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Drilling Problems
INTRODUCTION

NTGS has an obligation to provide geological information in areas of poor outcrop and inadequate drillhole coverage. Despite the best geophysical data, this can only be reliably addressed by stratigraphic drilling, where such drillholes provide lithological and stratigraphic information and allow collection of pristine samples for biostratigraphic, geochemical, geochronological and mineralisation studies. These data can then be used to build regional geological models and encourage exploration companies into new areas. Considering the paucity of outcrop and the limited coverage of existing drillholes over much of the Northern Territory, there is an ongoing need for the NTGS to undertake drilling programs. In addition, drilling undertaken by NTGS should be documented in a way that allows explorers to optimise their own drilling programs.

Objective and content of this document

This in-house manual is designed to assist NTGS staff in organising stratigraphic drilling programs and supervising on site. It is directed to those with little or no previous experience of drilling. It gives in-house guidelines and does not purport to reiterate government policy concerning drilling, unless this is explicitly acknowledged. It is not a textbook on drilling nor is it intended to be as comprehensive as company manuals. For comparison, the 1996 Santos onshore drilling operations manual is over 400 pages in length, including 58 pages of forms. In the present manual, much of the drillers’ jargon is explained in references listed in Appendix 1, and a glossary of common abbreviations provided in Appendix 2. Australian Standards referred to throughout the document are shown in the format AS1234. The symbol ▲ is used to indicate guidelines, procedures and checks for the NTGS site Representative. The symbol ➖ is used to distinguish worked examples of calculations. An index provides quick reference to specific topics.

It is anticipated that this document will be revised regularly, and any corrections or comments should be directed to the author or the Editorial Geologist.

History of NTGS drilling

The various governments responsible for what is now the Northern Territory have been involved in drilling for almost a century. No specific drilling reports were published prior to 1908 when the Territory was administered from South Australia, but summaries were included in earlier annual reports at least as far back as 1905. The first internal review of drilling activities by the NT government was undertaken in 1912 by HI Jensen, the then Director of Mines. He rationalised the 250 rapidly decaying boxes of core stored in the Government Stables, ‘put an end to the old system of boring at random’ and ‘introduced business methods into the work of the drills’ (Jensen 1915). He reported that during 1912-1913 eight holes totalling 3626’ (1105 m) were drilled using steam-powered diamond rigs at known prospects. The average cost was £1 15s 2½d per foot.

The Mines Branch, as it was called, continued to drill prospects at the behest of leaseholders until its demise in the late 1970s. From NT self-government and the birth of NTGS in 1978, the emphasis shifted to stratigraphic drilling as a complement to geological mapping. Another government division is responsible for waterbore drilling but their samples are stored in NTGS core libraries. As of July 2003, 644 NT government water and stratigraphic drillholes totalling over 57 000 m had been registered in our COREDAT database. The average depth is 88.8 m; 155 holes are ≥100 m and 19 of the holes exceed 500 m, the deepest to date being 845.9 m.

Types of drilling

The various types of drilling may be classified according to the hole-making action and the hole cleaning method. Those of relevance to NTGS are described below.

Open hole rotary drilling is widely used in petroleum and minerals exploration. It uses a slowly rotating (typically <100 rpm) drillstring and bits which cut by scraping (blade bit), point pressure chipping (roller bit with three cones of steel or tungsten carbide teeth) or percussion (rotary downhole hammer with rounded tungsten carbide buttons; 10-40 rpm). Figure 1 shows a selection of bits used in open hole drilling. Penetration rates while actually drilling are in excess of 8 m/hr, sometimes as high as 30 m/hr. The flushing of cuttings may be by water, mud or air (rotary air blast – RAB). The circulation can be normal (cuttings up the annulus) or reverse circulation (RC - in which cuttings come up the inside of the drillstring). There are numerous combinations of the various open hole rotary drilling techniques and hole clearing techniques. For example, blade bit and tricone rotary drilling can be done using mud or air. Hammer drilling uses air and specific hammers are designed for normal and reverse circulation. Mist and foam lift cuttings employ a combination of air and mud and can be used in each of these examples.

Coring, in which an annular bit cuts a solid cylinder of rock, is the technique most used in NTGS stratigraphic drilling. It is discussed at length in CORE DRILLING.

Alternatively, individual holes or drilling programs may use a combination of different drilling techniques. For example, the overburden may be drilled quickly and cheaply (termed a precollar) using a hammer before the target is diamond cored. Geochemical sampling may involve grid drilling using RAB for reconnaissance and the more expensive RC for more reliable samples.
Types of drill rigs

Petroleum rigs range from heli-transportable to huge offshore platforms. On most petroleum rigs, the drillstring consists of drill pipe with upsets (thicker walls at the joins) and heavy weight collars at the base which provide the weight on the bit. The drillstring is supported above the ground in a derrick and spun using a Kelly bushing in a rotary table on the drill floor. The string is said to be tripped in and out of the hole. Changing the bit necessitates a round trip.

Mineral rigs are typically truck, trailer or track mounted. They have a one-piece mast rather than a derrick and use a top drive. The rig itself provides the pulldown on the bit. The drillstring is usually thin-walled slick (no upsets) drill rods. Moving the drillstring in and out of the hole is referred to as running in and pulling out.

Drill rigs were originally designed specifically for a particular style of drilling and many remain so. However, the need for several different styles of drilling in the same hole or drilling program led to the concept of multipurpose rigs. These rigs were first developed in Australia and the United States during the 1970s-1980s. Mineral rigs, such as the heli-transportable Bourne 4000S (capable of 2500 m in 4.35” hole) were extensively modified to take blowout preventers (BOPs) for both open hole drilling and continuous coring of petroleum wells. These hybrid rigs use a top drive and either a heavy duty (CHD series) slick string for coring or small diameter drill collars and heavy weight drillpipe for open hole rotary drilling. Such light-weight petroleum rigs are only used for specialist exploration work, often in remote or inaccessible locations. These rigs are also referred to as slimhole, meaning a substantial portion of the drillhole is <100 mm diameter. Multipurpose rigs were also developed for mineral exploration, where they have become almost ubiquitous. These universal rigs come in a range of sizes and are capable of rotary, downhole percussion and diamond coring of both vertical and angled holes (Figure 2).

![Figure 1](image1.png)

**Figure 1.** Types of drill bits most commonly used in open hole, non-core drilling. (a) Chevron wing blade bit with replaceable cutters, commonly used for poorly consolidated near-surface formations. (b) Tricone roller bits; these are among the oldest and most versatile types of bit. The bit on the left has steel teeth; longer, more pointed teeth are used for softer formations. The bit on the right has tungsten carbide buttons; buttons come in a range of shapes from chisel-shaped for moderately hard formations to dome-shaped for extremely hard formations. Both bits are designed for mud drilling; mud is jetted through three nozzles (arrow) and differently sized jets can be fitted into the nozzles to optimise the hydraulics; the bearings are sealed. (c) Small-diameter hammer bit with tungsten carbide buttons, for percussion drilling. (d) Partial cross-section through a roller bit designed for air drilling. Air roller bits have different plumbing and bearings to those used with mud, eg the bearings are air cooled and there is a single air jet nozzle with a backflow valve inside the bit. Images courtesy of Baker Hughes, Kay Rock Bit and UralMBT.
Figure 2. Multipurpose rigs. (a) UDR 650 MKII, a medium-sized multipurpose rig, reverse circulation (RC) drilling an angled hole; note the flowline connection that enables the drilling fluid to be circulated down the annulus, bringing the cuttings up the inside of the drillstring. This rig is capable of RC hammer to 280 m with 3.5” rods. (b) The same rig as in (a), diamond coring in NQ diameter. It is capable of coring HQ to 575 m and NQ to 875 m. (c) Carrier-mounted UDR 5000 jacked up as a platform. This is one of the largest UDR multipurpose rigs, rivalling some conventional petroleum rigs in depth capacity, capable of downhole hammering to 1830 m with 3.5” rods and of coring CHD101 to 2960 m. (d) Bourne THD25, a medium-sized rig designed and built in Queensland, used for waterbore drilling and shallow mineral exploration. It would normally be truck mounted; the hydraulic top head drive is visible at the bottom of its travel and the driller’s platform and controls are to the left. (e) UDR 1000 on a platform in Papua-New Guinea. A standard UDR 1000 is capable of RC hammering to 415 m with 3.5” rods and of coring HQ to 1000 m and NQ to 1500 m. (f) Drillcorp rig 53, a UDR 1000 mounted on an 8x8 Man truck, showing the rod rack on the right side of the rig. (g) Boart Longyear UDR 1000, similar to the previous, showing the left side of the rig with pumps, compressor and driller’s platform. (h) Truck-mounted UDR 1000 drilling an angled hole. (i) Truck-mounted UDR 1200, capable of RC hammering to 550 m with 4.5” rods and of coring PQ to 820 m, HQ to 1100 m and NQ to 1650 m. (j) UDR 1500 shown jacked onto its platform with the mast set to drill an angled hole; the caterpillar tracks used to transport it are visible to the left. A UDR 1500 MKIII can hammer to almost 1000 m and core CHD101 to 1680 m and NQ to 2780 m. Images courtesy of Bournedrill, Drillcorp and UDR.
ADMINISTRATION

This section presents checklists and brief summaries to assist in the planning, execution and supervision of a drilling program. Safety and duty of care are discussed.

