When you are confident about your correlation, you can pick the required casing points (e.g. top of reservoir) as close as one foot, in an ideal case. This procedure works particularly good in carbonate provinces.

If you are sitting on a wildcat well in a fairly new area, especially in a clastic sedimentary environment, correlation by plain ROP plots is the exception and the pick will be more statistical. Good cooperation and communication with the driller on the brake is important. He "feels" a soft formation, a drilling break before you can see it on any monitor or strip chart. He will stop drilling (if he is instructed and authorized properly) and ask, if you want to core, circulate for sample or drill ahead. Unless you are very confident about you correlation, circulate bottoms-up and see how the lithology looks and if you have any show, if the gas increases or changes in composition. In sands, unless they are well consolidated, you typically do *not* see much stain or fluorescence because the oil may be washed out of the formation into the mud. In this case, use the gas chromatograph only to make a decision.

This bottoms-up-and-see approach is expensive, when you consider circulation times of one hour or more and relate it to rig time, rig cost respectively. The drilling people may be concerned about their daily progress (see also page 103, economics) -but as a wellsite geologist, you have to defend your position, that is getting the best information from the well and not to miss a core point and not to consider drilling time. Anyway, you will catch more problems if you miss the coring point than if you do, requesting two or three additional bottoms-up circulations.

If you have MWD (measurement while drilling, see page 100) or real time logging available, the correlation and formation identification is facilitated. However, the MWD sensors are several feet above the drilling bit and if you are going to core thin objectives, the drill bit may have passed the coring point by the time the sensors have "seen" the formation change. So, if you go for thin objectives, you have to rely on the conventional methods like ROP correlation and "feeling".

Do not worry if your core was far off with respect to the logs run afterwards or if you missed the coring objective by a few feet. Everybody is smarter afterwards. What matters is that you have used the best approach and judgement at a given time.

6.3.2. While the Core is being Cut

While coring, plot the progress of coring (ROP) for every foot (or half meter) in scale 1:50 on transparent paper (or delegate this to the mudloggers). A piece of blank film, as it is used for wireline logs is practical if you are not equipped with the proper forms. This form can be completed later with lithological descriptions as a graphical core log. The ROP plot gives you the first clue of the lithologies cored. Plot pump output, weight on bit and RPM with the drill rate, if this information is available from the read-outs in the mudlogging unit.

Do not write the cored interval on the outside of the boxes. This practice is mainly for the sake of confidentiality. People outside the company (this includes freight agents, service company personnel etc.) do not need to know at which depth your company found something interesting which they considered worth coring.

- Make up shipping documents (at least in duplicate) and report to the man in charge[19] that the core is ready for transport. Fax (or e-mail, telex) a copy of the shipping documents to your supervisor in town and advise him of the means of transport that will be used.

- If you have time, print the address labels on a good printer and run make a number of photocopies. Then stick or glue the labels on each core container or box.

[19] This may be the company man on board, the company's materials man or the radio operator.

6.4. Pressure Engineering

Pressure engineering, the science of predicting and interpreting pore pressures is often part of the mudlogging contract and, to a certain extent, subject to the wellsite geologist's supervision. The pressure engineer[20] in the mudlogging unit usually reports to the geologist *and* the company man, because his findings have direct bearing on both the drilling and the geological interpretation. Again, cooperation is appreciated.

If no pressure engineer is on location, as it may be the case on many development wells, the geologist takes care of reporting indications of abnormal pore pressures to the company man.

During drilling little is known about the actual formation pore pressure. Unless a RFT or DST, yielding directly measured formation pressures, has been conducted, all information about formation pore pressure is inferred from empirical formulas. Drill exponent calculations (D_{xc}) with all their various corrections and compensations are employed to get some information on the pore pressures. Even on development wells, that is to say in areas where much of the geology is no more secret, even there pressure conditions may vary in an unforeseen way. The general pressure alert with its pit drills, regular checks, etc. is an ingredient indispensable for *any* drilling operation.

The *general philosophy* for drilling is to adjust the mud weight in such a way, that it compensates for the formation pore pressure, allowing a safety margin for p pressures when tripping out. If the mud weight is too high, the drilling progress is slowed down, or, in other words, the cost per foot drilled increases.

The ROP depends as well on the differential pressure across the bore hole bottom. If the mud weight is too high relative to the pore pressure, the cuttings are held to the formation, the *cleaning* efficiency of the mud stream and is reduced, hence the drilling progress slowed down. Furthermore, if the mud weight is too high, the well is prone to lose fluids to the formation, thus inducing differential sticking of the drillstring and damage potential reservoirs. In contrast, if the mud weight is too low, the well is prone to kick, an unsafe drilling practice.

It is *outside the responsibility of the wellsite geologist* to find the correct mud weight. In fact the geologist and the drilling people (personified by the company man) may have a substantial difference in understanding as to what the correct mud weight should be.

From the perspective of the mudlogging shack, proper mud weight is deduced from the following observations:

- Reasonable drilling progress (considering *all* the factors contributing to ROP such as formation drillability, weight on bit, bit wear, etc.)
- Distinct trip gas (see page 54) and connection gas peaks over gas background. If you can see the trip gas and connection gas on the strip charts the mud weight appears to be correct. If the connection gas is higher than 50% of the background[21], the mud weight may be on the low side.
- Normal shaped cuttings with minimum (shale-) cavings. In particular if the shale cavings increase in number and size, you may be approaching a zone of overpressure or abnormal pressure. *Report to the company man* !

It can be seen from the points above, how subjective and biased pressure interpretation can be.

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[20]Some mudlogging contractors use the word ADT engineer, meaning *Advanced Drilling Techniques engineer*.

[21]Meaning something in this range. The actual values depend a lot on the regional setting and on other drilling parameters.

The term *abnormal pressures* is used to describe any situation of a pressure gradient deviating from hydrostatic pressure. However, it usually means overpressure, i.e., a pressure regime exceeding hydrostatic pressures. Abnormal pressures may occur in young sediments, zones of rapid sedimentation, young uplift and fast or deep burial. The advent of an overpressured zone will result in a change in a number of physical properties of the formation, which are reflected in the change of a number of parameters. The following observations might indicate a high pressure zone, however, almost all of them can have other reasons.

Indicators of increasing pore pressure while drilling :

- Gain in pit volume ("kick").
- Increase in ROP ("drilling break").
- Increased torque while drilling.
- Drag on trips and connections.
- Bottom fill after trips (or wiper trips).

From drilling returns :

- Increased background gas, connection gas (mud gas may show an increase in carbon dioxide).
- In some areas is has proven empirically true that an inversion of mud chromatograph gas, that is $C_3 > C_2$ or $C_2 > C_1$ indicates the approach to an overpressured zone. In those areas where this relationship has been established, this indicator is fairly reliable.
- Changes (increase) in flowline temperature. Only applicable, if the drilling is steady and the temperatures stabilized, otherwise external effects will cover the subtle changes of flowline temperature.
- *Change of shape of cuttings, typical pressure cavings.* (**Figure 23**f.) The shape of pressure cavings may not be mistaken for swelling or sloughing claystones. This is the most sensitive and still only a qualitative indication. Under overpressure conditions the shales (claystones) have a typical elongated shape. Pressure cavings have similar shape and increase in size.
- Try to establish if the caving lithology comes from the bottom of the hole (new formation) or if a formation drilled higher up caves in.
  If you see shale slivers coming over the shaker screens, that are bigger than the teeth of the drilling bit, the absolute alarm situation has been reached. Inform the company man a.s.a.p.

Indicators calculated or analyzed at the wellsite:

- Shale density decreases or deviates from the trend line.
- Water loss of shale cuttings increases.
- Significant increase in potassium content (mud, mud filtrate and shale water).
- Shale water (filtrate) may have amber color.
- Sharp change in cation exchange capacity ("shale factor" measured by titration with methylene blue).
- Decreasing D-exponent.

A number of empirical techniques have been developed to calculate pore pressures from wireline logs. The principle of most techniques is to establish a trend line of a parameter (logarithmic plot of resistivity, sonic travel time, density, neutron porosity, etc.) versus depth. Deviations from the trend line are interpreted to be indicative of abnormal pressures. These empirical relations work good in the areas where they were developed. Outside their classical application areas they are less correct, though not necessarily wrong.

A lot has been published about overpressure detection from wireline logs and empirical formulae have been developed to estimate pore pressures from logs. In any case the drilling bit must have *reached* the zone of abnormal pressure and it must have been logged. Overpressure situations need fast answers because the drilling problems may already start after a few feet of cap rock drilled. Back to square one.

The situation is, however, vastly different if you have MWD tools or real-time logging (see page 100). Therefore, watch all drilling parameters closely (in particular the mud pit level and the background gas) and try to come up with a sensible interpretation.

Another aspect of abnormal formation pressures are *sub-normal pressures*. Such situations are common when a well is drlled through a formation that has been produced as a reservoir. initial reservoir pressure is reduced as oil, gas or water has been removed from the reservoir. This may lead to particularly problematical situations:

- When drilling in producing oil fields where produced and unproduced reservoir horizons are close together. In this situation, a relatively high mud weight may be required to hold the fluids of the unproduced reservoir back in the formation while a relatively low mud weight may be required in order not to loose mud into the produced, sub-normally pressured formation.
  Ideally, these situations are taken into account when designing a well. The well program will then try to case-off one formation before drilling into the next formation that may have a different pressure regime.

- When drilling in old, abandoned oil fields with an unknown or poorly documented production history. In such situations, maximum care is needed because formation pressures may change in an unpredictable way at any time.

6.4.1. Leak-Off or Formation Integrity Test

The leak-off test (LOT), also known as Formation Integrity Test (FIT) is a pressure test to determine how much pressure a given formation can take before fractures are induced by the hydraulic pressure. This is necessary to know for kick-kill calculations, the leak-off pressure is the maximum pressure that can be closed-in the casing without risking an underground blow out.

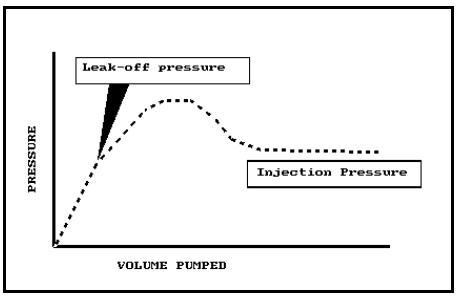

Figure 24: Schematic Diagram of a leak-off pressure plot.

To conduct a test, the well is closed in on the BOP and mud is pumped with the pumps of the cementing unit into the wellbore. The pumps of the cementing unit have a better control on pumping small volumes of fluid under higher pressure when compared to the rig's mud pumps. Also, the pressure monitoring equipment (charts, gauges, etc.) on the cementing unit are better suited for this purpose. Volume pumped is plotted against pressure. At the beginning this relationship plots as a straight line. Later, after more volume has been pumped, the pressure increases less per volume unit until it drops to a certain level where it remains constant. This is the fracture pressure. The formation integrity pressure is read at the point where the graph departs the first time from the linear relationship.

The leak-off pressure can be expressed as pressure measured at the wellhead or in equivalent mud weight (ppg or g/cm^3), the maximum mud weight that can be supported by the tested formation without fracturing. The fracture pressure is defined as

$$P_{frac} = (S - P_p)\,\frac{\mu}{1-\mu} + P_p$$

where P_{frac} fracture pressure [psi]
S overbuden pressure [psi]
P_p pore pressure [psi]
μ Poissons Ratio

In simple words, the leak-off pressure or its mud weight equivalent is the maximum pressure the formation can take. Mud weight cannot be increased above this point. If a kick is taken, the maximum pressure that can be closed in at the well head is equivalent to the leak-off pressure. Any higher pressure will fracture the formation.

The leak-off pressure is also the maximum pressure that can be contained in the wellbore when the well kicks and the BOP has to be closed. If the surface shut-in pressre exceed this mark, fluids *must* be diverted, blown overborad or into the countryside in a more or less controlled fashion.

6.4.2. Pressure Worksheet

Make up your own pressure worksheet. Plot formation pressure gradients, mud weight (its gradients) and all available data points from RFT, DST, kicks incurred (if any), leak-off tests, etc. against depth (true vertical depth !), on a sheet of graph paper. Vertical depth, horizontal pressure gradient in psi/ft (imperial) or g/cm^3 (metric), mud weight in ppg (or metric equivalents). Note and plot zones that are forecasted to be abnormally pressured. This diagram gives you a good indication if pressures are changing, how high the safety margin from the mud hydrostatic head must be and how pressure regimes change with formation changes. This type of worksheet is usually *not part of your routine report*, however, your interpretation of the situation may be asked sometime. Anyway, be prepared.

6.5. Wellsite Biostratigraphy

A wellsite biostratigraphic service is rather the exception than the rule on most drilling operatons. The decision for or against wellsite biostratigraphy as opposed to biostratigraphy in town on a hot shot (see page 45) basis is governed by the cost relationship for mobilization and day rates for the wellsite biostratigraphical services in comparison to the transport cost by an unscheduled helicopter flight (or similar) and also on the foreseeable need to base any decision making on the upshot of biostratigraphy.

On logistically remote exploratory wells a wellsite biostratigrapher may be on location to give a preliminary micropaleontological interpretation.

It is the responsibility of the wellsite geologist to supervise and instruct the micropaleontologist on location. He also has to interpret, integrate and *report* the findings of the stratigrapher. If no such "bug-man" is on location, the following section may serve as an introduction to the ideas and problems of stratigraphic analysis of drill cuttings samples.

6.5.1. Foraminifera

The study of planktonic and benthonic foraminifera is a pre-requisite for the determination of age and paleoenvironments in sediments of marginal to deep marine origin. Planktonic foraminifera are particularly useful chronostratigraphic indicators in open marine environments because of their wide geographic distribution, abundance and often restricted stratigraphic age.

Larger benthonic foraminifera enable age determination of material from shallow marine environments. When examined in thin section, these are especially useful in the analysis of thick limestone sequences.

- The study of foraminifera requires sufficient sample material. A full bag of unwashed material (wet sample) is ideal.

6.5.2. Nannofossils

Nannofossils are fossilized remains of nannoplankton (marine algae) and constitute a varied group which includes

- Coccoliths
- Nannoconids
- Discoasters

Nannofossils are an extremely useful group because they are morphologically diverse and key species can be identified easily. Their planktonic lifestyle results in a widespread geographic distribution. However, due to their nature, their study is applicable only in marine sequences. In some cases, good results were achieved in deltaic sequences.

- Biostratigraphy based on nannofossils requires a scanning electron microscope (SEM). The application of this device precludes any wellsite work on nannofossils.

- Nannofossil work requires less than 20 gram of sample material. The use of washed and dried samples is possible.

6.5.3. Palynology

Palynology, the study of acid insoluble microfossils, has grown from a scientific curiosity in the 1830s and through a rudimentary time-tool in the 1960s to provide the modern explorer with precise age dating and detailed information on depositional environments, source rock potential and organic maturity. Their small size and resistant chemistry allows vast numbers of palynomorphs to be recovered from small rock samples. Their rapid evolution, and occurrence in continental and marine sediments of Precambrian to Recent age, further enhance their value as biostratigraphic markers. Rapid turn-around aids cost effective drilling. Problems confronting the palynologist include reworking and caving (including mud penetration), barren reservoir sections, palynofacies, inconsistent data sets, and the current incomplete state of knowledge.

The organic residue recovered includes both recognizable microfossils (palynomorphs) and the remaining organic debris. Apart from megaspores which are spores >200µ, most palynomorphs fall within the size range 15...150µ.

Palynomorphs comprise:

- Megaspores, large asexual reproductive organs from fern-type plants.
- Miospores
  - Microspores, asexual reproductive organs from fern-type plants.
  - Angiosperm pollen grains, male sex organs from flowering plants.
  - Gymnosperm pollen, male sex organs from cone-bearing plants.
- Microplankton
  - Dinoflagellate cysts, resting spores of mobile unicellular green algae.
  - Acritarchs. *Incertae sedis*, probably sexual and asexual reproductive structures mostly of plants.
  - Algal cysts and bodies, reproductive organs and pieces of algae.
  - Fungi, mostly asexual reproductive spores or young germlings.
  - Scolecodonts, minute jaws of animals.
  - Chitinozoans, minute structures of probable plant origin, known from the Paleozoic.
  - Foraminiferal linings. Organic linings of dissolved foraminifera.