PLANNING AND MANAGING THE PROGRAM

▲ Stage 1 Planning

- Define drillhole(s) objectives
- Organise access with Traditional Owners and other stakeholders
- Prioritise order of drilling
- Prepare Drillhole Proposal(s)
- Prepare Authorisation for Expenditure (AFE –see AUTHORISATION FOR EXPENDITURE)
- Purchase long lead time consumables
- Finalise Invitations to Tender
- Organise earthworks (build roads, dams, dig pits etc)
- Assure secondary water supply
- Prepare draft work flowchart
- Evaluate tenders
- Collect intelligence
- Model costs
- Inspect equipment
- Interview key contractor personnel

▲ Stage 2 Contracts management

- Award contracts
- Organise site inspection by representative of drilling company
- Refine work flowchart
- Obtain any necessary insurance

▲ Stage 3 Site supervision

- Coordinate mobilisation and inter-drillhole moves
- Undertake site duties (see ONSITE DUTIES)

▲ Stage 4 Closeout

- Site restoration
- Depermit all stakeholders
- Appraise contractors and NTGS performance
- Audit project
- Prepare Technical Note and Drillhole Completion Report

AUTHORISATION FOR EXPENDITURE

A drilling budget should include:

- Permitting and depermitting
- Water supply (waterbore drilling and/or haulage)
- Roadworks
- Roadworks supervision
- Site preparation
- Site preparation supervision
- Rig mobilisation/moves/demobilisation
- Rig day rates
- Camp
- Fuel/lubricants and delivery
- Casing
- Bits and drilling consumables
• Mud supply and engineering
• Wireline logging and vertical seismic profiling
• Travel and accommodation
• Freight
• Field supplies and equipment
• Analyses
• Drilling Proposal/Technical Note/Drilling Completion Report
• Insurance
• Communications
• Site restoration
• Road repairs
• Contingency

RISK ANALYSIS

Anticipating and assessing the risks or potential problems is part of any project plan. In drilling, the emphasis in risk analysis will vary from one proposal to another. The checklist below gives examples of common risks. Quantitative comparisons are possible if the seriousness of the various facets of the program and their likelihood are each given a rating from one to ten with one being the least serious and least likely. The weighted average then ranks the relative risk of this particular proposal.

Once identified and prioritised, potential problems need to be matched with preventative actions, contingent plans or adequate solutions.

Planning and access problems
• Delays in Aboriginal clearance
• Problems with access logistics for mobilisation/demobilisation/interhole moves
• Difficulties with crew change
• Unable to get fuel to site

Technical problems while drilling
• Insufficient/unreliable water supply
• Bad weather delaying operations
• Lost circulation
• Fractured formation
• Overpressured formation
• Unsafe hydrocarbon intersection
• Intersecting faults or inclined bedding
• Intersecting evaporites
• No backup and replacement equipment has to be mobilised

Incorrect stratigraphic prognosis
• Stratigraphic prognosis too shallow, hole deeper than anticipated
• Original target beyond rig capacity

ONSITE DUTIES

▲ NTGS must maintain a technical presence on site from the arrival of the rig to mast down. The NTGS Geologist and Technical Assistants are responsible for the following duties:

• Survey the drillhole location with GPS and ensure that the rig is set up appropriately (especially for an angled hole)
• Ensure that all work is carried out in accordance with relevant legislation and under the terms of contracts
• Check and sign contractors’ daily operations reports (sometimes called DORs, DDRs, plods or tour sheets). They must be completed and signed daily and not allowed to accumulate. The driller will probably also have separate time sheets and safety checks to sign
• Brief all site personnel on NTGS guidelines concerning safety and confidentiality
• Organise and chair weekly safety meetings
• Recommend the sample interval during rotary drilling
• Supervise collection of all samples
• Ensure core and other samples are handled, marked and labelled according to best practice
• Provide a detailed geological description
• Detect and describe all potentially economically important aspects (eg oil shows, ore minerals)
• Provide an NTGS Daily Operations Report in a standard format (Appendix 3)
• Monitor costs relative to budget
• Photograph core
• Arrange transport of core and other materials
• Advise of termination depth (see Terminating the hole)
• Witness and QC wireline logging operations
• Supervise completion or abandonment of the hole in accordance with relevant legislation
• Provide photographic evidence and sign-off on environmental impact closeout

Terminating the hole

▲ Under normal circumstances, the NTGS Geologist on site will recommend when to terminate the hole. On a deep stratigraphic hole, a cutoff will have been clearly defined as part of the proposal (eg into top of igneous basement). If the hole is to be geophysically logged, remember to allow sufficient sump to enable meaningful readings of the lowermost geological unit (in this example, basement). Some of the large combo suites used in petroleum exploration need a 30 m sump; whereas 3 m might be adequate with other tools.

DATA HANDLING AND REPORT WRITING

NTGS drillhole naming convention

The NTGS drillhole naming convention is:
MapSheet code (two letters)_Year (last two digits)_Hole type (DD, RC, AC, RB)_Hole number (two digits)
eg VR03DD01 is the first diamond hole drilled in VICTORIA RIVER DOWNS in 2003. Drillhole names are best determined early, during preparation of the Drillhole Proposal(s) or Invitations to Tender. The list of MapSheet codes to be used with the convention is to be found at:
G:\Geological Survey\Administration\Standards & Procedures\GIS\File naming\NTGS_File_Names.xls

NTGS Technical Note, Drillhole Completion Report and data management

▲ All relevant background data from the drilling will be compiled into an NTGS Technical Note in a standard format (specified in separate guidelines). These data will be simplified and accompanied by a comprehensive interpretative report in the final Drillhole Completion Report. The geologist responsible for the project is also to provide all necessary metadata in standard NTGS format.

SAFETY AND EMERGENCY PROCEDURES

The following are basic checklists relating to safety and emergency procedures for drilling operations.

Site access by trained personnel only

• Only trained personnel on site
• Barriers to prevent access by unauthorised personnel
• Contractors are not to grant ingress to any third party without the consent of the NTGS Representative

Work hours

• Shift duration
• Tour of duty (duration of field period)
• Adequate light
• Working in extreme conditions (avoiding heat stroke)

Site layout and housekeeping

• Good site layout, ground stability, drainage, flood and fire risk, wind direction to camp
• Access and turning circles for support trucks and service vehicles
• Remove any obstructions (loose rocks, tree stumps) from site
• All rigs should ideally be fitted with elevated walkways (AS1657 compliant) to create a uniform work platform, irrespective of local site conditions
• No slippery walkways
• Check for underground cables and pipes
• Good housekeeping; site clean and tidy and free of tripping hazards
• Tubular items stacked in safe manner
• Safety signs must be displayed (AS1319)
• Any requirement for quarantine and disease control, for example steps to avoid spreading noxious weeds

Fire safety

• Fire breaks and fire fighting equipment; fire bans include campfires
• Fire extinguishers (AS1841, AS1845-48, AS1851 Part 1, AS2444)
• If rig is fitted with an automatic fire suppression system, include familiarisation in safety induction
• Fire prevention during welding (AS1674)
• Oxygen (from oxyacetylene) is not to contact hydrocarbons (eg grease or petrol) as this is potentially explosive

Fuel safety

• Trayback NTGS vehicles are limited in the number of 200 L fuel drums they may carry on a gazetted road without a permit (refer to NTGS Field Manual)
• Fuel stored away from rig and camp in accordance with regulations (eg tanks may require a bund wall)
• Spills or leakage of fuel for the use of Contractor are their responsibility but NTGS will monitor clean-up

Hazardous substances

• Appropriate signage in place
• Materials Safety Data Sheets for all potentially toxic or hazardous drilling additives
• Safe disposal of all potentially toxic wastes
• Spills or leakage of hazardous substances for the use of Contractor are their responsibility, clean-up is under NTGS supervision

Safety audit and safety meetings

• Site safety audit before spud
• ▲ NTGS should organise weekly safety meetings of each shift, to include both NTGS and all contract personnel. Such meetings must be recorded in the Daily Operations Report

Personal protective equipment (PPE)