The common characteristic is their chemical composition which is insoluble in acid. this also makes the various wall material difficult to study chemically, and they are loosely grouped under the term sporopollenin. Chemical variations do exist and are indicated to the palynologist by various palynomorph types responding differently to stains, and to maturation.

The small size of these resistant, variable, and plentiful fossils means they are widespread in many types of sediment, often in vast numbers, reducing statistical problems and enhancing species definition. Five grams of average shale will yield 500...10,000 individual fossils, and it is an adequate weight of sediment to produce sufficient strew-mount slides to study the assemblage. Organic shales may require only 2 grams, while organically lean limestones or sands may require 200 to 500 grams. Because of the small size palynomorphs normally "survive" drilling and can be recovered from the standard cuttings samples. Palynomorphs are usually destroyed by the high temperatures associated with turbo-drilling. Their abundance in cuttings often aids the recognition of missing zones in a condensed or incomplete sequence located between sidewall cores or conventional cores.

6.5.3.1. Fine Time Resolution

Dinoflagellates are very common and evolved rapidly through Middle Jurassic and younger times. Precise zonal resolution is thus possible in marine sections, often to the order of one million years. this rivals schemes based on ammonites and forams, although much more widely applicable. Study of several groups (especially nannofossils, foraminifera and dinoflagellates in the marine late Mesozoic-Tertiary) can provide zonal overlap, and extremely high precision. resolution based on dinoflagellates alone is improving. Spores and pollen produced by land plants do not show the same fast rate of change as dinoflagellates. Thus, time units based on spore-pollen assemblages tend to be in the order 5...10 million years, with boundaries between them imprecise.

6.5.3.2. Environmental and Age Range

Because palynomorphs occur in both non-marine and marine sediments, useful age data can be obtained from a wide range of environments. Palynology is not restricted to marine sections, it is the only microfossil group available in continental section.

Land plants have been common and diverse since the Devonian and consequently palynology can be used in most of the subsequent sedimentary record. However, acritarchs can be common in the early Paleozoic and algal remains extend back into the Precambrian.

6.5.3.3. Some Typical Problems when working with Wellsite Palynology

Reworking: The small size, large numbers and resistant nature of palynomorphs results in frequent and sometimes massive reworking. The problem is worst where sequences are rapidly deposited (particularly in turbidite sequences) and above major unconformities. In the worst case, a rich reworked assemblage will mask a lean in-situ assemblage and cause an erroneous, older age assignment. The likelihood of confusion is highest in cuttings, or where the palynologist is pressed for time.

Caving: If there is caving in a hole, a richly fossiliferous horizon can easily mask the age of deeper, less productive sediments, particularly in ditch cuttings studies. The caliper log run later will often indicate the source of the younger assemblage. the caving, particularly within a sandy interval, can penetrate into a sidewall core sample due to the pressure involved in the shooting, making careful cleaning of sidewall cores essential before palynological processing commences. With conventional cores, the problem is usually restricted to the top and the bottom of the core and coarse grained clastic lithologies over intervals where the core may be discontinuous, lost. Often during the trip to position the core barrel, a lump of material can be dislodged from the side of the uncased hole section and taken with it.

Mud contamination: A related problem to cavings is produced by mud contamination. Contaminants can be included from the drilling mud ingredients, various additives during drilling, or even from a previous well in the case of drilling vessels if the mud tanks are not cleaned between wells. This problem is even more specific to wells drilled with oil based mud, which is typically re-used if the situation permits. It is generally wise to keep mud samples for palynology in case initial results are problematic. It produces similar problems to cavings with sidewall cores. Accordingly, wireline conveyed coring is particularly prone to mud contamination.

- Be careful when asphaltic mud additives have been used or any other item from the mud engineer's list of spices may introduce alien palyno-species.

6.5.3.4. Equipment and Sample Preparation

Lab equipment for micropaleontological / palynological rig work is usually supplied by the respective service company or contractor. The wellsite geologist should check that it is complete and operational. Micropaleontological (foraminifera, etc.) sample preparation can be done in the mudlogging unit because only simple equipment such as ultrasonic processing, etc. are used for sample disintegration. Most of the situations give claystone and shale lithologies as the sample material for the micropaleontological analysis. A good conventional binocular microscope (incident light) is sufficient.

Palynology requires a special lab technician to handle the hazardous fluids (hydrofluoric acid) for sample processing. A special mobile lab unit or a specially designated working area with exhaust fan is necessary to accommodate for the needs of palynological sample processing. For the identification of the palynological taxa a microscope with up to 1200x magnification is necessary.

6.6. Wellsite Geochemistry

Wellsite geochemical methods, in particular wellsite pyrolysis ("rock eval") is available since a few years. This method is based on the rapid, inert atmosphere pyrolysis of organic matter present in small (ca. 100 mg) rock samples. Rock-Eval pyrolysis is usually done in the town lab of the analytical contractor. Wellsite geochemistry is used only on some exploration wells when hot-shot sampling cannot guarantee the fast answers possibly needed or on scientific stratigraphic test holes.

For planning purposes it should be remembered that the system requires a few days of training for the geologist or mudlogger designated to operate and maintain the device. Make sure also that there is enough space in the mudlogging unit to install and operate the system. Mudlogging units are known to be very cramped with space. Get the specifications from the geochem service company. For onshore operations it may be considered to install the geochem lab in an additional trailer or shack near the mudlogging unit. Also for planning purposes, the interfacing to computers and reporting formats should be considered.

Three basic configurations are available:

- Volatilization of free hydrocarbons and analysis of total hydrocarbons
- Thermal cracking of the organic matter not transformed into petroleum (i.e. kerogen), with selective detection of hydrocarbon compounds alone or hydrocarbon compounds plus CO_2 released.
- Oxidation of the residual organic matter remaining after pyrolysis in order to determine the total organic carbon content (TOC).

The applications and results of such wellsite geochemistry are as follows:

- Source rock characterization. Analysis of total organic carbon (TOC), petroleum potential, degree of maturation, type of organic matter, detection and quantification of free hydrocarbons.
- Interpretation of oil and gas shows.
- Detection of contaminant matter in the mud (organic mud additivesx
- Aid in determining the TD of a well (see also page 104), if certain maturation levels have been reached at a given depth.

6.6.1. Pyrolysis Data

The following information can be derived from pyrolysis:

S_0 Gas present in the rock (mg HC/g of rock).
S_1 Oil present in the rock (mg HC/g of rock).
S_2 Residual Petroleum Potential, that is hydrocarbon compounds resulting from cracking of kerogen (mg HC/g of rock).
S_3 (Not analyzed with current wellsite pyrolysis).
T_{max} Oven temperature of at peak (°C), a maturation indicator.

$T_{max} \leq 430...435$ °C

Immature zone.

$T_{max} \leq 465$ °C Oil window.
$T_{max} > 465$ °C Gas window.

S_4 Quantity of CO_2 produced by oxidation of the residual organic matter. This measurement is currently available at the wellsite.
GPI Gas Production Index: $GPI = S_0 (S_0 + S_1 + S_2)$
OPI Oil Production Index: $OPI = S_1 (S_0 + S1 + S_2)$
TPI Total Production Index: TPI = GPI + OPI
TOC Total Organic Carbon (in % of rock) = sum of residual organic carbon and pyrolyzed organic carbon (calculated from $S_0 + S_1 + S_2$)

6.6.2.Total Organic Carbon Content

This provides a first estimate on the quality of a potential source rock lithology, for instance: TOC < 0.5 % = source rock rated "poor"
TOC > 2.0 % = source rock rated "good" to "very good".
However, this measurement is not always sufficient to estimate the petroleum potential of a source rock (such as evolved or highly detritic source rocks).

6.6.3. Types of Organic Matter

The plot of T_{max} versus HI (Hydrocarbon Index) allows a quick estimation of the types of organic matter and their degree of evolution. This diagram is also called *van Krevelen diagram.* In such a plot, the organic matters are situated within "evolution paths" which characterize each type of kerogen.

6.6.4. Amount of Free Hydrocarbon

These quantities are given by the values of S_0 and S_1, which are expressed in mg HC/g of rock. Quantities are proportional to the petroleum potential (S_2) of the rocks and their degree of evolution. In the "oil window" the S_1 may be correlated with the solvent extract of the rock.

6.6.5. Migration

The production indices GPI, OPI and TPI corrdspond to the ratio nf organic matter tr`nsformed into oil and gas during burial. The indices can thus be used to check whether the free hydrocarbons were effectively produced by the organic matter in the rock where they were found. During maturation, these ratios increase steadily as a function of depth because S_0 and S_1 are formed to the detriment of S_2. If migration phenomena have affected these free hydrocarbons, an accumulation will be revealed by values of the oil and/or gas production indices which will be higher than they should be at the stage of maturation being considered.

7. Aspects of Drilling Practice and Technology

The wellsite geologist needs to become familiar with the basic equipment, techniques and terms ("jargon") used in drilling. Although he has no direct responsibility for the drilling or the rig, the geologist has to be conversant with the equipment and procedures so that he can advise on certain aspects and so that he can understand the effects of drilling methods affecting the parameters he uses for his interpretation. It is also important for the geologist to develop good working relationship with the drilling personnel to keep a two-way flow of information and gain the greatest benefit for the operation.

7.1. Rig Types

The different rig types can be classified as follows:

Land rigs, onshore rigs:

- *Heli rigs* are lightweight drilling with components consisting of small compnents that can be transported as sling load under a helicopter. This rig type is used for remote locations, jungle and swamp operations. A heli rig does not necessarily require a helicopter. Often heli rigs are used because they can be broken down into small truck loads of about one ton a piece and transported along small roads (remember the weak bridges in between !) to a location without having to construct a heavy-duty road.

- *Truck mounted rigs*. Self contained units installed on a customized truck. This rig type has usually only very limited depth capacity (reaching down some 1,000 or 1,500 meters) and is found rarely in the mainstream of oil field operations. Truck mounted rigs may be very useful, however, for work-over operations such as changing out downhole pumps or tubing on producing wells.
  Some rigs designed for desert operation are mounted on a wheeled substructure, self propelled or can be towed with a truck or Caterpillar. Although these rigs reach the depth performance of "normal" rigs but would by definition fall into this category.

Offshore rigs:

- *Fixed platforms*: Drilling rigs supported by a permanent steel or concrete structure. This configuration is used for field development. The rig is then used to drill the development wells and later, during the production phase, for work-over operations.

- *Drilling barges:* Used for shallow water and swamp operations. The drilling barge is towed to location and ballasted to rest on the bottom. Depending on the location, an access channel may have to be dredged. Drilling barges are relatively small and require therefore additional barges to carry casing, bulk chemicals and cement and services such as the cementing (pump-) unit, the testing surface equipment, etc. During rig move and while towed, the derrick of a drilling barge is laid down to increase the stability of the vessel.

Some rigs use a device called *automatic driller*. This is a mechanic device that releases the brake automatically and maintains a constant weight on bit. Experienced drillers claim, however, that a good man on the brake is superior and drilling more efficient than with the help of the automatic gadget.

7.2.1.2. Rotary Table Drive, Top Drive

The drive mechanism turning the pipe and with it the drill pipe can be one of the two: rotary table drive or top drive. The top drive is a relatively new concept and installed usually only on high-tech offshore rigs although top drive mechanisms are available also for smaller land rigs. The main advantage of a top drive are a reduction in rig time when making connections and when tripping. A further advantage is the ability to keep on pumping mud while pulling the pipe upwards, a practice also known as *back-reaming*.

The rotary table drives the drill pipe around transmitting torque to the drill bit. The rotary table is mounted on the rig floor, and is powered by either a mechanical take-off from the draw-works, or by its own electrical motor and gearbox. The rotary table is the measuring point for the RPM sensor and the torque sensor (page 29). Both parameters are usually recorded in the mudlogging unit.

The kelly is the topmost part of the drill string. Typically the kelly is 45 feet long, hexagonal or square. The interior of the kelly is hollow for the passage of the drilling mud. Around the kelly is the kelly bushing, or drive bushing, which is equipped with four (or six) rollers that engage the flats on the face of the kelly. Four pegs in the base of the bushing engage in the rotary table. Thus, the rotary turns the bushing, which forces the kelly to rotate, while the rollers allow the kelly to slide through the bushings as the hole gets deeper.

7.2.1.3. Motion Compensator

On floating rigs it is necessary to allow for the heave of the vessel which is caused by wave action or tidal motion. The motion compensator is fitted to the travelling block. The hook is the supported through two very large hydraulic cylinders that are driven by a system sensing the motion relative to the seabed (a delicate arrangements of wires). The action of the hydraulic cylinders should (so the theory) keep the distance between the kelly and the seabed constant.

Geological note: During wireline logging operations the motion compensation system is sometimes switched off without notifying the geologist. The effect on the depth control of the wireline logs is evident. Check the status of the motion compensator when logging !

7.2.1.4. Swivel and Kelly Hose

At its top, the kelly is connected with the swivel, which allows the kelly and the drill pipe to rotate below the (stationary) hook of the travelling block, from which the whole drill string is suspended. A flexible hose, the kelly hose, connects the mud pumping system to the kelly and the drill string. The part of pipe leading up the derrick and connecting to the kelly hose is called stand pipe.

with the open end pointing upwards. The actual use of it is, however, even questioned by drilling experts.

- *Stabilizers* are short subs with fins that are exactly of the hole diameter. The purpose of the stabilizers is to centralize the collars and to keep the hole straight. The faces of the stabilizer fins are coated with hard material such as tungsten carbide to reduce wear and tear. It is not the purpose of the stabilizer to increase the hole size after the bit or exert any kind of abrasive action - *reamers* are run in the BHA if this becomes necessary.

- *Bumper subs* are telescopic shock absorbers, typically with a stroke of 5 feet and are used either singly or in multiples. Bumpers are used to control vibration and also to compensate for heave motion. The inclusion of a bumper in the drill string must be noted by the geologist. The closing and opening of the bumper sub will cause problems with depth monitoring and can possibly be misinterpreted as a drilling break. (When in doubt - ask the driller on the floor !)

- *Jars* are made to provide a heavy upward pulling shock to the drill pipe and the BHA should it get stuck in the hole. You can hear a beating jar all over the rig - it sound like two stands of drill pipe crashing together. If you hear that noise during a trip, you should be available in the mudlogging unit to monitor the trip, note the amount of overpull and possibly figure out where in the open hole section the formation is causing problems.

- *Fishing tools* are tools run on the drill string in order to remove unwanted material, metal, a lost part of the drill string, from the hole. The most common types are the *overshot* to grasp outside the lost pipe in the hole and the *spear* to engage inside the lost pipe. There are nearly as many types of fishing tools as there are types of pipe, BHAs, cables, logging tools, bit cones, etc. that can be lost in a hole. If the drillers don't know how the end of the thing lost in the hole looks like, they will run a lead impression block (LIB) to get a imprint of the obstacle and to select the proper fishing tool.

7.2.2.3.3. Downhole Motors

Downhole motors are increasingly utilized and included in the BHA. These machines are located immediately above the bit and use the power of the flowing mud (pumped down the drill string) to turn the bit independently of the drill string. If a downhole motor is run then the RPM of the bit is that of the rotary table *plus* the RPM of the downhole motor. Unfortunately there is no direct method to measure the actual RPM of the motor, it has to be calculated from the pump rate of the mud (a parameter which is monitored in the mudlogging unit).

Positive displacement motors (e.g."Dynadrills") consist of a spiral cavity with an elliptical cross section (the stator) which houses a sinusoidal rotor driving the bit.

Turbines utilize a series of turbine blades to transfer the movement of the mud inside the drill pipe into rotational drive for the bit.

Turbines are commonly used with diamond bits. The high revolutions of the turbine complement the very long life potential of the diamond bit. This enables long sections of harder formation to be drilled without the need for time consuming (i.e. expensive) trips that would be necessary to keep changing less durable conventional bits.

lithlogies is relatively poor and their cost mcuh higher than the cost of ordinary tricone bits.

As a consequence, PDC bits are usually employed in a development situation where the lithogy is known and the efficiency of such bits has been established. PDC bits *can* last for several wells but *can* also be totally destroyed within a foot of drilled rock if junk is present in the hole.

For the geologist:

- If a PDC bit is to be run, tell the company man immediately if you see any metal debris or pyrite in the samples.

- Note that the shape of cuttings from a PDC bit is different from conventionally drilled cuttings. PDC cuttings are usually smaller and shale lithologies can be "scooped" together (see **Figure 31**) due to the different bit action. Limestone cuttings appear more chalky and can be powdered to dust.
  However, in most cases, PDC cuttings appear somewhat cleaner and there is no substantial problem to identify and describe the nature of the rock.

7.2.3.3. Classification and Grading of Bits

The IADC (International Association of Drilling Contractors) has a standard classification system, whereby each bit type, regardless of manufacturer is given a three digit code. Tables are available to show and compare the various types of bits from the main manufacturers.

There is also a standard classification for describing the amount of wear and tear a bit has suffered during use. The degree and type of wear can be expressed in three ways: Teeth, bearings and gauge (TBG). Every of the three items is graded on a 1 to 8 scale, eight being the worst. B=8, for example, would mean that all teeth are broken or worn. The geologist does not need to be conversant with the grading and all its sub-systems. However, as the grading of a worn bit is an entry on the graphical log produced, he should know what it means and what the rocks of the last section drilled have done to the bit.

7.2.4. Mud and the Mud Circulation System

The mud is of great importance to the drilling operation. Whilst drilling, the mud is constantly circulated from the storage pits, down through the drill string through the bit, returning up the annulus and back over the shale shakers before returning to the pits. This is termed *normal circulation*. Reverse circulation is applied only under special circumstances, e.g. when reversing out fluids in the drill string after a test.

The properties of the mud and its related functions are:

- Mud density: Controlling subsurface pressures
  and also
  help to support the weight of drill pipe or casing.
- Viscosity: Removal of cuttings from the hole
- Gel strength: Keeping cuttings in suspension when the circulation is stopped
- Oil, additives Cooling and lubrication of the bit and the drill string
- Filtrate, Water Loss: Lining the hole with an impermeable filter cake, the mud cake

The mud engineer, in a way the chemist on location, conducts a comprehensive series of tests at least once a day to determine the mud properties. This mud check is part of the daily drilling report, but more important, the geologist and the mudloggers must attempt to get a copy of the report (try the company man). More about mud, it's properties, etc. on page 92.

7.2.4.3. The Mud Pumps

A drilling rig has usually two mud pump to circulate the mud. Some big rigs have three pumps. It depends on the pump output volume required if all pumps run simultaneously or if one pump is sufficient to support the drilling. Big diameter hole usually requires both pumps operating. Mud pumps are either duplex double-acting or triplex single-action pumps.

Mud pumps are not only used to pump mud, but can also be used to pump cement slurry (replacing the cement unit when big volumes have to be delivered) or any other fluid. On jack-up rigs, the mud pumps can be connected to the ends of the legs in order to jet them free if they penetrated deeply into the sea bottom, to jet the legs free, as the jargon says.

Triplex pumps are found now almost universally on new rigs because of their better performance. The triplex pump has three pump cylinders operating on one crank shaft with 120 degrees phase difference. Every cylinder pumps with the forward moving action of the piston and recharges with the retracting action of the piston. It is obvious that this arrangement is superior to two-cylinder arrays which are 180 degrees out of phase and therefore create a much stronger pulsation of the mud pressure in the standpipe. In order to smooth the residual pulsation of the pump pressure, all pumps are equipped with *pulsation dampeners*

The cylinder liner and the piston of the mud pumps can be changed to provide different balances between volume and pressure. It is not uncommon to operate the pumps with 7" liners during the upper portion of a hole, where large mud volumes are required and then change to 6"liners for the deeper portion of the hole, where volume is less important than pressure.

Note, that the actual volume output of the mudpumps is *not* exactly the volume of liner length times piston area. The actual pump output is less, depending on the *pump efficiency*. The effieciency of normally operated pumps is somewhere between 85 to 95 percent. Use the efficiency discounted value of pump output when calculating lag time, etc. (page 36).

Geological comments:

- The liner size affects the output of the pump and finally the lag time. Operating two pumps with *different* size liners leads to problems monitoring the lag. The driller should keep both pumps identical.

7.2.4.4. Flow Line and Solids Removal

The mud flow returns to the surface up the annulus. On an offshore rig, the mud continues from the seabed to surface through the riser. Immediately below the rig floor, the mud is diverted down a large diameter pipe, the flow line, into the possum belly, the small tank that feeds into the shale shakers.

The shale shakers consist of an inclined frame on springs with a fine mesh screen stretched over it. Note that the screen sizes can change depending on the driller's requirements.

- The size of the cuttings fraction is therefore also dependent on the shaker screens.

An electric motor with an eccentric can causes the frame to vibrate. Double-deck shakers have tandem screens mounted one above the other, the top one being coarser. The mud pour onto the top of the screens and drops straight through, leaving cuttings and cavings to shake down the screen and to fall off into a discharge trough.

- Some companies place a magnet in the flow line or somewhere in the mud stream, before it reaches the shale shakers. This magnet attracts metal coming up with the drill cuttings such as

detrital matter of the bit, the stabilizers, the casing or anywhere else downhole where metal is eroded, worn. The mudloggers should check the magnet on a daily basis.

From the tank near the shale shakers, the *sand trap*[22], the mud is then pumped through the desander and desilter. These devices are arrays of funnels separating the (heavier) fines from the (lighter) mud by centrifugal force.

- The geologist and the mudloggers when taking a sample should always check the amount and material discharged by the desanders and desilters. The desander and desilter output should be combined with the sample taken at the shale shakers..

- Beware of mistaking barite for fine sand (see also page 53) !

Solids removal includes also the removal from solids in the borehole. If the hole cleaning is not sufficient, not all cuttings are brought to surface, two effects occur:

- The actual mud weight increases. The hydrostatic head of the mud in the hole increases due to the admixture of cuttings. In cases where the fracture gradient is near the hydrostatic pressure, fracturing of the formation and mud losses may occur, although the nominal mud weight going into the hole appear to be light enough not to fracture the formation.

- If cuttings accumulate, they may fall sink down to the bit or the stabilizers when the pumps are stopped, for example, when making a connection. In bad cases, the drillstring may become stuck when pulling up by a stand, when the connection is made.

7.2.4.5. Trip Tank

Nearly all rigs have an extra mud tank, usually sited away from the rest of the mud circulation system, called the *trip tank*. Its purpose is to aid the monitoring of the mud level in the hole during a trip. The trip tank is usually tall and slender, so that any volume change causes a relatively large fluctuation in level and is more easily and accurately monitored. The read-out on the rig floor is direct, not depending on any electronic or mechanic device. Often a string with a mark near the driller's console connects directly to the float in the trip tank.

Just prior to a trip, the trip tank is filled. When the main mud pumps are stopped, a small centrifugal pump is switched on. This circulates the mud from the trip tank into the hole, which then overflows into the flow line and is diverted back into the trip tank. Once the small pump is running, the hole remains always full and the hydrostatic head constant. As each stand of drill pipe is pulled out of the hole, the mud level drops by an amount equivalent to the displacement of the pipe removed. The trip tank immediately replenishes this, so that the mud level in the trip tank should fall by a certain amount. This change is monitored at regular intervals (e.g. every ten stands pulled). Any deviation from the calculated volume ("hole take") should alarm the driller. The volume of the trip tank is usually monitored independently by the driller *and* the mudlogging unit.

- *The majority of kicks and blow-outs occurs whilst tripping*. Correct monitoring of the hole fill on trips is essential. During trips, the most critical phase is near midnight and lunchtime when the crew on tour is waiting for the next crew to continue and when their concentration is reduced after long hours of work.

[22] The sand trap is a small settling tank for the coarser particles in the mud. It is emptied regularly. When the sand trap is emptied (dumped), the total mud volume decreases. This decrease should trigger the alarms in the mudlogging unit. (See also page 40.)

If the rig is not equipped with a trip tank, then the hole is filled up with the mud pumps. The number of strokes necessary to fill the hole is converted to volume and compared with the expected volume of *hole take*.

7.2.4.6. Mud Hydraulics

This chapter is supposed to introduce only to hydraulics of the mud flow and the implications for the implications on the geological side of the drilling operation. The novice wellsite geologist may be interested to know that this optimization process is one of the most important tasks of the drilling engineer when planning the drilling of a well.

In order to optimize drilling performance (fast, cheap, safe), the mud flow is optimized in order to have:

- maximum flow velocity at the bit's jets in order to maximize rate of penetration.
- minimum pressure losses in the drill pipe and the annulus.
- optimum cuttings lifting performance (hole cleaning).
- minimum turbulent flow in the open hole section (in order to avoid hole wash out and caving).

The limiting side conditions in this exercise are :

- the pumps available (or more precise their power and their output rate).
- the hole geometry.
- the drillstring in the hole.
- any obstacles restricting the flow inside the drill string (e.g. a downhole motor) or in the annulus.
- Mud properties (see page 94).

Some points are points of relevance for the geologist or of general interest are mentioned here:

- The most important factors controlling cuttings transport are the annular velocity (i.e. the velocity of the mud in the annulus) and the rheologic properties of the mud. Usually annular velocities of 50 feet per meter
  provide satisfactory cuttings transport in typical drilling muds. Cuttings transport efficiency increases with increasing viscosity of the mud.
- Cuttings size and fluid density (mud weight) have only moderate influence on the increase of the transport efficiency. (I.e. the effect of settling after STOKE'S Law is relatively small compared to the effect of viscosity, page 95.)
- Hole size, drill pipe rotation and drilling rate have only a slight effect on cuttings transport if the annular velocity is constant. It makes also a difference when a big hole is drilled with limited pump output and a big rock volume transformed to cuttings, however, this is a matter of plain volume calculations, not of the rheology and hydraulic in the sense of this chapter.

A build-up of cuttings in the annulus (due to low pump output, for example) is detrimental for the drilling performance:

- The mud weight increases uncontrolled and may - in the worst case - induce fracturing and losses to the formation.
- In extreme cases, cuttings adhere to the drill string thereby restricting the annulus and create a pressure loss.

Terminology Note that most of these formulae are made up in *oilfield units.* As unpractical as it may seem for an engineer, grown up in other fields of technology, these units are being used and most of the drilling specific software and much of the instruments on the drilling rig use these “funny” units. Some of the buzz words commonly used when describing mud hydraulics (and bit hydraulics) are explained herebelow:

Annular Velocity is the average speed at which drilling fluid is moving back up the annular space as the well is drilling or circulated. Although the mud pump output is constant, annular velocities vary at different points in the wellbore due to change in pipe, collar and hole sizes.

$$AV = \frac{24.5 \times GPM}{Dh^2 - od^2}$$

Whereby
- AV: the annular velocity in *ft/min*
- GPM: the actual pump output in *gallons per minute*
- Dh: the hole or casing diameter in *inches*
- od: the pipe outside diameter in *inches*

Jet Nozzle Area. A conventional rotary drilling bit has two to four (usually three) jet nozzles installed to impart a jetting action on the mud to clean the bottom of the hole. In some occasions (big hole) no nozzles at all are installed. In fact, this jet action does most of the drilling work by breaking up small fractures and lossening the cuttings from the solid rock ahead of the bit. The nozzle size is variable and measured in 32nds of an inch. Thus, a bit with "three 13's" has three nozzles with 13/32 inch diameter.

$$An = 0.000767 + (J1^2 + J2^2 + J3^2)$$

Whereby
- An: the area of all three nozzles in *square inches*
- J1, J2, J3 the area of the individual nozzles (measured in 32nds of an inch)

Jet Nozzle Velocity is the velocity of the mud exiting the jet nozzles of the bit and is calculated as

$$JNV = \frac{0.32086 \times GPM}{An}$$

Whereby
- JNV the jet nozzle velocity in feet per second
- An: the area of all three nozzles in *square inches*
- GPM: the actual pump output in *gallons per minute*

Total Hydraulic Horsepower The total hydraulic horsepower available for drilling hydraulics is defined by the circulation rate and the pressure of the mud pump(s).

$$THhp = \frac{Pp \times GPM}{1714}$$

Whereby
- THhp: the total hydraulic horsepower (*in horsepower* !)
- Pp: the pump pressure in *psi*
- GPM: the actual pump output in *gallons per minute*

Hydraulic Horsepower at the Bit Similar to the total hydraulic horsepower above, the hyraulic horsepower at the bit is calculated. Instead of the pump pressure, like for the whole system, the jet nozzle pressure loss is plugged into this equation.

$$\text{BHhp} = \frac{JNPL \times GPM}{1714}$$

Whereby	BHhp:	the hydraulic horsepower at the bit (*in horsepower* !)
	JNPL:	the jet nozzle pressure loss in *psi*
	GPM:	the actual pump output in *gallons per minute*

Jet Nozzle Pressure Loss. Pump pressure is the the total pressure expended throughout the circulatin system's surface equipment., but only the pressure expended through the jet nozzles accomplishes useful work for drilling. The remaining pressure losses are referred to as parasitic pressure losses. The useful jet nozzle pressure loss is calculated as follows

$$\text{JNPL} = \frac{MW \times GPM^2}{10{,}858 \times An^2}$$

Whereby	JNPL:	the jet nozzle pressure loss in *psi*
	MW:	the mud weight in *pounds per gallon*
	GPM:	the actual pump output in *gallons per minute*
	An:	the area of all three nozzles in *square inches*

Jet Impact Force. The jet impact force is the force that the mudstream jetting out of the bit nozzles exerts on the formation and makes the whole thing drill good, provided the jet impact force is optimal. the formula is

$$\text{JIV} = 0.000516 \times MW \times GPM \times JNV$$

Whereby	JIV:	the jet impact force in *pounds*
	MW:	the mud weight in *pounds per gallon*
	GPM:	the actual pump output in *gallons per minute*
	JNV:	the jet nozzle velocity in *feet per second*

Please note, that therse formulae are *not* the working kit of the geologist. They are copied here to give the wellsite geologist some understanding of the optimization processes that are going on at the wellsite and to give the geologist some basis of understanding the driller's tasks and the solutions he might choose.

- The well is still flowing when the pumps are shut off. Monitor the flow-out sensor closely. Flow out at the mud flow line should cease in a few seconds after the pumps ware switched off. When monitoring the flow out at the pit tanks, the afterflow is somewhat longer, depending on the type of mud cleaning equipment and the volumes contained in them.

- An increase in pit volume may be noticed only after the connection. When the levels have stabilized after the pumps are restarted. An increase in pit level indicates that flow into the wellbore has occurred.

- Loss of pump pressure when resuming drilling. If lighter fluids (oil, gas) have entered the wellbore, less pump pressure is required to lift the mud in the annulus to surface (i.e. a reduction of the hydrostatic pressure in the annulus has occurred).

7.2.5.2. Kick while Tripping

The majority of kicks occurs when tripping out of the hole. The reasons for this are the reduction of pressure at the bottom caused by swabbing action of the bit (and also by stabilizers which can be packed with shales and exert an even greater swab effect than the bit. The swab pressure increases with the speed of the travelling drill string. Usually the trip speed out of the hole is restricted to one or two minutes (or even much slower, depending on pressures estimated) per stand of drill pipe.

Of course, the well must be kept full with mud and the hole take compared with the calculated hole take. (See page 83, trip tank.)

7.2.5.3. Kick while Drilling

The first indication that a kick may occur is a drilling break, an increase in ROP. A *significant* drilling break is defined by an increase of ROP by the factor of two, i.e. twice the drilling progress per unit time.

- Any significant drilling break must be checked for flow. Call the rig floor and request a flow check if you have seen a significant drilling break and the driller does not take any action. For a flow check the pumps are switched off and the well is observed at the rig floor by peeping into the annulus with a torch *and* with a second watch at the shakers or possum belly. The time to observe the well should not be less than five minutes. (See also page 40).