• Head: hard hats (AS1800, 1801, 2210) must be worn within 30 m of the rig. Note that metal hard hats are not permitted; allowable accessories include sun brim, visor-type face shield, earmuff attachments, lampholder. Long hair must be restrained, even when a hard hat is worn
• Eye: safety glasses (AS1336:1982, AS1337), tinted or otherwise, must have the appropriate Australian Standard logo; welding shields (AS1338): a full-face shield is to be worn when cutting core. Filters in fluoroscopes and UV boxes (AS1338 Part 2)
• Hearing: hearing protection device shall provide protection to a level not exceeding 85 dB (AS1270). This can be earmuffs, disposable ear plugs or both, such that they do not compromise other safety equipment
• Respiratory: respiratory protection against dust (AS1715, AS1716). Breathing apparatus may be carried on some rigs and its use requires formal training
• Skin: sunscreen and insect repellent will be supplied by the employer
• Hand: general work gloves (AS2161), welding gloves (AS1558)
• Foot: safety boots (AS2210) with a steel toe cap must be worn by all personnel within 30 m of an operating drill rig; boots must have the Australian Standard logo
• Clothing: safe and adequate clothing, no loose clothing, a UPF (UV) rating of 50+. Some companies stipulate that long-sleeved shirts and long trousers be worn on drill rigs; welding apron, raincoats
• Harness: all personnel aloft must have a safety belt or safety harness (AS1891, AS2626). Note that these standards forbid the use of harnesses made from leather or natural fibre webbing. No tools to be hand carried into the mast

Personal health and hygiene

• Any medical condition that may affect Contractor performance must be reported to the NTGS Representative
• Be aware of high-risk individuals (eg asthmatics, diabetics, epileptics, angina sufferers)
• Prohibition of drugs; control of alcohol
• Camp conditions, especially food preparation areas and ablutions are to be clean and hygienic
Adequate rubbish and sanitary disposal facilities
Firearms, bows or similar weapons are prohibited
Domestic animals are prohibited
Occupational driving (AS2299)

Use of radioactive sources
Use of a radioactive source in downhole logging requires a licence under the Radiation Health Act. Any radioactive sources for use in downhole logging must be transported, stored and handled in accordance with the Commonwealth NHMR Code of practice for the safe transport of radioactive substances and Code of practice for the safe use of sealed radioactive sources in borehole logging. Requirements for signage on vehicles carrying sources must be enforced.

Pressure vessels and associated equipment
• Must comply with AS3788, AS3873
• All high-pressure hoses must be restrained to prevent whipping in the event of breakage or connection failure. Particular attention should be paid to the adequacy and placement of the restraining line between the sample hose and the cyclone on an air rig (failure has caused fatalities and serious injuries in Australia)
• Pressure relief valves (mandatory on air compressors, triplex and water injection pumps) should be function tested where possible. No shut-off valve is permitted between the pressure relief valve and the pressure chamber
• Compressed air handtools such as button bit grinders must only be operated through a pressure regulator
• Take care when pumping out inner tubes with drilling fluid or water. Use of compressed air is forbidden; a bumper must be in place and no one within 5 m

Guards on rig
• Hydraulic rod spinners should be fitted to minimise rod handling and ideally, safety cages installed to protect rig personnel while drilling is in progress. These cages should be fitted with a hydraulic interlock which immediately stops rod rotation when the cage is opened
• Check guards on belts, chains and gears

Gas hazards
Petroleum gas is the most common hazardous gas encountered while drilling. CO₂ and H₂S are also potential problems and can be associated with petroleum gas (up to 28% of natural gas could be H₂S) or gas-charged groundwater. Both petroleum gas and H₂S are explosive. These and CO₂ can all be fatal if breathed in sufficient concentrations. Ensure that all personnel are informed if gas is encountered. The driller will decide how to treat the problem, what fire prevention strategy to adopt, and if rig and/or camp evacuation needs to be considered.

H₂S (rotten egg gas) is not widespread in Australia, but several of the major aquifers contain local pockets of detectable H₂S. For example, the artesian groundwater at Winton, Queensland has a noticeable odour and there is anecdotal evidence of H₂S being encountered in mineral exploration holes in the Georgina Basin. Many petroleum rigs (and some mineral rigs) have H₂S detectors as standard equipment and carry breathing apparatus near the driller in the event that H₂S is encountered. It is extremely toxic, flammable at 4% concentration and makes steel go brittle. One of the main reasons that it has caused fatalities is that it deadens the sense of smell and gives the false sense that it has dissipated. It is colourless and heavier than air and will accumulate in tanks and confined and low-lying areas. Because it is soluble in water and hydrocarbons it is readily transported in the mud system. The driller must be informed at the first indication of H₂S (Table 1). Do not attempt to rescue anyone who has been overcome by H₂S unless you are wearing breathing apparatus. The OSHA Permissible Exposure Limit for a ceiling concentration is 20 ppm hydrogen sulfide, a level which may not ever be exceeded. The acceptable maximum peak, for 10 minutes only, once during an 8 hour day if there is no other measurable exposure, is 50 ppm.

<table>
<thead>
<tr>
<th>Concentration of H₂S</th>
<th>Effects</th>
</tr>
</thead>
<tbody>
<tr>
<td>10 ppb</td>
<td>First noticeable odour</td>
</tr>
<tr>
<td>5-10 ppm</td>
<td>Obvious odour of rotten eggs</td>
</tr>
<tr>
<td>10-20 ppm</td>
<td>Very unpleasant but safe for up to 8 hours exposure per day</td>
</tr>
<tr>
<td>20-100 ppm</td>
<td>Headache, dizziness, nausea and vomiting may develop, together with irritation of the eyes and respiratory tract; odour becomes sweet then disappears as it kills the sense of smell; continuous exposure to 100 ppm for several hours may result in death within the next 48 hours</td>
</tr>
<tr>
<td>100-500 ppm</td>
<td>Breathing difficulties; continued exposure fatal</td>
</tr>
<tr>
<td>500-700 ppm</td>
<td>Unconsciousness, immediate brain damage; continued exposure fatal</td>
</tr>
<tr>
<td>700-1000 ppm</td>
<td>Certain death within 4 minutes</td>
</tr>
</tbody>
</table>

Table 1. Effects of H₂S exposure.
DUTY OF CARE

Reporting systems

All contractors must have their own internal accident reporting system. The current reporting systems used to record OHS data within NT Government are:

- Hazard Report
- Incident Report: to record all incidents including near misses
- Incident Investigation: to record investigation details and outcomes

▲ Managers/Supervisors must ensure that all relevant forms are easily accessible and that they are completed and processed in accordance with the requirements of the OHS management system. They must also ensure that all employees are familiar with the forms and their responsibilities to use them. First Aid Kit - Contents List form ensures that kits have adequate materials and records use of first aid materials. Forms are available at:

All completed forms are to be returned to the supervisor.

An external NT Fleet Motor Vehicle Accident form is raised when any NT Fleet vehicle has been damaged. As well, an external DCIS Accident Report is raised when there is an injury to an employee and any of the following conditions apply:

- Employee(s) involved will be absent from work for one full day/shift or more (lost time)
- Hospitalisation is required
- The attention of a medical practitioner (this includes community nurses) is required
- Workers Compensation will be, or has the potential to be claimed (medical, pharmacy, physiotherapy, rehabilitation, etc)

Hazard Report

Any hazard that has the potential to cause injury or illness to an employee, visitor, contractor or member of the public must be reported and assessed using the prescribed Hazard Report form.

Incident Report

All incidents and any workplace-related illness must be reported on the Incident Report form. If the person involved is unable to do so, the supervisor or witness will complete the form as soon as possible. Any other witnesses should independently complete forms.

Statutory accident reporting

The HR Manager is required to report all prescribed accidents to the Work Health Authority within 24 hours, followed by a written report within 7 days. An external two-page DCIS Accident Report Form is used for this.

The standard NT Government definition of a prescribed accident is when:

- A death occurs
- The accident is likely to result in more than 5 days lost time
- A worker suffers an electrical shock
- Exposure to a hazardous substance results in admission to hospital
- The accident results in injury to a person other than a worker
- Overturning, collapse or failure of a lift, crane, hoist, lifting gear or scaffolding occurs (this would include the rig mast)
- Failure of pressure equipment is involved
- A height of more than 1.5 m of an excavation or shoring collapses
- Part of a building or structure collapses
- Fire or explosion results in normal work being stopped for more than 24 hours (see added comment below)
- An accident involves plant coming into contact with live electrical conductors, or
- Personal protective equipment fails affecting the health and safety of a person.

In the case of drilling we need to add:

- Any drillhole flows uncontrolled
- Any combustion of material in or flowing from a drillhole occurs
The scene of any such accident must be rendered safe, but otherwise disturbed as little as possible. Photographs may be advantageous. A safety inspector will probably need to visit the site.

**Vehicle accidents**

It is a legal requirement that all motor vehicle accidents resulting in bodily injury or damage are reported to the police as soon as possible. If an NT Fleet vehicle is damaged, an external NT Fleet Motor Vehicle Accident form must be completed and forwarded to the Office Services Manager. This form is in addition to the internal DBIRD Incident Report and Incident Investigation forms, which still have to be completed.

**Qualified first aiders**

The drilling Contractor’s crew should include a designated first aid officer who has a minimum Senior First Aid qualification. This should be documented in the contract and records kept on site. All NTGS personnel on the rig site should have current similar qualifications.

**First Aid Kit - Contents List and first aid reporting**

The First Aid Kit - Contents List ensures that kits have adequate materials and records use of first aid materials. Managers and supervisors are to inform all employees of the location of the nearest first aid kit and the nominated First Aider. Where applicable, they are also to include a copy of the procedures to be followed with all first aid equipment. The Manager of the work area will ensure that a procedure is implemented to restock the First Aid kits on a regular basis. If a situation arises whereby an employee requires first aid treatment, the Manager should record the materials used from the first aid kit on the form provided inside the kit. The nominated First Aider will collect and forward these forms to the HR Manager for collation and review of first aid usage. This procedure does not replace the requirement to notify all incidents to your Supervisor as soon as possible.

**Casualty evacuation and general rig evacuation**

As part of the NTGS Field Plan, casualty evacuation and general rig evacuation procedures must be formulated in consultation with the drilling Contractor and submitted to the NTGS Field Supervisor before drilling commences. A Royal Flying Doctor Service-approved airstrip has to be nominated for evacuation. Ideally, there should be all-weather access to and from the airstrip. If not, contingencies for helicopter evacuation should be put in place. Remember that not all helicopters can carry a stretcher.

**Safety induction**

All rig-site personnel should receive a safety induction specific to the rig and location before their first shift. This includes all NTGS, contract and subcontract personnel. This should be documented in writing.

**Emergency communications**

In addition to the satellite phone/fax on site, the NTGS Field Plan should include at least one form of standby communications that can be relied upon in an emergency. This may be VHF/UHF radio or the drillers’ satellite phone. Note that if vehicle-mounted satellite phones are used there must be at least one such NTGS vehicle on site at all times.

**CORE DRILLING**

**INTRODUCTION**

Coring uses a rapidly rotating (350-1000+ rpm) thin-walled drillstring and an annular bit to cut a solid sample. The volume of the annulus in a cored hole is only one tenth that of a conventional rotary-drilled open hole of the same diameter.

In conventional coring, as done on a petroleum rig and for some bottom hole cores (eg waterbores), the core is retrieved by pulling out the entire drillstring to get the core barrel at the end. This technique was pioneered in engineering and mining and first introduced to the oilfield in the early 1920s, where it remains prohibitively expensive and is used sparingly, mainly for reservoir evaluation. Petroleum core barrels come in 30’, 60’ and 90’ lengths.

Continuous coring uses an overshot on a wireline run inside the drillstring to retrieve the core in an inner tube and has become the standard of the minerals exploration industry. There have been over 200 different core diameters used in the minerals industry and for slimhole petroleum coring. Many sizes are obsolete. Some are specific to a country, for example, South Africa or Canada, and rarely seen in Australia. There are as many as ten in routine use in any one place at any one time. The core and hole diameters commonly used in Australia over the past 40 years are shown in Table 2. Hartley (1994) gives a
more comprehensive listing of 150 Australian types. In the old DCDMA system, the first letter refers to range of hole size. The second letters X and W are group letters indicating that all similar letter equipment (eg HW and NW) are complementary for decreasing hole diameter. DCDMA ‘X’ is now referred to as ‘WG’. Q indicates wireline, J and other letters are thread types and the remaining letters and numbers are barrel type, bit type, rod thickness or metric hole diameter. For example, in HQ3, H refers to a hole diameter of about 60 mm, Q indicates that it is wireline and 3 denotes triple tube. Note that different manufacturers claim different specifications for the now largely obsolete AWL core. For example, Bradley’s is 27.0 mm (others AQ), Hartley (1994) gives 29.59 mm and Longyear’s is 30.1 mm (others AX or AWM).

The core bit may be face set with diamonds, or diamonds can be impregnated throughout a matrix that is designed to progressively wear away. Other core bits have cutters or disc-shaped insets made of PDC. This polycrystalline diamond compact is synthetic diamond powder bonded into tungsten carbide. Some specialist core bits use tungsten carbide chips. A selection of such bits is shown in Figure 3. Figure 4 shows a typical diamond bit in cross-section with the components labelled. Traditional diamond bits cut using a combination of crushing and scraping; most of the other types have a greater shearing action. The circulating fluid is usually a polymer-based liquid. Diamond coring is normally at least three times more expensive than any other method and 5 m/hr is a realistic overall average penetration rate for holes <1000 m. Figure 5 shows the components of a core barrel and associated equipment. Core barrels come in a variety of lengths. The most common contain 1 m, 3 m or 6 m of core. The more efficient 6 m barrels are routine in deep holes where there are few drilling problems. The smaller barrels are used when only a spot core or bottom-hole core is required, or when coring is difficult. Normal practice in wireline coring is to have at least two inner tubes on site so that one can be dropped and drilling resumed while the other tube is being emptied. The interval drilled to fill the tube is called a run.

Air coring is a combination of RC and diamond coring in which a special bit (similar to that shown in Figure 3c) cuts a small-diameter core which is air-lifted up the inside of the drillstring. This technique is suited to sticky clays and semi-consolidated rocks with hard bands. Overall penetration rates are typically about 15 m/hr.

<table>
<thead>
<tr>
<th>Size</th>
<th>Core diameter (mm)</th>
<th>Hole diameter (mm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>AQ, AQ-U</td>
<td>27.0</td>
<td>48.0</td>
</tr>
<tr>
<td>ATW</td>
<td>30.3</td>
<td>48.0</td>
</tr>
<tr>
<td>AWG, AWM, AWL, AX, AXM</td>
<td>27.0, 29.6 or 30.1</td>
<td>48.0</td>
</tr>
<tr>
<td>BTW</td>
<td>42.0</td>
<td>60.0</td>
</tr>
<tr>
<td>BQ, BQ-U, BQWL</td>
<td>36.5</td>
<td>60.0</td>
</tr>
<tr>
<td>BQ2.32</td>
<td>38.6</td>
<td>58.9</td>
</tr>
<tr>
<td>BQ3</td>
<td>33.5</td>
<td>59.9 or 60.0</td>
</tr>
<tr>
<td>BW, BWG, BWM, BWL, BX, BXM</td>
<td>42.0</td>
<td>59.9</td>
</tr>
<tr>
<td>CHD101</td>
<td>63.5</td>
<td>101.3</td>
</tr>
<tr>
<td>CHD134</td>
<td>85.0</td>
<td>134.3</td>
</tr>
<tr>
<td>CHD76</td>
<td>43.5</td>
<td>76.3</td>
</tr>
<tr>
<td>EW, EWG, EWM, EWL, EX, EXM</td>
<td>21.5</td>
<td>37.7</td>
</tr>
<tr>
<td>HQ, HQWL</td>
<td>63.5</td>
<td>96.0 or 96.1</td>
</tr>
<tr>
<td>HQ3</td>
<td>61.1</td>
<td>96.0 or 96.1</td>
</tr>
<tr>
<td>HQ3.18</td>
<td>66.2</td>
<td>93.5</td>
</tr>
<tr>
<td>HW, HWG, HX</td>
<td>76.2</td>
<td>99.2</td>
</tr>
<tr>
<td>LTK46</td>
<td>35.6</td>
<td>46.2</td>
</tr>
<tr>
<td>LTK56</td>
<td>45.2</td>
<td>56.3</td>
</tr>
<tr>
<td>NQ, NQ-U, NQWL</td>
<td>47.6</td>
<td>75.7 or 75.8</td>
</tr>
<tr>
<td>NQ2</td>
<td>50.7</td>
<td>75.7</td>
</tr>
<tr>
<td>NQ3</td>
<td>45.0 or 45.1</td>
<td>75.7</td>
</tr>
<tr>
<td>NTW</td>
<td>56.0</td>
<td>75.7</td>
</tr>
<tr>
<td>NW, NWG, NWM, NWL, NX, NXM</td>
<td>54.7</td>
<td>75.7</td>
</tr>
<tr>
<td>PQ, PQWL</td>
<td>85.0</td>
<td>122.6</td>
</tr>
<tr>
<td>PQ3</td>
<td>83.0 or 83.1</td>
<td>122.6</td>
</tr>
<tr>
<td>RWG</td>
<td>18.7</td>
<td>29.8</td>
</tr>
<tr>
<td>2¾&quot; x 3? &quot;</td>
<td>68.3</td>
<td>98.4</td>
</tr>
<tr>
<td>4&quot; x 5¾&quot;</td>
<td>100.8</td>
<td>139.6</td>
</tr>
<tr>
<td>6&quot; x 7¾&quot;</td>
<td>151.6</td>
<td>196.9</td>
</tr>
</tbody>
</table>