- If there is any indication that the well is not static after the pumps are shut off - call the driller on the rig floor *immediately*.

The second indication of a kick is an increase in the flow rate out. Once flow begins, the rate of flow increases proportional to the depth of penetration into the reservoir. Most mudlogging units have computerized alarm that go off when the flow rate[out] is bigger than the flow in.

- If you see any increase of flow out without a corresponding change in pump output -call the driller on the rig floor *immediately* and alert him about the situation.

The third possible indication of a kick while drilling may be seen in an increase in hook load. If the invading fluid is lighter than the mud then the buoyancy of the drill string is reduced and an increase of hook load registered by the sensors.

The fourth possible indication of a kick while drilling may be an increase in the pump rate. The reasons are similar to the ones explained above. The invading fluid is lighter than the mud and the force required to lift the mud in the annulus is less. The pumps usually respond to this loss in back-pressure with an increase in speed seen as increased strokes per minutes (SPM).

7.2.5.4. Gas Cuttings

Certain relatively harmless conditions may give the false appearance of a severe kick, notably gas cuttings. Rock chips cut by the bit may contain gas which, although suppressed in down hole conditions, may escape as the cuttings rise to lower pressure levels. Alternatively, the background level of gas in the mud may get too high, which will also expand as the mud nears the surface. In the top few hundred feet of the hole this gas cutting can be severe, foaming the mud and vastly increasing its volume. At the surface this appears very serious but the well has not taken a kick since the gas not entered the hole from the wall under uncontrolled conditions. The mud weight does not necessarily require increasing. However, it will be necessary to remove the accumulated gas from the mud by running the degasser. It may be necessary to close the BOP for a short time to prevent loss of mud if the foaming is severe enough to lift the mud over the top of the flow line. The conditions leading to over-accumulation of gas in the mud must be remedied.

7.3. The Art of Drilling

This chapter is far outside the actual duties and responsibilities of the wellsite geologist. However, it is equally important that you understand the principles of drilling practise and the impact of drilling practise on the quality of geological data.

For example, drilling is different when using fast turning downhole motors with a PDC bit and different for coring or conventional tricone-bit drilling. Also, there is a big difference if the driller sets the bit on bottom with a lot of weight and then starts rotating or if he runs slowly to bottom with a rotating bit and hits the bottom of the hole while rotating. Different bits, different drill strings and different rocks may require different approaches.

7.3.1. “Making Hole”

The art of drilling is to put enough weight on the drill bit (by releasing the brake) and to keep the weight steady. If the weight on bit (WOB) is too high, the bit may be damaged very fast, if the weight is too low, no drilling progress is made. Of course, there are spec sheets and smart computer programs that calculate how much weight on a bit would be ideal, nevertheless, it comes down to the driller to optimize this process.

The choice of parameters, RPM, WOB and pump output is limited by a number of factors and design criteria: For example, the ROP depends of the bit and hole size and possible resonance in the drill string. The pump output depends on the horsepower of the pumps, the mudweight, hydraulic conditions and the WOB depends on bit type and lithology. This interrelationship is by far more complex, but also beyond the scope of this book.

The *weight on bit* (WOB) required to drill properly depends on the type of bit and the type of rocks being drilled. Soft rocks, usually drilled with a long-tooth bit, take relatively little weight. Too much weight would spud the teeth in the shale and make it difficult for the bit to turn. The torque would be increase to levels that are technically not acceptable. In contrast, hard formations, usually drilled with a short-tooth bit can take more weight. The drilling action in hard rocks is optimized to crush and fracture the rock ahead of the bit and break the fractures with the action of the jets.

When drilling with PDC bits, the weight on bit is relatively less compared to tricne bits. PDC bits do not crush and fracture the rock. PDC bits are designed to scratch and scoope the formation. Therefore, PDC bits are run *usually* with less weight and higher RPM can comparable tricone bits.

Geological note:

It is far outside the scope of the geologists work to find the right drilling parameters. However, a good understanding of the drilling paramters give a deep insight and help with the interpretation of the ROP curve, Dx-exponents, etc. Such formulas work only within the limitations of the methods whereas there is a number of situations in which the ROP (or Dx) curve may indicate a change of lithology where in reality an abrupt change of drilling parameters may have caused a break in the log curve.

For practical purposes, ROP and Dx curves shold only be compared within the same hole size, for similar bits and comparable mud weights.

7.3.2. Depth Control - How Deep Are We ?

Depth control on a drilling well appears to be trivial. However, it can be a very complex and controversial subject. In simple terms, depth is measured by summing the length of the drillpipe in the hole. Every drill pipe is measured and numbered and then added to the list, the pipe tally. The exact depth is established every time a connection is made. In the drillers' jargon this sounds like "next kelly-down is 7436.7 meters", meaning when the next connection is due, the hole will be at exactly 7436.7 meters, as an example.

- The drill pipe tally is the first and ultimate depth reference. All other depth measurements relate to this pipe tally.

The pipe tally is relative to a datum, and there are two depth reference datums are used in drilling operations:

- The Rotary Kelly Bushing (RKB)
- The Rotary Table (RT)

Go to the rig floor and inspect the difference ! Drilling depth is measured from RKB, that is the top of the kelly bushing, *about* 1 foot above the rotary table. When drilling the kelly is marked with chalk in meter or foot increments to see the progress and calculate the ROP while drilling a single.

When running logs, the kelly and with it the kelly bushing is removed at put aside. The depth reference for logging is the rotary table (see page 109) which is usually level with the rig floor.

- You have to be aware of the difference in datum and the possible error introduced by the two reference points.

In case of any doubt as to the correct depth of a well, the drill pipe will be strapped, i.e. every stand of drill pipe is measured again, totalled and the result is compared with the pipe tally. If operationally relevant, the geologist can request pipe strapping (SLMO, steel line measuring while tripping out).

Drill pipe can and will stretch under its own weight and depending on the mud weight, which determines the boyancy of the drill pipe acting against its weight. This stretch is in the range of three feet (one meter) for a medium deep well. A good drilling engineer will have have tables and charts to estimate the exact stretch of the pipe. An additional uncertainty is the drill-off practise: While drilling, the lower part of the drill string is in compression and the weight of the lower part of the string acts as weight on bit (WOB). If, before tripping out of the hole, the driller keeps on drilling until the weight on bit approaches zero, an additional one to three feet are drilled without adding drill pipe. This extra hole is not accounted for. So, when comparing drillers depths, find out from the driller on the floor how this final depth has been reached. With the full weight on bit or drilling off to near-zero weight on bit. The described practise is often used prior to running casing (and logging), because it adds some "extra hole" which does not appear on the daily report but may be of help when running casing to accomodate possible problems and unconsistencies in the casing tally.

Common Errors:

- Depth discrepancies in the range of one to two feet are common and not really substantial. Pipe stretch and inaccurate measurements can be an explanation (see also the previous chapter).

- Wireline logging depth is shallower than the drilled depth derived from the pipe tally. It can be assumed that cavings have accumulated on the bottom of the well and the loggig tools cannot reach the bottom of the hole.

Uncommon Errors:

- The number of drill pipe singles is wrong or a stand of pipe that is included in the tally has not been run into the hole. Therefore, beware of depth errors which are close to 30 feet (one single pipe) or 100 feet (one stand).

- The rig or platform measurements are wrong. This introduces a datum error which is not obvious because the tally measurements are consistent and only formation tops and fluid contacts are shifted.

7.4. Mud Engineering

Mud engineering is the science (or art ?) and application of controlling drilling fluids in an optimum manner. The mud engineer on location reports to the company man. The geologist cannot give much input as to how the mud should be treated. the properties of the mud do, however, strongly affect the geological work, the wireline logging (page 109), the pressure engineering (page 63), and many other aspects of the routine drilling and geological operation.

The function of the mud is to remove the drill cuttings from the bottom and transport them to the surface, to create a hydrostatic head in order to control the pore pressure (see also page 63, pressure engineering) of the formation, and to cool and lubricate the drilling bit.

These purposes are achieved by systems and mixtures of various chemical compounds in either water or oil as continuous phase. Other systems like drilling with foam or with air (or gas) are used occasionally under special circumstances.

7.4.1. Water based Mud Systems

Water based mud is the most common type of mud used for exploration drilling. The water used to mix the drilling mud can either be fresh water or sea water. Clays, such as bentonite and/or synthetic polymers are added to water to increase viscosity and density. Additional chemicals are used to control viscosity, pH, foaming, etc. The most common material to increase the weight of a mud fluid is barite.

7.4.1.1. Lignosulfonate Muds

Freshwater lignosulfonate muds are commonly employed for drilling in areas where *mud making* formations are prevalent, i.e. where part of all of the shales in the formation drilled are dispersed into the mud system. Such systems are sometimes referred to as native muds. Lignosulfonate muds provide rheological control and afford a degree of inhibition to drill solids.

Lignosulfonate muds can be based on fresh water or sea water. A pH value close to 10.5 is required and maintained by the addition of caustic soda (NaOH).

Geological comments:

- Shale cuttings are usually under-represented in the total drill cuttings. Their shape is rounded due to solution processes. Shales may also appear softer in the sample, in particular if they have travelled up a deep hole.

- Undissolved lignosulfonate may be mistaken for coal or lignite from the formation.

7.4.1.2. Lime and Gypsum Muds

Lime i.e. $Ca(OH)_2$, or gypsum muds are muds treated with calcium and used in areas where shale hydration and swelling results in significant bore hole instability (i.e. sloughing and heaving). Increased levels of soluble calcium are maintained in these muds to provide an inhibitive environment to minimize shale swelling. The solubility of lime or gypsum is controlled by the pH of the system and typical pH values range pH = 9.5-10.5. Lime and to a lesser degree also gypsum muds are temperature sensitive and are subject to solidification at 275 °F.

7.4.1.3. Saltwater Muds

Saltwater muds are used to drill salt (halite, NaCl) containing formations. Some application also for sensitive shale sections. The most commonly used salt muds contain NaCl or KCl (occasionally also $CaCl_2$). Viscosifiers can be salt tolerant polymers, gels, or clay (attapulgite or bentonite).

7.4.1.4. KCl Muds

Potassium chloride muds are a special class of salt muds, in that potassium (K^+) is utilized as the principal inhibition ion. Potassium in concentrations from 3% to 15% is used to inhibit the swelling and dispersion of clays contained in various formations. KCl is primarily used as a shale control agent, but is also frequently used to prevent formation damage from clay swelling in producing zones (as a completion fluid). KCl can be combined with a polymer base but also with clay base muds.

Geological comments:

- KCl muds will exhibit a slow increase in chlorides (Cl^-) over a few days if the same concentration of K^+ is maintained.
- When calculating R_{mf} from chlorides, bear in mind that the resistivity of KCl solution has to be transformed into NaCl equivalent. (See the relevant charts and chart books of the wireline logging contractor for this.)
- The potassium content in the KCl mud does affect the gamma ray logs, both the conventional GR and the spectral gamma log. The wireline contractors apply correction algorithms when processing the logs, but not on the wellsite. For a quick-look interpretation it may be suffcient to shift the GR log towards the sand base line.

7.4.1.5. Polymer Muds

The basic component of polymer base drilling fluids is a high molecular weight water soluble viscosifying polymer. Various types of polymers are available. Polymers are required only in low concentrations as compared to conventional viscosifiers. They are subject to temperature thinning and tend to be more corrosive than conventional muds. Their temperature limitations are below those of most clay base systems, however, high temperature polymers are available.

Geological comments:

- Polymer muds encapsulate shales without exposing them much to free water. Shale cuttings are therefore firm and in original shape as drilled by the bit.
- If the mud system is changed over from conventional mud to polymer the change of cuttings shape from soft rounded to splintery or platy shale cuttings may be misinterpreted as a formation change.

7.4.2. Oil based Mud Systems

Oil based mud systems are emulsions of water in oil. The advantages of oil based muds are:

- Better temperature stability in high temperature environments.

- Non-reaction with shales, clays and evaporites[24].
- Easier maintenance of the mud weight, in particular when weighting material such as barite or hematite are used.
- Faster drilling (therefore cheaper operating cost) owing to better hole cleaning and better viscosities.
- Better drill string lubrication.

Disadvantages:

- Relatively high cost per volume unit (this however being offset by recycling of used muds and faster drilling).
- Pollution problems and toxicity.

An emulsion is typically made up of 75% oil and 25% water. Increasing the amount of water leads to a less stable, more viscous, but cheaper mud. To this mix is added: emulsifiers, viscosifiers (bentonite), lime (gives the alkalinity necessary for emulsification), salts and weighting agents (barite, etc.).

Geological comments:

Washing : The oil base mud does not cling to the surface of the cuttings like water based mud, and so no washing of the cuttings is usually necessary. Should the geologist require cuttings to be washed, then clean diesel followed by ordinary detergent is be used. Minimize the use of water in order to prevent the swelling of shales.

Fluorescence : The thin layer of oil mud on the cuttings will slightly decrease the amount of any crude oil fluorescence seen in the cuttings. The base oil of the mud will either not fluoresce at all or will fluoresce with a distinctive white or blue-white color, quite unlike any crude fluorescence which usually shows shades of brown, yellow, gold, etc.

Log evaluation :
The water phase of oil based muds is highly saline and this salinity may increase to saturation when drilling evaporites. Be aware that conventional methods determining the R_{mf} of oil based muds *may* underestimate the actual salinity of the filtrate.

Kick detection: CO_2, CH_4 and other hydrocarbon gases are soluble in oil muds. If gas enters the wellbore, it can be in solution under the hydrostatic pressure of the mud. As the mud moves up the the wellbore, it can break out of solution at the bubble point pressure and rapidly evacuate the hole.

7.4.3. Mud properties

The most important parameters describing the properties of a given mud system are:

- The mud weight, the specific density of the mud expressed in g/cm^3 or in pounds per gallon (ppg) in imperial units[25]. The mud weight controls the hydrostatic head of the mud column in the well bore designed to counterbalance the pore pressure of the formation or reservoir. More about the implications of the mud weight on page 63. The mud weight is measured using a mud balance.

[24] The choice to drill a salt section is either a NaCl saturated water based mud or oil emulsion mud.

[25] The unit pounds per cubic foot (lb/cuft) is rarely used any more.

- Viscosity. The viscosity controls the ability of the mud to lift the drill cuttings from the bottom to the surface. Equally important is its influence on the hydraulic behavior of the fluid, hence another point to optimize drilling parameters and to drill more efficiently, cheaper.

  The easiest - although not very precise - way to measure viscosity is to measure the time it takes for a given volume of fluid to pass through an flow restriction. On the rig, a plastic funnel containing one quart of mud is used and the time is measured it takes to empty this funnel. Viscosity is therefore expressed in seconds.

Viscosity and density are parameters in the REYNOLDS equation which indicates whether turbulent or laminar flow conditions prevail under given velocity of a flowing medium. Owing to the importance of the two parameters many rig contractors announce the mud weight and viscosity regularly every half hour or so over the rig's PA system. This is a very useful practice.

Other mud properties, not less important, are:

- Salinity. Expressed in ppm NaCl or Cl^-. Both units are used parallel and are therefore prone to create confusion. In the realm of drilling people usually chloride (Cl^-) is used. Multiply by 1.64 to get the same ppm value for NaCl.
- pH
- Gel strength (PV/YP)
- Solids content. Solids content can be reported as high gravity solids (HGS) such as barite or hematite, used as weighting material and low gravity solids, such as quartz.
- Oil content.
- Water loss. The property of the mud to separate under pressure on a filter into filtrate (the liquid) and filter cake (the solid).

Note: When barite or any other weighting material is used in a well, the GR logs *must* be corrected for the attenuation of gamma radiation by the material. Charts are available for this.

7.4.4. Mud Filtrate Tracers

Whilst drilling through a permeable formation, mud filtrate will invade the region close to the well bore and mix with natural fluids in the formation. Formation water samples obtained using a wireline tool or during a drill stem test (DST) are usually contaminated by mud filtrate. It is important to know how much of the fluid sample is formation water and how much is mud filtrate for the following reasons:

- The true salinity of the formation water must be known to enable accurate measurement of the hydrocarbon saturation in the reservoir from electric wireline logs.