Table 2. Common diamond drillcore and hole diameters.
Figure 3. There is a wide variety of different types of core bits using diamonds, tungsten carbide or PDC, and the correct bit must be chosen to optimise penetration and bit life for specific formations and drilling conditions. (a) Impregnated flat-crown diamond bit, probably the most versatile and commonly used type in mineral exploration. More diamond fragments are exposed as the matrix is worn away, so that these bits have a long life when drilling homogeneous material; these bits are disposable. (b) Surface-set, step-faced diamond bit for hard sedimentary formations. This is an older design and the bit has to be pulled once the exposed diamonds are worn away, but such bits are then reset and reused: an eight-step bit would typically make at least 450 m at >2.5 m/hr in average Proterozoic or Cambrian carbonate and fine siliciclastic rocks; 600 m at 3.0-5.0 m/hr is achievable in the best drilling conditions. (c) Carbide chip bit can be used to core sedimentary rocks, but is more usually used to clean metal junk out of a hole. A similar design is used for air core. (d) Large tungsten carbide saw teeth on this bit are used in coring very soft rocks in geotechnical investigations. (e) Ridge-set, round-crown natural diamond bit for hard, dense, moderately abrasive rocks. (f) Diamond bit for general purpose coring in medium to hard rocks such as limestone. (g) Small cutter PDC for medium to hard rocks. (h) Medium-set PDC with large fluid courses internally and externally, designed for soft to medium rocks. Images courtesy of Baker Hughes Christensen and Dimatec.

Figure 4. Partial section through a typical diamond bit, with component features labelled.
Figure 5. Components of a core barrel. Image courtesy of Longyear.
Ordering core trays

At present, either NTGS or the drillers can supply the core trays. Normally, unused core trays provided by the driller are non-returnable. Trays should be ordered, with the assistance of the DBIRD Core Library Manager, well in advance of mobilisation. Note that the DBIRD core libraries use 400 mm x 1000 mm trays and that this size may not be standard in other states. Also remember to obtain core trays appropriate to the diameter of the core; for example, NQ2 core is too tight in NQ trays. At the very least, lids will be required for trays that will be stacked as the top layers of a pallet. However, it is considered standard practice for every tray to have its own lid. The nominal capacity of trays is given in Table 3. Allow about 5% extra for drillers’ blocks and gaps between core pieces.

<table>
<thead>
<tr>
<th>Core size</th>
<th>Nominal metres per tray</th>
</tr>
</thead>
<tbody>
<tr>
<td>BQ</td>
<td>9</td>
</tr>
<tr>
<td>NQ</td>
<td>7</td>
</tr>
<tr>
<td>HQ</td>
<td>5</td>
</tr>
<tr>
<td>PQ</td>
<td>3</td>
</tr>
</tbody>
</table>

Table 3. Nominal capacity of core trays for different core sizes; allow 5% extra when ordering.

DRILLING PROBLEMS WHILE CORING

Dropped core

Unconsolidated, brittle or fissile rocks can all cause problems with dropped core. Such core falls from the core lifter in the base of the inner tube as the tube is being recovered. The core falls to the base of the hole and has to be overdrilled during the next run. It is difficult to redrill because the bit tends to spin it and there is a tendency for this piece of core to lodge within the inner tube causing a wedge off. In the early days of coring, dropped core had to be crushed up with a rotary bit before coring could resume. This often necessitated dozens of round trips to change back and forth between tricone and diamond core bits. Even today’s core bits will wear prematurely if repeatedly used to overdrill dropped core.

If there is no indication that the formation is the cause of dropped core, equipment malfunction should be suspected. Core will be dropped if the inner tube fails to seat, if an inappropriate type of core lifter is used, or if the core lifter is bent or worn. The degree of wear can be easily checked at the surface using a piece of in-gauge core. It is often difficult to snap hard, competent rock such as massive limestone at the end of a run. Core of such rocks commonly has chatter marks left by the teeth on the core lifter skidding up the core. These are a sign that the lifter is under stress and may bend or wear prematurely.

Wedging off in the inner tube

Faulted, fractured or overpressured formation and overdrilled core commonly become wedged inside the inner tube as a run is being drilled. This is termed ‘wedging off’ and necessitates a short run. Split liners and triple tubes are designed to help overcome this problem.

Poor quality of core

Overdrilled core occurs where the base of the cut core falls from the core lifter and gets redrilled at the start of the next run. A sudden change in core diameter will occur when a worn out bit is replaced or where there was a sudden change in pressure on the bit. Corkscrewed core of variable diameter is a sign of excessive bit pressure. Breaking in a new face-set bit too quickly will also result in inferior core.

CORE HANDLING PROCEDURES

Preparing core trays

To prepare trays for drillsite use, paint one long side and, as viewed facing this painted long side, the top left lip and bottom right lip, using two-pack white epoxy paint (Dulux Durebild STE or equivalent). Personal protection equipment must be used in accordance with the Materials Safety Data Sheet(s) for the particular brand of paint being used. When the paint is dry, write ‘Start’ on the painted top left lip of the core tray using a black paint marker (Artline 440XF or equivalent). The tray is now ready to receive core (see also Labelling core trays).

Lining core trays

The galvanising on metal core trays as used in NTGS core libraries is prone to abrasion by core during transit. Some sulfides (Figure 6) and evaporites, if present in the core, break down to produce acid and salt which attack the tray. Aside from the damage to the trays, this can result in significant contamination of the core, particularly by zinc. To minimise this, trays containing suspect core should be lined with plastic sheeting.
Figure 6. The good, the bad and the ugly. (a) Core interval from an intersection of sulfide ore that contains reactive pyrite, photographed immediately after drilling in 1988. (b) The same core interval after slabbing and storage, photographed in 1996. (c) Another example showing extreme breakdown of sulfides. The white material is gypsum, formed by the reaction of calcite with remobilised sulfate; this reaction also generates acid, which attacks the metal core tray, liberating Zn from the galvanised coating. The Zn is scavenged by the gypsum and the altered rock, so that geochemical analysis of this material is misleading.
Core catching

There are several methods whereby the driller can lay out the recovered core. In the petroleum industry, where every conventional core costs tens of thousands of dollars, each core run is laid out on a suitable rack (two lengths of pipe tied together over two 200 L drums are adequate). Normally the core is recovered in a disposable liner which is cut away. There is no possibility of getting pieces of core out of order or upside down.

Different practices are used during continuous coring in the minerals industry. If a split inner tube is used, the splits function similarly to a liner and provide a platform for the core to be examined and marked up. The core can then be slid directly into the core tray in the correct orientation.

Otherwise, when using a conventional barrel, normal practice is for the driller’s assistant to deposit the core directly into the trays while the tube is still suspended by the wireline. This is fraught with problems and is not recommended. Firstly, the core comes out of the tube bottom first, so the assistant has to judge how far into the empty tray to begin depositing the core. It is normally necessary to hammer the core lifter with a rubber mallet to free the lowermost piece of core protruding from the tube. This invariably flies off and has to be reoriented. Once freed, careful coordination is necessary to prevent the remaining core falling uncontrolled from the tube. The driller has to feed out the wireline from the winch and the assistant move the tube along the segments of the trays while keeping the lower end of the tube close enough to the tray to prevent core spilling out. If the core is recovered in long solid sticks, the assistant has to juggle the tube while using a hammer to break the core at the start of the next core box segment. Not only does this risk misorienting core but it is potentially dangerous (see Safety note). Most drillers have a tendency to overfill each segment of the tray, making it difficult to get the core out again.

▲ Preferably, when using a conventional barrel, onsite NTGS staff should ensure that core is deposited onto a suitable rack for marking up and is then transferred from there to the trays by a trained NTGS Technical Assistant. If – and only if – this is not feasible, core may be dumped directly into trays. Drillers should be closely supervised during this procedure for each and every run. (This is one of the reasons for NTGS to maintain a technically competent presence on site during drilling). Edge matching and marking-up of the trayed core will then need to be done, metre by metre.

Irrespective of barrel type, NTGS practice is to load core trays from the top left (‘Start’), so that contained core runs continuously from shallowest at top left to deepest at bottom right when viewed facing the painted long side of the tray.

Edge matching, washing and core orientation lines

A standard convention of marking the core longitudinally:

• Enables broken edges to be easily rematched (between and within runs), ensuring accurate recovery measurements
• Provides a datum for relative measurement of sedimentary features and metamorphic fabrics (eg relative directions of crossbeds, orientation of cleavage)
• Means that large sections of the core are already oriented when an absolute determination of orientation is undertaken (see Determining absolute core orientation and measuring true dip and strike)

▲ Determines that composite sampling of core is consistent relative to a longitudinal frame of reference
• Ensures that core can never be returned to the tray upside down

▲ The last piece of marked core from the previous run should be left on the core rack or near where the core is being examined in the boxes. Immediately after removal from the inner tube the new core should be laid out starting with the bottom piece from the previous run, so that all the ends are matched. The new core is then washed. A nylon brush may be used but cloth is to be avoided since lint fluoresces under UV light. Once dry, the core can be marked up. If there is no apparent fit between adjacent pieces and it is certain that pieces of core have been laid out in the correct order, two arrow-up chevrons are marked on either side of the cores that do not match. All core is to be marked with permanent continuous longitudinal orientation lines using the AAPG standard of black line on the right, red line on the left when core is viewed in correct orientation (but see Sealing oil-soaked core). Two marking pens taped together are used (Figure 7b). The tips of the marking pens will wear rapidly, so be sure to have adequate supplies. Chisel-tipped pens last longest.

Labelling driller’s blocks

▲ The drilling Contractor should label driller’s blocks with end-of-run metreage (Figure 7c), depth of change in core diameter, absolute orientation points and end-of-hole metreage. Be sure that it is clear in the contract as to who is supplying the blocks. Wooden blocks or plastic markers are acceptable. The latter are the disadvantages that they must be the exact width for the core tray and are easily dislodged by hosing the core or if open trays are left out in high winds. An approved permanent marking pen is to be used. Alternatively, inscribed aluminium tags can be stapled to the wooden block. All labels are to be oriented to

Safety note

On no account is anyone to hold their hand under the end of the inner tube or put their fingers up the end of the tube at any time. Safety glasses must be worn if the core is being broken. The inner tube of a triple tube system should be pumped out using liquid, never air. An appropriate bumper must be placed at the bottom of the tube to prevent core flying out under pressure and noone is to stand within 5 m of the tube while pumping is in progress.
read such that the top of the label is toward the top of the hole. Labels must be legible from eye height when the core tray is on the ground.

Dealing with lost core

▲ In the event of less than full recovery, drillers assume that core loss occurs at the top of the run and will put in blocks to indicate that. In reality, the lithology and edge matching will usually locate the actual interval of loss. If this is not possible, a better convention is to assume, at least initially, that any unrecovered core comes from the base of the interval cored. This is because with continuous coring, the core usually breaks some centimetres above the total depth to which it was cut. This will appear as core loss in one run, but the next run may recover it (ie the second run recovers more core than the actual length of the run drilled). If these few centimetres not recovered accumulate over successive runs and the accumulated total is then successfully picked up, it may completely fill the inner tube before the length of the inner tube has been drilled. After this, the apparent core losses can be rationalised. Be sure to check that driller’s depths on core blocks are not being ‘fudged’ to account for discrepancies in recovery between runs. The graphical geological log (see Describing core) should show the core loss as interpreted by the Geologist not the driller.

Measuring and depth labelling

▲ The full length of each core recovered is measured and recorded in the appropriate column on the drilling log. Depths are written on the core, between the red and black lines, every full metre. Labels may face so as to read uphole or from top right to bottom left when the labelled side of the core tray is facing the viewer (as in Figure 7c). Every half metre may be marked by either writing the depth or putting a tick mark between the red and black lines. Depth marks for 100% recovery should approximately line up along a line from upper left to lower right in a tray (Figure 7c). Top and bottom of intervals of substantial core loss should also be so labelled.

Core sample depths

▲ Sample depths are almost always given as driller’s depth to correspond to labels on core. This applies even if there is a discrepancy with wireline depths or if the original depth labels are subsequently proved wrong. Sidewall core points, which are picked from wireline logs, are the only exception.

In most onshore petroleum wells and larger mineral rigs on a platform, the Kelly bushing or slips are used as datum and depths may need to be so specified or corrected. For NTGS drilling, the depth datum will normally be the ground surface. The driller should be advised of this prior to commencement of drilling.

Arrow up

▲ Arrows on samples always indicate stratigraphic-up. In the case of overturned bedding this is not correct with respect to the present frame of reference but any ambiguity is resolved by adding an overturned dip and strike symbol. Arrows on core from underground drilling are not necessarily up-hole since such holes can drill up, rather than down, stratigraphy.

In contrast, drillers tend to use arrows to indicate a downhole direction on the start of core trays and driller’s blocks.

Labelling core trays

▲ NTGS uses a standard layout of labels in its core libraries and this is to be followed on site (Figure 7). Labelling of pre-painted core trays (see Preparing core trays) must be done using black paint markers: Artline 400XF or equivalent for sides of trays, and finer Artline 440XF or equivalent for lips of trays. Neat, legible labelling is essential.

Once a tray is filled and its contained core measured and marked up, label the painted top left lip (‘Start’) with the interval start depth and the diagonally opposite, painted bottom right lip with the interval finish depth, so that these are visible when the tray is photographed. The white-painted side of the tray is then permanently labelled with (from left to right) tray (box) number, location, drillhole name, and start and finish depth. Remember to leave a 75 mm blank space on the far left for rack location numbers to be added later in the Core Library, and to leave a gap along the top so that the labels will not be obscured if a lid is added to the tray. Example:

[75 mm blank space]   1 (tray number)   Golden Grove (location)   NTGS DD04GG01 (hole name)   100.0-105.5 m
(interval)

Determining absolute core orientation and measuring true dip and strike

▲ Even if the azimuth and declination of the hole are known (see ENGINEERING), and the long axis of the core marked with continuous red and black lines, the core is still unoriented relative to the hole. Rarely, a penetrative fabric in the core (such as cleavage) can be matched to nearby outcrop. More usually, this has to be done by using a special core lifter that scribes a line along the core and various downhole devices that use gravity to orient the core. These instruments
only work in holes with declinations of less than -75º (ie greater than 15º from vertical). The recommended device is the simplest. After the core tube has been pulled, a heavy metal spear is lowered down the hole on a wireline. The tip of the spear makes a percussion mark on the lowest point of the rock yet to be drilled (Figure 8). When the percussion-marked core is recovered in the next run, it can be oriented with the mark at the lowest point of that end of the core. In very hard rocks, a wax pencil can be added to the tip of the spear. Spear marks will not work if the core has broken in a jagged manner. Pencil and percussion marks can be easily destroyed if the ends of core rub together during transport. Ensure that an appropriately labelled driller’s block separates them and a permanent ink triangle should be marked on the outside of the core opposite the orientation mark. Repeated trials by the author have demonstrated that in a hole declined -70º (ie 20º from vertical), 90% of the spear marks fall within 5º either side of vertical from the core axis.

When both hole and core orientations are known, features within the core can be accurately oriented. This can be done mathematically using trigonometry, a Wulff stereonet, specialist software or by physically orienting a section of the core in special jig or a sandbox. **True dip and strike** should be calculated this way on site as part of routine core logging.

---

**Figure 7.** Correct labelling of core and core trays. (a) The start of the tray should be labelled in advance, with start depth recorded on white-painted corner of lip as indicated. (b) Core is marked with continuous red and black lines using two marking pens taped together; black line is always on the right when the core is stratigraphically oriented, and full and half metres are labelled between the red and black lines. (c) Depth labels on core in a tray with full core recovery should approximately line up diagonally from top left to bottom right (in the illustrated orientation). Note that the driller’s block reads from the same side as the core depth labels; the block and all other labels should be legible from eye height when the core tray is on the ground. A specimen label for the white-painted long side of the core tray is shown at bottom.
Figure 8. A percussion spear is used to make an orientation mark on core. Modified from unpublished work by RW Marjoribanks.
Recording maximum dip in core

▲ In situations other than those described above, it is important to routinely record the **maximum dip** in core. Note that some mineral companies term this the **acute bedding to core angle**. This is done by removing a section of bedded core from the tray and rotating it such that the maximum dip can be measured (ie the strike is at right angles to the line of sight) (**Figure 9**). Measurements should be made nominally every 5-6 m (ie once in each core tray) and at every significant change. In most cases, the maximum dip can be used as a proxy for true dip even if the strike is unknown. The maximum dip is used to estimate true vertical thickness of a formation.