- If wireline or DST fluid samples recover water from a zone thought to be oil bearing, then either the zone is water bearing or the mud filtrate has swept oil away from the bore hole. To enable the cause to be established and a decision on testing to be made, the source of the recovered water must be known.

- Quantitative evaluation of the presence of formation water recovered on tests enables the selection of the best water samples for further laboratory analysis. Knowledge both of the tracer content and mud filtrate characteristics will then allow a quantitative determination of formation water properties.

- Deeply invaded zones will flow mainly mud filtrate when sampled with an RFT. Note that the possible presence of oil in the formation may be hidden. The relative abundance of tracer in the recovered fluid may indicate such a possibility.

By adding a tracer to all the fluids that are introduced into the drilling mud at a known constant concentration it is possible to determine the quantity of mud filtrate in a fluid sample by measuring the tracer concentration.

The tracer can be any substance that does not affect the mud properties, that can be easily analyzed quantitatively and is easy to handle. The following methods have been used:

- *Nitrate* (NO_4^-) in the form of Sodium- or Potassiumnitrate can be used. Analytical detection is by titration. High concentrations of lignosulfonate can mask the detection. Recommended concentration of Nitrate is 500 ppm, so few sacks of Nitrate tracer substance are sufficient to hold a detectable concentration of the drilling period of a deep well. However, Nitrate decomposes under higher temperatures and the concentration can therefore not kept stable. Results will still bear some ambiguity.
  Note that KNO_3 and $NaNO_3$ are oxidizing agents that react as explosive when mixed with a reducing agent such as many mud additives (CMC, starch for example). Nitrate is also used as fertilizer.

- *Uranyl compounds* are colorful greenish-yellow fluorescing substances that can be detected in very low concentrations (ppm - range) by photometric methods.

- *Triated water* is chemically identical to untreated water but has one of two Hydrogen atoms replaced by a Tritium[26] atom. It is suitable as a tracer because it does not occur naturally and allows rapid and accurate measurements even at low concentrations. It is chemically stable under downhole conditions, not absorbed by mud solids or the formation. Safety standards applicable to low radioactive materials have to be followed.

- *Iodine*. (Sodium- or Potassium Iodide). Available in liquid form in drums. Detected with electrolytic methods (halide electrode). The test kit is usually furnished by the mud contractor. Recommended concentration is 127mg/l of Potassium Iodide giving a concentration of 0.058 ppb.
  However, some regions have naturally iodine rich formation waters. The origin of such iodine rich waters is speculated to come from thick marine shale sequences where iodine has been accumulated in marine phyton. Needless to say, that iodine as mud filtrate tracer is not applicable in such areas.

[26] Tritium is the heavier isotope of Hydrogen. It is radioactive emitting beta-(β)-radiation.

7.5. Directional Drilling

Directional drilling is the technique to drill holes that are not vertical in a planned and predictable way.

Directional surveys of some sort are made in all wells, even in a vertical well, to see if the hole is really vertical. The directional surveying is supervised from the company man as representative of the drilling department. The verification and advice of the geologist to the company man is important, if the well is drilled directionally towards a certain target in the subsurface. The geologist will also specify the tolerable deviation from the planned well course.

The well course of almost any well is typically spiral, like a cork screw. The azimuth is changing clockwise. It depends on the details of drilling practice (BHA, weight on bit, rotary speed, etc.) how much the well course can be affected by exterior parameters such as changes in the formation drilled (see also below).

Terminology

A *dogleg* is usually defined as any deviation greater than 3 degrees per 100 feet, and it occurs when a sharp change of direction is taken in the wellbore. In a vertical hole, a dogleg is often caused by a change in the dip of a formation or by a change in the weight applied to the bit (WOB). Severe doglegs can result in stuck casing or stuck drill pipe, in particular when tripping out of the hole. If casing is run through the dogleg, excessive wear on the drill pipe or production equipment can occur (watch for metal chips in the samples, page 53). *Dogleg severity* is a measure of the "straightness" of a hole. The smaller the radius of curvature in a given hole section is the greater the dogleg severity.

Key seats usually form as a result of dog legs. s key seat is formed when a channel or groove is cut in the side of the hole, parallel to the axis of the hole. The drill pipe dragging action through the sharp bend is in a dogleg creates the groove in the side of the wellbore. Overpull with the risk of sticking the pipe will be experienced when tripping out through a key seat. Overpull will occur when the first, topmost stabilizer passes through the key seat.

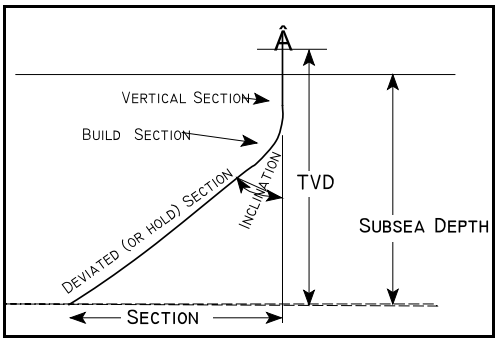

Figure 34. The basic terminology on deviated wells.

Techniques available for directional surveying:

- Single-shot survey. A pendulum type device hits a graded disk or a compass and pendulum assembly is photographed downhole.
- Multi-shot survey. Essentially the same as a photographic single-shot, but with timed repeat capability.
- Gyro survey, an electronic recording device with gyrometric orientation. This type of survey yields the most accurate results.
- MWD survey.

Single-shot and multi-shot surveys are run inside the drill pipe. A spear like device with a thin retrieval wire is dropped into the drill pipe and sinks to the bottom of the drill string. After a few minutes it reaches bottom and a time delayed camera or mechanical pendulum is activated. A measurement is taken. The survey tool can be retrieved. If a compass type device is run, a non-magnetic ("monel") drill collar is required.

On a vertical well, directional data are used to see if the well is really vertical. If the well course is deviated more than some 3 or 4 degrees from the vertical, problems like *key seating* may cause trouble when tripping or when running wireline logs.

Directional data are also used to convert logs (mudlog and wireline logs) from measured (MD) depth to true vertical depth (TVD). When drilling (deviated) development wells, the directional survey data are of much higher importance. They are used to construct three-dimensional models of the subsurface for development geology and reservoir engineering. Directional data, the precise knowledge of the well course is of importance also, if relief wells have to be drilled after a blow-out has occurred.

There may also be some geologic information in the directional data. If the plot of the well course shows a distinct change in direction although the drilling parameters were kept constant, the change in direction is likely to come from the rocks. The bit is usually deviated down dip of inclined geological surfaces such as fault planes or tops of hard formations. In a similar way, the azimuth of the well course may change when such a surface is penetrated. In fact, the azimuth plot (map view) of the well course is much more sensitive to geologic changes than the deviation from the vertical.

Note also, that a sudden departure from a well course may have a geological significance. Given that all drilling parameters have been kept the same, this departure may mean that a steeply dipping or foliated unit hat been encountered. The tendency to depart from a more or less straight well course increases if the newly encountered unit is much harder (in drilling terms) than the overlying unit.

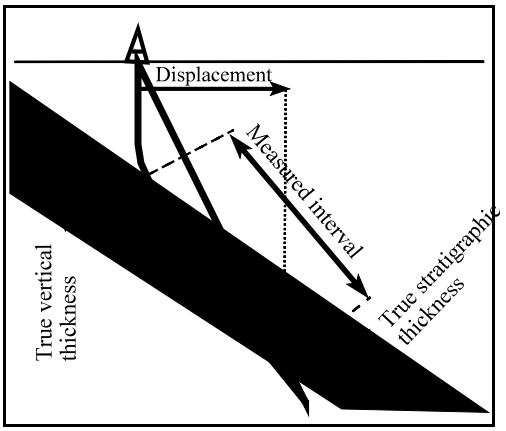

Figure 35: True vertical thickness and true stratigraphic thickness in relation with a uniformly dipping stratigraphic unit.

The wellsite geologist is not directly involved in the process or supervision of the directional survey work, however, should perform a quality control on the directional data in the sense of a plausibility check:

- When drilling development wells, the gas/oil or oil/water contacts are known and can be used as reference and subsurface depth datum.
- Compare the directional results with the directional data obtained with a dipmeter log (see page 115). But note, that the different accuracies of the two methods allow only a coarse plausibility check.

Formulas used in this situation need to consider the three dimensionality of the well course and the penetrated geology. In a plan-view situation, the following algorithms are applicable. The first of the three equations is the bread & butter when sitting on a deviated well.

$$TVD = \sum (MD_i - MD_{i-1}) \times \cos\alpha_i$$

$$NSD = \sum (MD_i - MD_{i-1}) \times \sin\alpha_i \cos\beta_i$$

$$EWD = \sum (MD_i - MD_{i-1}) \times \sin\alpha_i \sin\beta_i$$

Where	TVD:	is the true vertical depth of a deviated hole segment between the measured depth MD_i and the next measured depth point MD_{i+1}
	NSD:	is the displacement in north-south direction from the well zero, the surface point.
	EWD:	is the displacement in east-west direction.
	α	is the inclination angle, in degrees from the vertical
	β	is the compass bearing in degrees, clockwise, zero is north.
	i	the n-th survey point (i=0 is the first survey point at surface)

Several algorithms are being used and are implemented in the various software available to the technicians. The list of methods below increases from top to bottom in sophistication:

- The *tangential or terminal angle method* assumes a constant deviation for the entire survey interval until the next survey point is taken into consideration.
- The *angle averaging method* uses the average between two survey points at either end of the segment.
- The *balanced tangential method* is derived by placing the interval depths half way between the individual survey points thus assuming that the deviation is constant in the interval around the measured point.
- The *radius of curvature method* approximates the well path as a circular arc in the vertical plane, which is then wrapped around a vertical cylinder.

Of course, different methods will give - slightly - different results, but it is beyond the scope of this book to go into all the details of directional computations and surveying.

Another point of attention is the *computer accuracy* when carrying out several of such trigonometric calculations. Computer accuracy of trigonometric functions is finite ! The consequential effect is that the small inherent error of such calculations may become quite important when a series of calculations is summed. This problem should not arise from professional and tested programs or handheld calculators which usually have a 15 digit accuracy. However, the problem of low computer accuracy may well be relevant when home spun programming or programs of unknown orgin are employed.

7.6. Real Time Logging (MWD, LWD)[27]

A technique that became available in the oil fields in the early eighties is the MWD. MWD tools are part of the bottom hole assembly near the drilling bit. MWD tools can have sensors for resistivity, gamma radiation, density, downhole torque etc. similar to wireline logging tools. Two concepts of MWD tools are commonly available:

- Memory tools, that is MWD collars, that record the parameters in a solid state memory. The data can be played back every time the collars are pulled, i.e. usually on a bit trip.
- Other tools have the capability to transmit the data to surface while drilling.

Most modern tools can operate in both modes, some selected parameters are transmitted to the surface, other parameters are stored in the memory.

MWD tools provide the geologist with a display similar to wireline logs, which give an excellent tool for correlation with offset wells, a great help when selecting coring points. However, the sensors are several feet above the drilling bit. Thin layers may have been penetrated already by the time you analyze the log-plots. Furthermore, MWD is not cheap and therefore used only on wells where conventional mudlogging techniques appear not sufficient.

For the drilling people the MWD may introduce limitations and sometimes even unwanted but necessary re-arrangements of the bottom hole assembly.

7.6.1. Benefits and Drawbacks of Real Time Logging

Benefits of real-time logging, whether data are telemetered through the mud or stored downhole include:

- "Insurance" logging. Guaranteed data recovery, even if the well is lost or cannot be logged by wireline. This applies of course only for MWD tools that can transmit the data in real time to the surface unit.
- Real-time location of casing and coring points. This “real time” logging has a drawback as the logging sensor are a few feet above the drilling bit. In cases of fast drilling and thin coring objectives, the bit may be already through the objective to be cored before the downhole sensors actually see the objective.
- Early reconnaissance of potential pay, particularly gas zones.
- R_t determination while invasion is taking place - in effect, a dynamic R_t. If several passes of resistivity measurements are recorded over the same zone, a time-invasion profile can be constructed. For this purpose it is most desirable to re-record data over the zone of interest on every bit trip made. The difference of the logs are affected mainly by the increasing mud filtrate invasion over time.
- Improved statistical accuracy of nuclear measurements when ROP is 50 feet (15 meters) per hour or less (however, see comments below).
- Improved pore pressure estimates. (Compare with page 64.)

[27] MWD (Measurement While Drilling) and LWD (Logging While Drilling) have basically the same meaning: Parameters are measured downhole while drilling. SCHLUMBERGER and ANADRILL have coined the term LWD to promote downhole methods that parallel wireline logging as opposed to MWD which gives a surface read out of drilling related parameters such as downhole weight on bit (DWOB) or directional information.

- Integration of mudlog, cuttings and real-time log data on a single database. MWD data can be stored on diskette in the same format as wireline log data and loaded into the same software packages for interpretation.

Drawbacks

- Cost: Real-time logging is expensive. The advantages outlined above must be carefully balanced against the cost. Many small or shallow onshore operations will therefore not benefit from MWD logging.

- The MWD tool in the BHA is a restriction for the mud flow and may limit some operations. The MWD tool may plug if coarse LCM material is pumped through it. It also may pose a problem if cement needs to be pumped through it. Drilling people often prefer not to run an MWD in the drill string if the section to be drilled is prone for lost circulation.

- Depth control: MWD data are less accurate with respect to depth control than good wireline log data. Assume that MWD data are affected by a non-systematic error of at least one foot - usually more.

The data quality of MWD logs depends - amongst other parameters - on the ROP. MWD data are transmitted or recorded in regular time intervals. Therefore, in times of fast drilling, less measurements are taken per depth increment. If the drill rate exceds some about 100ft/hr the sample density can drop below one sample per foot. As a consequence, the log becomes more spiky. This effect is particularly strong on radioactive tools (neutron, density) which require a longer time to take a reading. Very often, a smoothing filter is applied to the data to correct or compensate the overly active log trace. Depending on the situation, this may be correct, however, in some situation some real, fine resolution data may be lost. The author recommends to leave any kind of smoothing, filtering or data shaping up to the people in the processing center in the town office of the MWD contractor. For the wellsite, it is sufficient to have the apparent readings displayed properly.

- If MWD log data are very spiky or do not correlate properly, check if the log in question was recorded over intervals with excessively fast drilling.

The MWD data transmission through the mud stream is a low frequency signal. The pulsations may coincide with the pulsation from the mud pumps. If the two frequencies come near to each other, inform the driller to speed up or slow down the mud pumps to avoid interference.

8. Decision Points in Drilling a Well

That's why you are there: Contribute to the process of decision making. The wellsite geologist collects data and *contributes* to decisions that may be necessary. It is rarely the case that the geologist makes a major decision by himself, he usually needs the consent of his supervisor in town or at least fo the company man on location. However, the geologist is the skilled geological eye of the management and his *opinion* will be heard when it is required. Be ready to make your contribution by saying "*My recommendation is ... because ....*".

8.1. Correlations and their Problems

The well program can be changed as new information becomes available. Is the well still drilling in the formations forecasted for a given depth or is it deeper or higher relative to the forecast ? Did you get any information back from the office in town if there was a change in program or if preliminary results change the current interpretation drastically ?

- Report immediately to your supervisor in town if you find significant discrepancies between the "forecast" and the "actual" rocks drilled.

8.1.1. Faults

A fault may be the reason that the well prognosis does not agree with the formations actually encountered. Or, there is a fault in the well program, however there is no indication of any fault when drilling.

- If you can establish correlation[28] with nearby wells, normal faults are seen in the correlation as a part of the section missing. The well drills from the lower fault block through the fault into the higher fault block.
- Reverse faults manifest themselves as a part of the section drilled twice, repeated, normal faults cut out a piece of section - an interval is missing.

A facies change, an unexpected change in lithology may be another reason to loose correlation. More problematical are volcanic interbeds, dikes, but also mineralized faults. Those lithologies are often mistaken for basement because of their mineral content, although there is still a prospective sedimentary section underneath.