Calculating true stratigraphic thickness and Stratigraphic Efficiency

▲ Ideally, a stratigraphic drillhole should penetrate bedding at right angles and the bedding thickness in core will be a true stratigraphic thickness. In reality, hole deviation, faults and folds complicate the situation. The true dip (or maximum dip as a proxy) and hole deviation are used to calculate true stratigraphic thickness. Stratigraphic Efficiency is the ratio of equivalent true stratigraphic thickness to metres drilled, expressed as a percentage. There are several freeware software packages that will calculate these. A graphic representation and manual calculation are shown below.

> **Example 1**

A vertical hole that has a true dip of 60º in the core will actually drill double the true stratigraphic thickness (**Figure 10**). This is a stratigraphic efficiency of only 50%.

Hole deviation (see **ENGINEERING**) introduces an extra complication. In this case, the true stratigraphic thickness of a formation is calculated as follows:

\[
T = AB \left( \sin a \times \cos b - \cos a \times \sin b \times \cos c \right)
\]

where:
- \(T\) = true thickness of formation
- \(a\) = declination of hole expressed as the angle from vertical
- \(b\) = true dip of formation
- \(c\) = angle between direction of formation dip and direction of hole
- \(AB\) = thickness of intersection in hole

> **Example 2**

<table>
<thead>
<tr>
<th>Target formation</th>
<th>True dip from horizontal = 60º</th>
</tr>
</thead>
<tbody>
<tr>
<td>Dip direction</td>
<td>130º</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Hole</th>
<th>Declination (deviation from vertical) = 10º</th>
</tr>
</thead>
<tbody>
<tr>
<td>Dip direction</td>
<td>110º</td>
</tr>
</tbody>
</table>

Thickness intersected in hole = 100.00 m

\[
c = 130º - 110º = 20º
\]

\[
T = 100 \left( \sin 10 \times \cos 60 - \cos 10 \times \sin 60 \times \cos 20 \right)
\]

\[
= 100 \left( 0.1736 \times 0.50 - 0.985 \times 0.866 \times -0.940 \right)
\]

\[
= 100 \left( 0.0868 + 0.8016 \right)
\]

\[
= 88.84 \text{ m}
\]

Stratigraphic Efficiency is 88.84 m of true thickness for 100 m drilled, so 89%.

Photographing core

▲ All core **must** be photographed on site. This is recommended practice under formal state and federal exploration guidelines where such legislation exists. Such photographs provide a useful record of the pristine core before transport and deterioration due to mineral breakdown, natural fracturing and clay expansion (**Figure 6**). The photographs are invaluable should a core tray be accidentally dropped and have to be repacked. It also prevents deliberate tampering. Usual practice is to photograph core trays in lots of two with a blackboard or similar showing the hole name and depths. The core is normally photographed wet in natural light, avoiding any distracting shadows. A standard colour scale is to be included. To enable the trays to be framed with minimum distortion by parallax, a zoom lens is recommended and the photographer should stand on a sturdy support. For best results, a frame can be constructed to support the camera at a constant focal length and an infill flash and cable release incorporated.
Describing core

Core logging is normally done on site by filling in a pro-forma core description sheet (Appendix 4) by hand at a vertical scale appropriate to the level of detail (normally 1:100 in stratigraphic holes). This form can be modified to include details specific to the project. This will probably be the most comprehensive record of the entire core ever undertaken by NTGS. It has to be legible for inclusion in the NTGS Technical Note and dark enough to photocopy. It will be simplified for later entry into geological software for use in the final Drillhole Completion Report.

Be objective when logging core; it is easy to allow personal preference for a particular geological discipline to bias the description. Petrology, structural geology, economic geology and palaeontology are all important. Remember, we are logging facts, and where interpretation is given, it should be so noted. Core is normally described in natural light and wet. However, the internal features in some carbonates and shales become less obvious when the core is wet. There are fewer tricks and pitfalls when describing core as opposed to cuttings, but many a geologist has logged ‘conglomerate’ or ‘massive limestone’ when a cement plug, with or without cavings, has been drilled. Phenolphthalein stains cement purple.

For examination, individual core pieces should be removed from the tray and all sides examined. Look at the ends of core! The author knows of a supposedly Proterozoic type section core which had been logged in centimetre detail on site and examined by dozens of other geologists in the Core Library, all of whom missed trilobite fossils only visible on the ends of the core. Core will break along natural fractures and veins. These surfaces should be checked for epigenetic mineralisation.

Packing and palletising core trays and their weight

NTGS will provide special framed steel pallets designed to carry core trays. Once packed with trays and fully assembled, these should be strapped at least twice in both directions. Where these special pallets are not available, Figure 11 shows how to pack core trays on a pallet. Wooden pallets should normally be used in this case. Again, packed pallets should be strapped at least twice in both directions. Note that the labels are visible and that there are only two trays (of HQ size) per layer. In either case, it is considered standard practice for every tray to have its own lid affixed.

Use Table 4 to estimate weights of core. If the 31 trays shown in Figure 11 were full of HQ sandstone core, they would weigh 1.2 tonnes. About 220 m of NQ dolostone core, equating to 32 trays, weighs 1 tonne; 123 m of HQ weighs 1 tonne. A single 3 m tray of PQ lead-zinc ore is almost 60 kg, with only 17 trays per 1 tonne pallet.

Slabbing core and composite core sampling

Core sampled for multielement geochemistry should be quartered lengthways using a diamond saw, not mechanically split or edge ground. Properly done, this is not a trivial exercise. Samples have to be consistently oriented with respect to the red and black core marks such that all the quarter cores should be able to join end to end. Ensure that core with depth labels and longitudinal lines is returned to tray. Composite sample intervals should not span intervals of lost core and intervals should be adjusted according to core recovery. For example, including intervals of 100% and 70% recovery in the same composite is contaminating good sample with bad.

HYDROCARBON DESCRIPTION

There is an old saying that ‘oil is where you find it’. All stratigraphic holes should therefore be monitored for the possibility of hydrocarbons, irrespective of whether they are in a known petroleum basin or not. There are several mineral exploration
Figure 10. A vertical hole that intersects bedding with a true dip of 60º will actually drill double the true stratigraphic thickness. This is a Stratigraphic Efficiency of only 50%.

Figure 11. NTGS has special frames for transporting pallets of core. If these are not available, the pallet should be packed as shown. Note that the labels face out and there are only two trays per layer. The pallet needs to be strapped twice in both directions.

Table 4. Weights in kilograms per linear metre for each common core diameter and lithology. Other core diameters can be calculated using proportions derived from the core diameters listed in Table 2. BHT = Broken Hill-type.

<table>
<thead>
<tr>
<th>Material</th>
<th>BQ</th>
<th>NQ</th>
<th>HQ</th>
<th>PQ</th>
</tr>
</thead>
<tbody>
<tr>
<td>clay</td>
<td>1.945</td>
<td>3.308</td>
<td>5.887</td>
<td>10.549</td>
</tr>
<tr>
<td>limestone</td>
<td>2.813</td>
<td>4.784</td>
<td>8.515</td>
<td>15.257</td>
</tr>
<tr>
<td>dolostone</td>
<td>2.677</td>
<td>4.553</td>
<td>8.103</td>
<td>14.519</td>
</tr>
<tr>
<td>sandstone</td>
<td>2.531</td>
<td>4.304</td>
<td>7.660</td>
<td>13.725</td>
</tr>
<tr>
<td>quartzite</td>
<td>2.761</td>
<td>4.696</td>
<td>8.356</td>
<td>14.973</td>
</tr>
<tr>
<td>gneiss</td>
<td>2.813</td>
<td>4.784</td>
<td>8.515</td>
<td>15.257</td>
</tr>
<tr>
<td>slate</td>
<td>2.928</td>
<td>4.980</td>
<td>8.863</td>
<td>15.881</td>
</tr>
<tr>
<td>basalt</td>
<td>3.137</td>
<td>5.336</td>
<td>9.496</td>
<td>17.015</td>
</tr>
<tr>
<td>granite</td>
<td>2.845</td>
<td>4.838</td>
<td>8.610</td>
<td>15.427</td>
</tr>
<tr>
<td>iron ore</td>
<td>4.497</td>
<td>7.648</td>
<td>13.611</td>
<td>24.388</td>
</tr>
<tr>
<td>porphyry copper ore</td>
<td>2.719</td>
<td>4.624</td>
<td>8.230</td>
<td>14.746</td>
</tr>
<tr>
<td>BHT lead-zinc ore</td>
<td>3.660</td>
<td>6.225</td>
<td>11.079</td>
<td>19.851</td>
</tr>
</tbody>
</table>

holes in our Core Library that have intersected oil bleeds without them being recognised at the time. NTGS intersected oil bleeds in Victoria Basin despite this not previously being recognised as a petroleum basin. Never disregard a potential show because of the host lithology. There are commercial oil reservoirs in fractured metamorphic and igneous rocks!