8.1.2. Seismic Correlation

On rank wildcat wells, the only correlation may be provided by seismic in the form of seismic sections. Without going into the details of seismic time depth conversion, it can be assumed for practical wellsite purposes, that the seismic forecast is accurate to about 50 meters absolute depth only. (I am aware that this statement will be challenged by geophysicists.)

Many exploration wells are targeted to markers identified in the seismic. The wellsite geologist is then supposed, sometimes even pressed to find and identify those markers in the ditch cuttings under the microscope, often an impossible exercise.

[28] Good, reliable correlation is often only established by means of electrical logging. ROP plot and other methods are usually not conclusive enough, except maybe, in carbonate areas, where beds can be correlated easily over tens of kilometers.

- As a rule of thumb, never expect a seismic marker to coincide with a lithology change unless there is reliable information as to what this lithology change may be. Too many forced interpretations consisting more of wishful thinking than of reflections and rocks have been seen. Describe only what you see and don't let yourself box into an interpretation which is not warranted by the facts seen.

8.2. Bit Selection

The selection of the right drilling bit is *not* the job of the wellsite geologist, however on some well managed and cooperatively spirited drilling operations, the company man *might* consult the geologist. He may ask about lithology, hardness and abrasiveness of the hole section to be drilled next. Basic types and properties of drilling bits are described on page 80ff.

Remember, that all drilling operations are optimized for cost, i.e. to drill the hole as cheap as possible. The cost of a drilling bit is relatively small compared to the cost of rig time. A trip to change the bit is unproductive time (no progress) and even an expensive bit can drill relatively cheap, provided in stays long enough on bottom and makes reasonable progress.

- You should know that chert, concentrations of Pyrite, Anhydride can ruin or dull a drilling bit very fast. Tell the company man if you expect such layers over the distance of the next bit run. Soft, plastic clays (*gumbo*, in the drillers' jargon) need an other bit and different drilling parameters.

- Restrict your comments to the prognosed lithology only, by no means try to mix with the decision making process of the company man or any driller.

The mudlogging unit monitors some of the drilling parameters. The mudloggers and the geologist would therefore also be in the situation to comment on bit performance. It is recommended, however, to restrict the geologist's comment only to critical situations, such as an abrupt change in torque possibly indicating locked cones etc. or sudden changes in standpipe pressure indicating plugged nozzles or a washout somewhere in the drill string. In these cases *report immediately* to the company man or the driller on the rig floor[29].

8.3. Selecting Casing Points

Casing points are dependent on a number of aspects *outside the responsibility of the wellsite geologist.* Firstly, the casing design and program is set up in the drilling program of the well. Not much can be changed in the course of the drilling operation if someone finds out that the casing should be of a different quality or should be set deeper if there is only a certain length of casing string available.

The *geologist advises* the company man about the top of a certain formation that may be defined as casing seat or the approach of an abnormally pressured zone (see page 63) that could warrant that the casing be run earlier. He may advise also that the base of a problematical interval has been reached.

The ideal casing point is a formation that can take and hold maximum pressure without fracturing, a shale or a tight limestone. When cementing the casing, the maximum hydrostatic head of the cement slurry is at TD, and the density (and with it the pressure gradient) of cement is much greater than mud. If the formation might fracture under given pressures, more sophisticated cementing techniques (like double stage cementing, light weight cement etc.) must be used. Furthermore, casing points are selected in a way

[29] The driller has the same or similar sensors reading torque and standpipe pressure and should have realized the situation himself anyway.

that troublesome intervals (swelling shales, salt, zones of mud loss etc.) are "cased away" to permit normal drilling operations to continue.

Consider for logging operations, that the logging tools cannot reach to the very last foot drilled. Some sensors can be as far as 90 feet (ca. 30 meter) away from bottom. (See also page 107, for aspects of combining logging tools.) Therefore, request another hundred feet (ca. 30 meter) to be drilled, if any zone of interest was penetrated near casing point. This "extra hole for the geologist" is sometimes called rat hole.

8.4. TD'ing the Well

Everything comes to an end, sometime. When the well has reached its target depth *and* penetrated the objectives described in the well proposal and/or drilling program drilling will stop and the well will be plugged and abandoned or completed after running the final suite of wireline logs. This appears to be simple,however, in many situation the process of decision making is more complicated, because further subsequent decisions as whether to run casing, to sidetrack or to run drill stem tests will have to made. In any case, the wellsite geologist *advises* his supervisor in town whether to stop drilling or not, but the decision is made in the office, best after consulting with the drilling department.

Go through these points:

- Have all geological objectives which were defined in the geological well prognosis been encountered ? If yes, the well may be stopped. Unless there is some exploratory thinking in the office and some budget money yet to be spent. Some oil fields in this world have been discovered by drilling deeper than planned.

- Is there any reason to stop drilling before planned total depth (encountered economic basement) ? If so, are you sure and double sure that it is “basement”. Many wells have encountered volcanic sills or volcaniclastic layers that had the appearence of basement. However, later phases of exploration have shown that there is more section and possibly even commercial reserves under the igneous layer. Don’t recommend to stop too early.

- Structurally shallow or deep to prognosis ?

- Target below field's oil-water contact ? If so, is there a wish to explore for a deeper pool or try to recover a sample of the source rock that may be underneath the reservoir ?

- Technically impossible, unsafe or economically not feasible to continue drilling under given circumstances ? Consult with the company man, safety and drilling matters are his responsibility and - finally - his decision. In such a situation, drilling people have the last word.

- A well may be TD'ed because porosities encountered and extrapolated may be too low to expect a commercial reservoir. But then again, such assumptions are based on the extrapolation of a single porosity-depth relationship. Furthermore, oil reservoirs are anaomalies and can also be porosity anomalies.

- The maturity of the expected or known source rock may be over the threshold under which oil or gas can be expected. For example, if thermal maturation, vitrinite reflectance, bottom hole temperature or any other parameter indicates dry gas generation, it is useless to drill deeper to find an oil accumulation. Exceptions are, of course, complicated geological situation such as thrust belts. Here, high grade maturity strata may have been thrusted over formations with a lower degree of thermal maturity.

What will happen after the well's TD ? Plans for further action:

- Plug & abandon the well, because the were no zones of interest ? Or does the office want to see logs over critical zones first and will then make a decision ? If so, how much time is there to make a log interpretation. Who makes the interpretation (wellsite or town ?) and what data are considered required and sufficient to make a decision ?

- Set casing and run drill stem tests over zones of interest ? For safe practice, no drill-stem testing is done in open, i.e. uncased hole. If the zone of interest is near TD and the open hole section relatively short, packer may be set in casing and the hole tested *barefoot*.

- Sidetrack the well to a different, structurally higher subsurface target ?

- Change of the logging program ?

- Will the rig move to another location or be released ? Think of confidential data to be packed up and sent to the office.

- Ask the wireline engineer specifically for the availability of rarely used equipment on location, even if there is only a small chance that it might be used at surface or run downhole.

- Ask and check (as far as possible) if the surface logging equipment is good shape. Ask particularly if all software to run the tools and to do the planned wellsite processing is available. Software for the more rarely used tools such as the full-wave-sonic, VSP, dipmeter processing, etc. might be not available.

- Ask, find out and note which version, which release of logging software is used. See page 125 for possible complications.

Some of the usually troublesome items are listed below:

- Lubricator (wireline BOP) for wireline operations under pressure.
- Cable length. Can he cut off some cable from the drum and still continue logging operation to PTD ?
- High temperature gear. If you expect high temperatures, that is anything coming close to 320°F to 350°F or above, check the temperature rating of every tool. Ask, if the explosives for sidewall cores (and perforation, if necessary) are rated for given temperatures.
- Air guns and their accessories for the velocity survey (page 116).
- Find out if external logistic support is needed for certain logging operations. In particular some VSP operations need a supply boat and precise radio navigation or differential GPS positioning.
- Tool pusher or TLC , a tool kit to run the logging tools on drill pipe (see page 110), if you are on a deviated hole.

Discuss with the logging engineer the sequence of the individual logging runs and set up a program, so that the most important tools, like resistivity, are run first and the least important tools are run last. Sidewall cores are the last logging run because they may leave bullets or metal debris in the hole, a problematical situation if other logging tools are run later.

Many tools can be combined on one string, however, there are restrictions:

- The tool string may become too long, so that the tools at the upper part of the string cannot see zones of interest near the bottom of the hole. This distance can be as far as 100 feet (30m).

- The combined tool string is more prone to sticking and creating other downhole problems, if the hole is in bad condition.

- Some tools such as the sonic or the induction tool must be run centralized[31] whereas other ones need to be decentralized, such a s the neutron tool in the hole. This is overcome with a knuckle joint, joining the centralized and excentralized part of the string, and a bow spring that holds the decentralized tools agains the borehole wall. This configuration increases the risk of sticking but may be technically necessary for a long string. As an alternative, shorten the string and make more logging runs.

- In any case, let the engineer prepare a sketch of every tool string to be run. This sketch also part of the final log presentation and be printed on film.

- Prepare a time estimate as to how long the anticipated logging job may take. This is important for the drillers who may want to get their casing ready and also may want to use the quiet logging time to do some rig maintenance.

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[31] Some tools should be as close as possible to the bore hole wall. Therefore a bow spring is attached to force the center line of the tool off the center line of the bore hole.

- A second wireline engineer is required for logging operations in excess of 30 to 35 hours. Even better if there is a second man (or woman, as the case may be) to take over the job after 16 hours. Some logging contractors do not share this point of view and allow their logging engineers to work over 80 hours in a row. This is not safe ! This man will have to handle delicate substances (explosives and radioactive). Sometimes the company man will decide to make a wiper trip (to condition the hole - as it will appear on the reports) to give the logging engineer a few hours of rest. As the case may be, a second engineer to continue logging is cheaper and safer than any other practice.

Supervising the logging is not enough. You have to *report* and transmit at least part of the logging results to the decision makers in the office. Modern technology and communication techniques allow the transmission of digital log data straight from the wellsite to the company office.

- Make sure that the town office is aware of the timing of the next logging job. Find out if someone is standing-by in the office or at home to receive the results and distribute them to the decision makers.

- If data transmission is requested find out which communication path will be used, whether all necessary modems are installed and operational, or if certain format standards for transmission are necessary. You may even try a short test transmission before the actual logging job starts.

9.2. Depth Control

Which parameter is given free of charge by the logging contractor ? Answer: The depth (see also page 90). To find the correct depth of the hole is not as easy as it may appear. For practical purposes the wellsite geologist should be aware of the factors controlling the depth measurement. A table on this page summarizes the possible errors of depth control.

- The best method of depth control is to find the casing shoe when going into the hole. Run a short log across the casing shoe and pick the depth from the resistivity. The depth of the casing on the logs shold be maximal 5 feet off from the nominal casing depth as calculated by the driller. The, re-set the depth counter to the nominal casing depth and run to bottom.
  On the way out, check the casing depth again on the main log. It should be the same, it *may* be somewhat shallower if heavy tool sticking was occuring during the logging run.

If the logging engineer reaches deeper than the depth given by the driller something is likely to be wrong. Request the re-measurement (strapping) of the drill pipe *and* check if the depth control (zero setting and correlation) is correct beyond any doubt.

If the drilled depth is deeper than the depth tagged by the logging tools, caving may be suspected. This becomes more likely if more and more bottom fill is encountered in consecutive logging runs, not interrupted by hole conditioning operations.

Potential Depth Error at 10,000 ft / 3050 meters (after Theys, 1991)		
	meters	**Remarks**
Elastic cable stretch	2.4	
Inelastic stretch	1.8	Experienced on first run only
Temperature	0.6	assuming 300°F BHT
Cable twisting	0.5...1.5	1 ft for each 50 turns
Measuring wheel	1.0...3.0	

Sheave movements	0.6...1.0	
Viscous drag	0.6...1.0	
Error due to tool sticking	up to 12	only if tool sticking occurs on the logging run

The table above gives some indications of depth errors that can be expected on a logging run.

9.3. When the Logging Job Starts

Before tripping out, i.e. when the mud is still circulating, catch a mud sample from the flowline. The mud engineer should run a full mud check on this sample. Preserve the filter cake and filtrate for the logging engineer. He will use this material to determine R_m, R_{mf} and R_{mc} at surface condition. This information is of extreme relevance for the evaluation of the logs run.

Before the logging job starts, you should update your notebook with a number of data:

- Type of mud in the hole ? Does it contain Barite, Diesel oil, KCl, Mica ? Any of these materials have an effect on the logging results and may require correcting the logs. Get the last mud check from the mud engineer (see also page 92).

- Hole size and condition. Note the hole size, depths of any tight spots, overpull, dog legs, etc. Is it safe to run the holes to TD or wold it be better to stop at a certain depth to avoid sticking ? Are there any porous zones that in the case of high mud weight might cause differential sticking of the logging cable or tools ?

- Directional data, to generate a TVD playback (see also page 97).

- Casing data. Get the *precise* depth of the last casing shoe. On deep wells, this may need correction for stretch (as the casing string is stretched out by its own weight) and on floating rigs a tide correction may be applicable. Have a friendly word with the drilling engineer if the company man does not answer to you.

- Note casing inside diameter (ID) and weight per foot, a parameter pertaining to wall thickness of the casing.

- Get the *elevation* of the rig floor, kelly bushing, water depth and the actual final depth of the hole prior to logging.

- Get the present *depth* of the well. Check with the driller or company man, if the drill pipe was measured stand-by-stand on the last trip out. On floating rigs, you should ask if a tide correction has been applied. This background information gives you a good clue as to how precise you can expect to hit TD when logging.

- On floating rigs, the depth reference is taken from the nominal depth of the first casing string. All subsequent logs will tie into the GR of the previous logging job. For example, the depth reference for the first log of the 8 1/2" hole section is the first descent of the 12 1/4" hole section.

- From the mudloggers you will get the reading of the last MTO (mud temperature out) and the total circulation time, that is the number of hours since the last trip, including wiper trips, circulating samples up, etc. Note, that a long riser on marine operations can cool the mud significantly. You need the MTO and the average surface or sea bottom temperature later to correct the log temperatures for static bottom hole temperatures (BHT).

- Note down the time, when the rig floor was free for the logging company to rig up (check with the company man as to what he puts down on his report) and the time, when the first tool passed through the rotary table.

You should also have available a copy of the mudlog and/or the master log. If a MWD log was recorded, you should have a copy. When logging, you will "read" the available logs against the wireline logs being acquired.

9.4. Hole Problems while Logging

Logging in open hole may be affected by a number of problems. Most bothersome are sticky hole conditions. Inform the company man as soon as you see some overpull on the logging cable.

- *Do not stop the cable but keep on moving up and down* ("yo-yo") until you get free or find another solution. If you suspect bad (sticky) hole conditions or if you had overpull or sticky experiences on the previous tool run, inform the company man and request a wiper trip to condition the hole.

Many logging tools can be run on drill pipe[32]. This is common practice on deviated and horizontal development wells, where the logging tool string would not go to the bottom of the well by its own weight. Depending on the hole conditions and the tools used, the maximum deviation angle that can be logged with conventional wireline methods is between 50° and 60°.

9.5. The First Run

The first set of logging tools going into the hole is the resistivity (Laterolog or Induction type), combined with a sonic log, a gamma ray log, a caliper and an SP. This combination gives the most valuable information. Even if the hole is lost after this logging run, the basic data would be sufficient (but not perfect) to calculate S_w and ϕ, the most important parameters. Some general log checks are applicable for this tool string (see the following chapters for specific tool checks):

- Casing shoe. When going down, check if you find the end of the casing where it should be. Note discrepancies. Make a GR correlation with the formation logged previously (i.e. behind the casing). Apply depth correction if necessary.
- Watch the tension indicator and note the weight of the tool plus the free cable.
- Check if the casing ID is correct (caliper).
- Check if the sonic reads a correct 57 µs/ft (for steel) inside the casing.
- Stop for at least one minute in open hole and see if the SP reading stays constant or if it is drifting.
- Check if you reach *TD where it should be.* This is indicated only by a small reduction of weight on the tension indicator. If the tools hit bottom earlier than expected, think if there is a fill (cavings) on bottom or if your depth setting may be wrong. Tidal variations may be another explanation (floating rigs only). Check also if the drilling crew has changed anything on the heave compensator.
- *Repeat section.* Select an interval, preferably over zones of interest to record a repeat section. Check if the repeatability of the tools is plausible (See comments for the individual tools on the following pages).
- When the tool comes back out through the rotary table, see if the depth indicator passes zero (tool zero is usually set to the lower end of the tool string).

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[32] Drill pipe conveyed logging, SCHLUMBERGER calls this technique TLC, meaning tough logging conditions, GEARHART/HALLIBURTON'S' trademark is Toolpusher.

Compare the logging data on the screen immediately with logs available, such as with the mudlog or any MWD data (if available).

9.6. Detailed Log Checks

The checks included below are intended to sort out some of the common problems encountered in wireline logging[33]. They are by far not as comprehensive as those which a log analyst at the wellsite might investigate and cover only a small selection of typical openhole logs. The world of cased hole and production logging is outside the sphere of wellsite geology.

9.6.1. Gamma Ray Log

Principle: Scintillometric measurement of natural formation radioactivity.

Uses: Definition of bed boundaries, correlation, indicator of shale and zonation of sand and shale.

Checks :
- Near-zero API[34] counts are uncommon except in massive evaporite sequences. (Check with sonic in questionable evaporite sections.)
- Repeat sections may not repeat perfectly due to the statistical variation in gamma ray radiation.
- Readings are affected by the logging speed (more scatter, less repeatability).
- Readings are reduced by barite in the mud system.
- Readings are increased in KCl mud systems and in mud that contains mica (both due to potassium content). If a KCl system is used, the log header should have a comment entry stating concentration of KCl and correction algorithm used, if any.

Display : Usually 0 - 100 API or 0-200 API, linear, left track.

Comment : The GR is a fairly reliable tool, not many problems are expected.

9.6.2. Gamma Spectroscopy

Principle : Measuring gamma ray energies in different parts of the gamma ray spectrum which can be related to different radioactive decay series.

Uses : Mineral and in particular clay mineral identification, help for interpretation of sedimentary environment.

Display : The gamma spectroscopy is can be displayed as ratio-plot on a separate film with four tracks: Thorium [ppm], Uranium [ppm] and Potassium [%]. The left track of the display shows total GR and Uranium-free GR. The calculated GR can be merged into the usual GR display (see page 111).

9.6.3. SP (Spontaneous Potential)

Principle : Measurement of formation electrical potential.

Uses : Calculation of formation water salinity R_w at given R_{mf} and given temperature. Correlation tool.

Checks :
- Check stability with static logging tool (see page 110).

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[33] This summary does not refer to the individual tool names used by the wireline logging companies. It is in any case suggested that you go through the technical books of the logging companies or refer to independent publications.

[34] The API units are arbitrary units, whereby 100 API are the GR reading generated by an "average Mid-Continent Shale" as defined in a test well in the United States.

- If formation water salinity and mud filtrate salinity are close, the SP curve may be flat, without characteristic.
- The SP is very sensitive to electric potentials created technically on the rig. Check if the cathodic protection is switched off. Cathodic protection is an electrical potential applied artificially to the body of marine rigs to decrease corrosion induced by the contact of steel and seawater.
  Sharp spikes indicate, that electric welding is going on.

Display : Usually 10 mV per division, linear, left track, together with the GR. Note that the SP is no "absolute value", SP reading from different logging runs rarely line up and need therefore to be shifted to tie.

Potential Problems: *Magnetism* appears as regular cyclic disturbance. The wavelength of the disturbance is exactly the length of the cable drum circumference, about 5 meters. The disturbance disappears when the cable stops and is generated by one or several parts of the unit or truck transmission that are magnetized. To get rid of it, the logging cable and its drum must be demagnetized in the shop. Sometimes it may also be necessary to demagnetize the chain linking the logging unit engine and drum separately.
Bimetallism: In some cases, a DC potential is superimposed on the SP curve. It is generated when two distinct metals are in contact with an electrolytic solution (mud, sea water) and form a battery. The noise is reduced when the metallic parts are identified and insulated.
Telluric currents: Naturally occurring earth currents are induced by solar activity and usually subside at night, except for the Northern Lights. Telluric currents are observed on the SP track as slow, random drift. The cure is to run a differential SP with a downhole return electrode.
Random electrical disturbances: are caused by an electrical anomaly around the ground return electrode. Electric weldic, generators, etc. are often the cause.
Cable noise is caused by the making and breaking of the bimetallic cell constituted by the cable armour and the casing. The cure is to put the fish at some distance from the rig and to prevent the cable from rubbing against any metal (rotary table, etc.)

Comment : The SP is usually given free of charge by the wireline logging company.
The SP can give you some information and a lot of headache. Don't worry too much. It is a give-away.

9.6.4. Sonic Logging

Principle : Measurement of acoustic travel time (based on the identification of the first arrival of the acoustic signal).

Uses : Porosity indication. Overpressure / undercompaction indicator.
Needed for the correlation to seismic and to generate synthetic seismograms. Correlation.

Checks :
- Sonic must read 57 µs/ft in the casing (Δ_t of steel).
- Maximum reading 185-189 µs/ft, that is the sonic travel time in water or mud. If the sonic tool records a more or less straight line around this value it is reading mud only.
- Watch for spikes (cycle skips, noise trigger, see below) on the log. Slow down logging speed if you have more than one or two spikes per 200 feet (50 meter).

Display : Usually linear, 40 - 140 µs/ft scale, integrated travel time marked as "pips" in the depth track. Near surface and in unconsolidated formation a display of 90-190 or 40-240 µs/ft may be more convenient.

Potential Problems : *Noise triggering* and *cycle skipping* : If the sonic travel times are very slow or the received signal is very weak, the sonic tool will accept the first break of any random noise as the sonic signal and calculate the travel time time accordingly.

These "mistakes" show on the log as sharp spikes to the *fast* side of the sonic track if the erroneous first break pick was earlier than the actual first arrival. If the first break is detected late, relative to the expected arrival, the error will show as a sharp spike to the slow side of the track.
To cure the problems described above, slow down logging speed. If this does not help and if time allows, pull out and change the configuration of bow springs and stand-offs that may be attached to the logging tool string.

Comment : The sonic is a very reliable tool and not very sensitive to bore hole or electrical disturbances. It should be combined with the first tool string going into the hole to have at least one porosity indicator.

9.6.5. Full Waveform Sonic

Principle : Recording of the full wave train of the sonic signal (as opposed to the first arrival).

Uses : Processing, extraction of compressional, shear and Stoneley Δt can be used for fracture detection, rock elastic properties and even indicate permeability from STONELEY wave attenuation.

Display : Wellsite display like a conventional sonic log. Check with your supervisor or the petrophysicist in charge if any wellsite processing is required.

Comment : The Full Waveform Sonic records large volumes of digital data. This is usually too much (i.e. too expensive and time consuming) for digital data transmission (see page 108).

Uses : Evaluation of formation density, porosity, shale content and lithology identification. The density log is also required to calculate a synthetic seismogram using the sonic log.

Checks : Repeatability should be within 0.05 g/cm^3, except a in washed out hole. The Δ_ρ (delta rho) should be mainly positive except in dense baritic muds or over gas zones. Consistent offset or drift above zero is suspicious.

Comment : The density sonde is a "pad-tool" and therefore sensitive to rugose bore hole wall and mud cake. Thick mud cake, in particular when it contains barite or hematite (both dense substances), will affect the ρ reading.

Display : Together with neutron-porosity (see below) in units of g/cm^3. Some companies like to display the density log in porosity units relative to the selected matrix For limestone matrix ρ = 2.71 g/cm^3, for sandstone matrix ρ = 2.65 g/cm^3..

9.6.8. Neutron Log

Principle : A neutron source bombards the formation and the resultant scattering and neutron deceleration depend largely on the formation hydrogen content (that is a straight relationship to formation water or hydrocarbon content). Epithermal neutrons are detected.

Uses : For porosity evaluation, in fact, the neutron log is the most reliable porosity log. Direct indication of gas in the formation. In combination with other tools it is used for lithology identification and evaluation of shale content.

Comment : The neutron sonde contains a radio nuclide emitting neutrons. This substance is dangerous. Safe handling practice is necessary at surface. Fishing operations for stuck neutron and density tool string are extremely tedious. Radioactive contamination of the whole mud system may be one of the extreme consequences. Make sure the company man and the safety officer on the rig are fully aware of this problem before you embark on fishing operations for radioactive tools.

Display : Linear scale, together with the density. Porosity units or percent.

9.6.9. Dipmeter Log

Principle : Comparing the depth shift of four or more microresistivity curves recorded by a multi-arm pad tool.

Uses : Determination of structural (tectonic) and sedimentary dip. Facies interpretation. Fracture identification. Also as high resolution resistivity tool (can replace MSFL type tools in log processing).

Secondary : Directional data (with limitations) and calculation of hole volume for cementing.

Checks : Individual traces should be identical and slightly shifted. Statistical noise on all pads usually indicates poor hole conditions and/or poor pad contact to the bore hole wall. On deviated wells, statistical noise on one pad means that the tool's arm does not reach the upper side of the bore hole. Centralizing rubber finns might cure the problem, provided the pad contact force is strong enough. All efforts must be made to overcome this "floating-arm-problem" because it cannot be cured by any processing afterwards, even more, it renders the data acquired close to useless.

Display : The wellsite presentation is usually only a record of the resistivity traces. Processing is necessary to turn the log curves into meaningful tadpole displays to reveal dips. The hole volume is calculated and printed at the log header.

Comment : Dipmeter data recorded on digital tape are voluminous. They are usually only handcarried to town as the data transmission would take too long. Furthermore,

- If in doubt about the hole condition, talk to the company man and explain in detail what the RFT programme will be like, how many levels will be tested, etc. and get his endorsement for the programme.

9.6.12. Sidewall Cores

The sidewall coring is usually the last run of a logging suite at a given depth. It is the responsibility of the wellsite geologist to select the levels for sidewall cores. Sidewall cores are taken for various different purposes:

- Shales / claystones for paleontological purposes (age dating).
- Shales / claystones and coals for geochemical purposes (source rock and maturity studies).
- Reservoir intervals to check fluid content (shows?).
- Reservoir intervals to determinate reservoir properties like porosity and permeabilit. The data quality of reservoir parameters from sidewall cores is usually much inferior to full-bore cores, however, in some situations, sidewall cores will be taken and analyzed.
- Anywhere for "rock-typing", that means to recover cores over intervals with obscure lithologies or exotic mineral content to assist the petrophysicist with his interpretation.

Select the levels for the sidewall cores on a 1:200 scale log. Use the caliper log and watch for washouts in the hole. Be aware that the logging engineer can select bullets with different penetration depths for soft and hard formations, and that he can adjust within certain limits for over gauge hole size.

- Note the expected maximum bottom hole temperature (BHT_{max}) during the SWC sample log run. The common explosives are rated to 280°F for one hour. If you go for higher temperatures, special high temperature charges have to be used. List the requested sampling levels on paper, note hole size and expected lithology, and give it to the wireline engineer.

- When the sidewall core gun is loaded and above the rotary table, absolute radio silence is required for safety reasons. Radio frequencies, and even more, arc welding or thunderstorms may in severe cases fire the explosives in the sidewall core gun. It is *not your job* to inform the radio operator, safety engineer or company man, but for good practice you should check and make sure that the logging engineer has reported properly. If not, tell the company man. Radio communication may resume when the gun is below mud line.

- The wellsite geologist *must* supervise at least the depth correlation of the sidewall core gun with previous logs. Request a film, not a paper copy of the correlation GR and do not hesitate to request another correlation run or interval from the engineer, if you are not positive about the correlation. The GR tool running with the sidewall core gun is less sensitive than the "normal" GR logging tools. Look for peaks, troughs and patterns for correlation purposes.
  If the correlation does not fit, do not take any "sales talk" about cable stretch, tide motion or moon phases from the engineer. Find out what is wrong and make another correlation, best over another section of the hole.

- When shooting, watch the tension indicator. Good recoveries show a medium tension when pulled free. Heavy pull indicates that the bullet will be lost. Note down the maximum pull on line or request this on a report from the wireline engineer.

- When the gun comes to surface count the bullets lost in the hole. If bullets were left in the hole, the company man may want to clean the hole with a wiper trip, a junk mill or a magnet, before resuming drilling. If casing will be run, a wiper trip will be made in any case to clean and condition the hole.

Remarks Section:

- Operating engineers (and wellsite geologists) should not be afraid to add drilling circumstances or mud characteristics into the remarks section of the log film. Drilling conditions (for instance, BHA changes) may directly impact logging data by the bias of hole condition. Mud parameters and circulation timing are essential in the understanding of invasion, which affects most logs.
- The presence of barite, Kcl or mica in the mud. Has the log presented already been corrected for mica and potassium ? Which algorithm has been used for the correction ?

- Are all unusual events (e.g. tool sticking, change of logging speed) recorded in the remarks field. If a tool was run in a different configuration than normal (e.g. centralized instead of excentralized), it should be noted on the log.

9.8. Quick Look and Computer Based Log Evaluation

All modern logging units provide on-site data processing, quick-look methods to determine S_w, mineral content, basic dipmeter processing, etc. It depends on the operating concepts of your company whether these services will be used. Some operating oil companies have their own log data processing center, other companies prefer the quick answers from the wellsite. The cost of the wellsite processing is another aspect.

By the time this text is written, virtually all wireline service companies can copy the log data or any selection thereof onto diskette or transfer to a desk-top computer. With the help of inexpensive PC software it is now possible to make a fairly comprehensive log analysis at the wellsite.

9.8.1. The R_{wa} Check

R_{wa} the apparent water resisitivity of the formation water can be calculated when a porosity log is available. Usually, the porosity is derived from the sonic log by assuming a matrix velocity. R_{wa} can then be calculated in real time and displayed on the GR track, given an appropriate scale. The R_{wa} value has not much to do with the actual formation water resistivity, however, any excursion in the R_{wa} can be interpreted as the

- first indication for hydrocarbons

or

- change in formation water resistivity indicating a formation change or - less probable - a significant change in pore pressure.

In simple cases, R_{wa} is equal to the water resistivity in a clean, water bearing zone.

$$R_{wa} = \frac{R_t}{F}$$

whereby F, the formation factor is a function of porosity

$$F = \frac{1}{\phi^2}$$

The R_{wa} is also the first indication where to pick your first guess for R_w - unless you are in a development situation, where the water resitivities are known or you have a formation water sample. The latter can come only from a RFT sample or from water byproduction during a DST.

9.8.2. Density - Neutron Logs

Large separation of the neutron-density curve ($\Phi_D < \Phi_N$) is often indicative of a shaly zone. In known areas, the changes in the known separation help to identify zones of marginal reservoir potential.

As the neutron tool is sensitive to the presence of hydrogen atoms in the formation it will also detect hydrogen of hydrocarbons. The effect of liquid hydrocarbons is relatively small, the effect of gas, however, is significant.

- If the neutron tool shows extremely high porosities without any similar response from the density tool then the formation is gas bearing. This indication is usually more sensitive than the gas effect on the resistivity logs and can be used as a very reliable indicator. Owing to the shape of the curves, this gas effect is occasionally and for obvious reasons called "Dolly Parton Effect".

9.9. Money: Checking the Service Ticket

At the end of the logging job, you may be asked to sign a service ticket. (See page 8 for authorities.) With your signature on this document you acknowledge that certain services have been rendered and you will see an outlook on the expected cost. It is not an invoice and the figures may change, when this ticket is used in town to generate the monthly or final invoice.

- Note on the service ticket any comment, that may have a bearing on the final cost (for example "GR not working from ... to ..., should not be charged" etc.

It's even better to discuss critical issues with the wireline logging engineer at the location, before he makes up the service ticket in order to solve the problem at the wellsite instead of bringing all problems to town. In any case, it is suggested that you familiarize yourself with the *price list* of your wireline logging contractor. If you don't have one, get one from the office or from the logging contractor. Read all the small comments and exceptions set out in footnotes. That is where the service company makes the money. It takes quite a while to dig through all this legal and cotractual stuff, but it is very likely that you can save some money for your company. Some supervisors appreciate that. Furthermore, it is a good way to get an introduction to the economics of logging and drilling operations.

Computer spreadsheet programs are an excellent method to forecast and control the wireline logging cost. If you have the right tools available at location, you may even be in the situation to fine tune the logging program, maybe replacing one type of survey with another one that suits given conditions better. But in any case, usually a change of the logging program needs authorization from your supervisor.

Wireline logging or formation evaluation is expensive. The comparison of formation evaluation cost with other cost incurred gives you the right picture and will demonstrate that it makes no sense to save on a some one dollar items in the mudlogging unit and then to throw out huge amounts for poorly designed logging operations. Sometimes you will even have to educate your supervisor and give him the right picture, i.e. cost figures when you are proposing any changes.

10. Data Integration and Interpretation at the Wellsite

The time after completion of the logging operation is usually a quiet phase from a wellsite geological point of view. Casing is run and cemented and BOP testing and changing may take up as much as two or three days on deep wells. Time to do the homework and integrate the log data into the general geological framework.

- Update your pressure worksheet (page 66).

- Relate the geology of the last section to seismic time. Find out where you are on the seismic section by updating you time/depth graph with the help of an integrated sonic log or check shots. Or use the display from the VSP.

- Correlate logs with offset wells.

Record, document and interpret all your findings properly. This compilation may be a valuable contribution to the final well report (see page 50).

10.1. Temperature Analysis

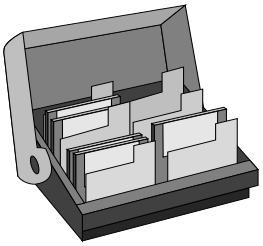
Based on circulation time, time elapsed since circulation stopped until the log tools reached bottom, and with the use of chart books (a graphical solution of the HORNER Equation) the static bottom hole temperature is calculated. Compare the results with direct temperature measurements, if available. Integrate with temperature data from DST's, if available. Plot temperatures against depth.

The resulting geothermal gradient graph is needed for geochemical (maturity) calculations and basin modeling. Beside, the cementing people on the rig need the temperature data to design the right blend of retarding or accelerating additives to the cement slurry.

10.2. Tie to Seismic

Use the integration of the sonic log (counting the ITT ticks) to establish a seismic time depth graph or use the velocity or VSP survey, if available, to tie into the seismic. Although it is not the responsibility of the wellsite geologist to make seismic ties, you should have an idea, what section of seismic has been drilled, how the reflectors relate to the observations of the drill cuttings (a relation, that is rarely established with sufficient clarity on the wellsite) and which horizons are still ahead of the drilling bit.

11. Computer, Electronics and Communication



Like it or not: Computers are a fact of life. Computers have made their way to the wellsite and help in any branch of a drilling operation. The main areas of wellsite geology, where computers are used are wireline logging and log interpretation, mudlogging, in particular the database keeping of drilling and geological parameters, and the reporting systems. A geologist should have access to a modern computer system at the wellsite. The future may bring networked systems on the rig that allow the exchange of data and parameters between all parties working on the rig (the driller, the mud engineer, the geologist, the directional driller, the mudloggers, etc.). Networked systems (wide area networks) and e-mail systems to correspond with the town office are common.

11.1. Data Formats

The most significant problem in tape retrieval and diskette exchange is negotiating the maze of data, in particular tape formats. Sometimes, a data user attempts to decode data with a software incompatible with the recording software (most of the time, recording software has many more features than the reading software). It is therefore essential that the compatibility of recording and reading software is checked long in advance.

The following tape formats are available :

- SCHLUMBERGER LIS format.
- AMERICAN PETROLEUM INSTITUTE (API), DLIS format.
- WESTERN ATLAS BIT format.
- WESTERN ATLAS EBIT format.
- GEARHART DDL format.

11.1.1. The LIS Format

The Log Interpretation Standard (LIS) is a standard for the exchange of well log information. Not only well log information, but also mudlogging data are exchanged and stored on LIS format tapes. Though it generally relates to data encoded on magnetic tape, it can also be used to represent log data on any other storage support.

LIS distinguished three types of information associated with well logging:

- *Data frame*. It is a collection of sensor readings put in conjunction with an index value. The index may be of two types:
  - For tapes recorded in the field, the index is recorded only once at the beginning of data frames.
  - For tapes recorded with a computing center software, the first data channel of each frame is dedicated to the index.

  In the field tape, the sequence of data frames is preceded by the primary index set at the depth where the log is started. The following data frames contain only data channels. With the computing center software, the record starts directly with data frames. Each data frame contains a primary index channel in addition to data channels.

- *Transient information*. It consists of the dialogue between the system and the logging engineer, in addition to comments and messages.

- *Static information*. It consists of the information about the logical structure of the reel or disk file. They are used to describe how data frames are formatted.

11.1.2. The DLIS Format

When more complex logging tools were introduced, people handling log data were slowed by the limitations of the existing tape formats. One of the major problems is the wide variety of data types (among others, wave forms and arrays) and record length (from a few bits to several thousand bits). The existing formats have difficulty handling variable sampling rates, which can eventually be recorded during the same logging run.

The DLIS format has the following features:

- Ability to contain both standard and auxiliary logging data.
- Possibility to merge, splice and flip log data.
- Presentation of channels regardless of sampling rate and dynamic range.
- Allowance for complex forms of data including arrays.
- Record of indefinite length.
- Textual data capabilities.
- Encryption capabilities.

11.2. Software

A coherent set of software programs on the logging unit needs to be used for a given logging job. All calibration and logging phases should be covered with compatible software versions. For instance, if a tool is calibrated with the June 1988 version, then logged with the January 1989 version, with an algorithm change from September 1988, a systematic shift may appear on the data..

It is imperative that all changes in the constants during logging are reported along with the depth where they were performed. These changes can have a disastrous effect on the value of data and only an in-depth scrutiny of the print or field tape can detect them. As an example, all calibration parameters should be frozen and the software should make their modifications *on-the-fly* during logging *impossible* or obvious.

In the event of a computer crash, the status and values of the logging constants should be noted before restarting the operations. Such system crashes should be reported on the film.

There is a vast variety of PC-based log evaluation programs[38] and as big is the variety of data formats used. Their common denominator is the ASCII-format, the most simple and basic file structure. Others use proprietary formats without releasing any information about their structure. The message conveyed in this chapter is very simple:

- Do not take for granted that computer stuff, hardware or software works. *Test everything before you use it* in a mission critical situation. Compatibility does not mean that it really works under real conditions. So, whenever you have to rely on data transfer - try it out first. If it has not been tested in all detail, do not use it on the wellsite.

[38] A market review made by Geobyte in 1991 showed already some 20 different log evaluation programs available commercially. This does not yet include the public domain share-ware and some home-spun software created by weekend programmers with various skills.

11.3. Data Media

The most common data media for small computers today is the 3½" diskette with 1.4Mb formatted capacity. The older 5¼" data diskettes are rarely used anymore.. Keep sufficient stock of diskettes with you when you go to the wellsite.

On big computers, such as the wireline logging unit, big reels of 9-track tape are increasingly replaced by video-8 or DAT cartridges. Such cartridges are able to hold up to several gigabytes of data. One complete logging run, often also including the "bulky" data like dipmeter or full wave sonic can fit onto one single cartrige.

11.4. Data Transmission

Data transmission depends on people, software, modems and communication lines. That's about most of it. You will need somebody *on the other end* of your communication link who can operate the receiving computer. It is recommended that you establish personal contacts with your computer operator on the other end before your go to the wellsite. Also, get the home phone number.

Modems come in pairs - a sending modem and a receiving modem. Although the manufactureres claim that their particular modem can communicate with any other modem - don't rely on it unless you have tested the system personally. Two modems of the same brand work - usually - better together.

Communication lines can be ordinary phone lines (very often), dedicated data lines, VHF point-to-point systems, dedicated satellite lines (such as the Inmarsat on many ships or floating rigs), SSB shortwave radios; also any combination thereof.

- If you are preparing to transmit large volumes of data, you should consider to *compress* the data file. Data compression programs are readily available and can compress file to less than a half of its original size. However, as many modems are also using some kind of compression algorithm, transmission time is not speeded up any more because the compressed file cannot be further reduced.

Data compression is in any case useful to reduce file size of logging data copied onto diskette to be sent to town or to the office overseas.

- Make sure that the receiver has a copy of the decompression software. If not certain, include one on the first diskette and explain the method of operation in a short READ.ME file.

It needs to be tested and found out if a data compression gives a time advantage while using a high-speed modem or not.

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Alphabetical Index

Appendix A, Mudlogging Checklist and Technical Audit

Inspection carried out by _____
Date: _____
Rig: _____ Location: _____
Mudlogging Contractor: _____ Logging Unit Number: _____

Names:			
Day Shift Crew		**Night Shift Crew**	
Logger #1		Logger #3	
Logger #2		Logger #4	
Pressure Engineer #1		Pressure Engineer #2	

Services Provided:

Yes:✔ No:✘

Total gas detection ☐
Gas chromatography ☐
Depth / ROP analysis ☐
Sample catching (sample catchers only) ☐
Monitoring drilling parameters ☐
Drilling efficiency ☐
Pore pressure prediction ☐
Sample preparation and packaging ☐
Lithologiocal description ☐
Mud property data monitoring ☐
H_2S detection and alarm ☐
Core retrieval and packaging ☐
Daily reporting functions ☐
Directional services ☐
Database services ☐
Communication/modem ☐

Total Gas Detection System

Ist the detection system reliable ? Yes ☐ No ☐

Does the gas alarm system work ? Yes ☐ No ☐

Has the gas flow rate been regular ? Yes ☐ No ☐

Were carbide checks run ? Yes ☐ No ☐

Last carbide check at (date, depth) _____

Were the carbide returns of sufficient magnitude to allow for good control on lag time ? Yes ☐ No ☐

After the carbide check, has the hole size and pump efficiency been re-calculated ? Yes ☐ No ☐

What are the alarm setting on the total gas recorder system _____units

Chromatograph Analysis

Has the instrument been calibrated ? Yes ☐ No ☐

Last calibration made date/time _____
depth _____rkb

Lab analysis certificates on on calibration gas bottles ? Yes ☐ No ☐

Are records of the last calibration kept on file ? Yes ☐ No ☐

What kind of drilling fluid was used over the last drilling interval or prior to the last calibration ?
Air ☐
Water ☐
Diesel ☐
Mineral Oil ☐

Was the recorder rate increased over intervals with shows ? Yes ☐ No ☐

Brand name and serial no. of the chromatograph _____

Gas Traps and Lines

Is the gas trap located in optimum position ? Yes ☐ No ☐
Has the gas trap been cleaned and serviced ? Yes ☐ No ☐

How long since the last inspection: _____ days

Water Vapor Condenser
Type of Condenser : _____
Serial No.:_____ Installed at:_____
Has the gas line been inspected for cracks, leakages and internal condensation ? Yes ☐ No ☐
Type of gas line :_____
Diameter: _____mm
Approximate length: _____m

Have the inspections been documented in the log book of the mudlogging unit ? Yes ☐ No ☐

Does the automatic flush-back system work properly and efficiently ? Yes ☐ No ☐

Does the line failure alarm operate when the gas line is blocked ? Yes ☐ No ☐

Mud agitator:
Agitator speed : _____rpm

Are all agitator blades in the mud ? Yes ☐ No ☐

Does the agitator malfunction trigger an alarm in the unit ? Yes ☐ No ☐

Depth and Drill Rate Recorder

Type of recorder ? Microswitch ☐
Hydraulic ☐
Crown Block ☐
Drawworks ☐
Other (specify): _____

Is the depth system independent from the depth system of the rig used by the driller ? Yes ☐ No ☐
Does it cover the entire kelly movement ? Yes ☐ No ☐

Is the recorder reliable when compared to the drilling contractor's pipe tally ? Yes ☐ No ☐

Has the recorder been operating continuously ? Yes ☐ No ☐

Is the selected chart range appropriate ? Yes ☐ No ☐

What kind of sensor/indicator is used to operate the ROP system ? _____

Other Sensors

Are pit level sensors installed in *all* mud pits (including reserve and kill pit) ? Yes ☐ No ☐

How many pit sensors are installed ? _____units

What is the alarm setting on the pit level totalizer ? ±_____bbl

What is the usual back-flow from the surface system after the pumps have been switched off ? _____bbl

H_2S sensors installed and running ? Yes ☐ No ☐

Last check / calibration ? date____/____/____

Alarm level threshold _____ppm

Is a carbon dioxide detector installed ? Yes ☐ No ☐

Sample Catching and Preparation

Are the sample being caught at the intervals specified by the well programme or the geologist ? Yes ☐ No ☐

Is the sample board under the shakers cleaned every time a sample is taken ? Yes ☐ No ☐

Is the mud temperature measured at least every six hours with a thermometer and compared to the sensor measurements ? Yes ☐ No ☐

Is the output from the desander checked every time a sample is taken ? Yes ☐ No ☐

Is the fine material included in the bagged in the sample bag ? Yes ☐ No ☐

Are samples packed into pre-labelled bags ? Yes ☐ No ☐

Are wet samples in cloth bags dried prior to packaging and shipment to town ? Yes ☐ No ☐

Sample Description and Documentation

Are the lithological descriptions discussed and agreed with the geologist ? Yes ☐ No ☐

Are all samples screened for fluorescence ? Yes ☐ No ☐

Has the mudlog been kept up to date and available for the geologist's inspection ? Yes ☐ No ☐

Is the geological description and interpretation professional and correct ? Yes ☐ No ☐

Are the work sheets filled out and filed properly ? Yes ☐ No ☐

Data Gathering and Documentation

Are the strip charts annotated properly with a time mark every hour, date, type of operation (drilling, circulating, etc.) and are all unusual events marked, reasons given ? Yes ☐ No ☐

What computer system is used _____

Is the computer system and data format compatible with the system used by the oil company ? Yes ☐ No ☐

Are the data backed up regularly ? Yes ☐ No ☐

What back-up system is used _____

When was the last back-up made : _____/_____/_____

Has the computer been checked with an anti-virus program ?
Yes ☐ No ☐

Video Display Units (VDU)
How many units are installed ? _____screens
Where ?
#1 at _____working ? Yes ☐ No ☐
#2 at _____working ? Yes ☐ No ☐
#3 at _____working ? Yes ☐ No ☐
#4 at _____working ? Yes ☐ No ☐
#5 at _____working ? Yes ☐ No ☐

Operational Efficiency
Was rig time lost due to mudlogging equipment malfunction ? Yes ☐ No ☐

Was rig time lost due to any problems arising from the mudlogging ? Yes ☐ No ☐

Safety standards in the units:
Fire extinguisher available ? Yes ☐ No ☐
Exhaust and fresh air supply o.k. ? Yes ☐ No ☐
Safety goggles worn near the shakers ? Yes ☐ No ☐
Safety boots worn at all times ? Yes ☐ No ☐

Is the unit manned and powered up at all times during drilling, tripping, testing and other operations ?
Yes ☐ No ☐

Do the mudloggers communicate properly with the rig floor ?
Yes ☐ No ☐
Any language problems ? Yes ☐ No ☐

Language used for communication : _____

Is the access to the unit limited to authorized personnel only ? Yes ☐ No ☐

Rating of Services :
☐ GOOD/EXCELLENT ☐ FAIR/ACCEPTABLE ☐ POOR ☐ DANGEROUSLY POOR

If the rating of services is less than fair, indicate reasons for it:

☐ Poor/old equipment
☐ Unqualified Personnel
☐ No support from drilling
☐ Insufficient maintenance
☐ Attitudinal problems
☐ Technical environment problems (no electricity, no water, etc.)
☐ No support from contractor's town office
☐ No support from operator

Other Comments:

What measures can be taken to improve the situation ?

Signed by:

Mudlogging Unit Captain : _____ Date: ___/___/___

Wellsite Geologist : _____