Signs of gas in core

Core of a gas-filled reservoir usually has a noticeable odour; there may a core flash (igniting gas being liberated from the core), or gas may bubble from drilling fluid or water surrounding the core (most obvious when the core is removed from the inner tube but can persist surprisingly long – up to several days). Most gas reservoirs will also have a bluish-white fluorescence under UV light.

Safety note

The driller must be immediately notified of any signs of oil or gas as this indicates a potentially dangerous situation on a rig without spark-arrestors or a blowout preventer.

Oil shows in core

▲ NTGS drilling is most likely to detect oil shows in core rather than cuttings. The following section explains how oil shows are to be described and how the core is to be treated. The driller should be informed immediately that oil is detected.
Oil bleeds

Most oil bleeds are obvious to the naked eye and have a distinctive odour. In natural light, oil can range in colour from opaque very dark brown to colourless. Figure 12 shows typical oil bleeds from Cambrian rocks. Light oil is usually first detected in the drilling fluid surrounding the core by iridescence and surface tension affects. In tight reservoirs, even light oil bleeds may not appear until minutes or hours after the drilling fluid is wiped off. Such phenomena should be fully described, such as ‘straw coloured live oil bleeding from hairline fracture at 456.8 m; first appeared 15 minutes after core removed from inner tube’. Very light oil may dissipate even before the core is removed from the inner tube. Heavy oil is less mobile.

Sealing oil-soaked core

Core with significant live oil must be sealed to help prevent loss of volatiles and biodegradation. This involves wrapping the section of core in aluminium foil, several layers of plastic cling film and a final wrapping of aluminium foil held in place with masking tape. Do not write directly on the core with marker pens – this may compromise any subsequent organic geochemical analyses. The masking tape is marked with the ubiquitous red and black lines and labelled with drillhole and depth. On a petroleum rig, these samples are than sealed by dipping in molten wax. Samples that contain live oil should be stored in a cool place.

Fluorescence

Benzol rings in a hydrocarbon cause it to fluoresce under UV light and a suitable lamp should be on site for all potentially prospective holes. Three types of UV lights designed for use with hydrocarbons are available: a high-intensity hand-held UV light, a box-mounted fluoroscope (also known as a viewing cabinet) and a corvascope (combination stereoscopic zoom microscope and UV light). These operate in the range of 350-400 nm, nominally 365 nm, ideally with an intensity of ≥850 uw/cm². Hand-held UV lamps designed for mineral prospecting come in various combinations of short (254 nm = 2537 Angstrom), medium (302 nm) and long (365 nm) wavelengths. All will make hydrocarbons fluoresce, but the longest wavelength is comparable with those designed for petroleum exploration. Most mineral prospecting lamps are of such low intensity that all other background illumination has to be excluded. When using this method to examine core, it may be necessary to work at night or under a blanket. Alternatively, a ‘darkroom’ viewing cabinet can be used. Areas of fluorescence are marked with chalk (not a solvent-based marking pen) so that they can be relocated under natural light.

Colours of hydrocarbon fluorescence include green, gold, orange, yellow, blue, blue-white or white. This colour range broadly corresponds to heavy through to light oils. Oils of 35-45 API gravity fluoresce white to blue-white. Intensity is described as bright, dull, pale or faint. Figure 13 shows typical oil-stained core in UV light. Very heavy biodegraded oil may not fluoresce in its natural state, but will after solvent extraction (see Cut and solvent tests). Very light condensates may fluoresce beyond the human visible spectrum. Be wary of mineral fluorescence; calcite and dolomite can both fluoresce blue-white, brown or red. Most greases and many other contaminants fluorescence (see Contamination).

Safety note

UV light will harm your eyes. Shorter wavelengths are the more dangerous. Do not look directly into a source of UV light and avoid working for more than 15 minutes at a time with reflected UV light. Normal eye glasses or transparent safety glasses will reduce UV exposure.

Cut and solvent tests

A ‘crush cut’ is the solvent extraction of hydrocarbons from a crushed rock sample. Fluorescing cuttings or core chips are hand picked and placed in a white porcelain dish (spot dish) and a few drops of solvent added. Any hydrocarbons present will dissolve and sometimes oil may be seen moving into the solvent even in natural light. This is termed a ‘streaming cut’. This phenomenon is best observed under UV light. In less than a minute, the cut will impart a fluorescence to the solvent. As the solvent evaporates, a residual ring of fluorescence is left in the spot dish. The solvent is also added to an identical spot dish without any cuttings. This blind test, which should of course not fluoresce, checks for contamination in the solvent. It is also prudent to set up standards of all the possible contaminants on site.

Safety note

Various solvents have been used for rig-site hydrocarbon detection. Those recommended in older manuals have been phased out because of health or environmental concerns. Toluene, a common ingredient in petrol (up to 13% toluene), glue and paint thinners, is currently the preferred choice. Toluene is variously known as C₇H₈, methylbenzene, methylbenzol, Methacide, phenylmethane, Toluol and Antisal 1A. Its international CAS Registry Number is 108-88-3. Absorption through the skin or exposure to its vapour is potentially dangerous. It can damage the nervous system and cause an irregular heartbeat. Workers with a history of asthma induced by solvent exposure should be warned. You can smell toluene when it reaches 290 ppb and it is considered safe to work in levels up to 100 ppm. The Occupational Safety and Health Administration has set a limit of 200 ppm of workplace air (690 times the detectable limit in humans). Toluene is heavier than air. Both liquid and vapour are flammable. Contact with strong oxidisers may cause fire or explosion. The liquid can accumulate static charge by flow or agitation. It should not be carried on aircraft. Proprietary detergent-based substitutes (eg Sample Clean) are also available but can be difficult to source.

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Figure 12. Examples of oil and bitumen in core. Scale bar = 1 cm.
Acid bounce test

Oil shows in a carbonate rock can be detected by immersing a suspect chip in dilute HCl. The CO₂ generated and the surface tension of any oil will cause iridescent bubbles that buoy up the chip. As the bubbles burst at the surface the chip will sink again. This test is overly sensitive; even slightly calcareous carbonaceous shale or drilling fluid contaminants may give a positive result.

Hot water extraction

Tipping very hot water (>75°C) over a suspected oil sample in core will extract some oil. After the resulting suspension has separated, a thin surface film of oil should fluoresce under UV light.

Standardised oil show description

NTGS uses a modification of the Wyman & Castano (1974) method of standardised oil show description. This method was developed for cuttings (chips) on a conventional petroleum well; but it also works with whole core and small chips broken from it.

A description form (Appendix 5) must be completed on site. With core, the interval being described must be precisely stipulated. The following discussion will aid in the standardised show description.

Morphology

A textual description of the distribution of hydrocarbon indicators on a rock surface. Examples: irregular stain around vug, bleed from fracture, oil associated with bitumen on stylolite.

Mobility

The rate at which fluid emerges from the rock sample. Examples: immobile oil, live show bleeding when core was recovered and persisting for several hours.
**Percentage stain**  
What percentage of the fresh surface is stained when viewed in normal light?

<table>
<thead>
<tr>
<th>% Stain</th>
<th>Code</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>0-40</td>
<td>1</td>
</tr>
<tr>
<td>40-85</td>
<td>2</td>
</tr>
<tr>
<td>85-100</td>
<td>3</td>
</tr>
</tbody>
</table>

**Hydrocarbon odour**  
How strong is the odour on the fresh surface? Strong would be the intensity of smelling the same amount of refined oil.

<table>
<thead>
<tr>
<th>Odour</th>
<th>Code</th>
</tr>
</thead>
<tbody>
<tr>
<td>none</td>
<td>0</td>
</tr>
<tr>
<td>slight</td>
<td>1</td>
</tr>
<tr>
<td>fair</td>
<td>2</td>
</tr>
<tr>
<td>strong</td>
<td>3</td>
</tr>
</tbody>
</table>

**Natural fluorescence**  
Note the amount, intensity and colour of hydrocarbon fluorescence under UV light. The percent fluorescence should be similar to the percent staining recorded above. If fluorescence is restricted to fractures, vugs or mineral type, this should be noted.

<table>
<thead>
<tr>
<th>% Fluorescence</th>
<th>Code</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>0-40</td>
<td>1</td>
</tr>
<tr>
<td>40-85</td>
<td>2</td>
</tr>
<tr>
<td>85-100</td>
<td>3</td>
</tr>
</tbody>
</table>

The intensity of the fluorescence is qualitatively estimated. A benchmark reference sample should be retained.

<table>
<thead>
<tr>
<th>Intensity of fluorescence</th>
<th>Code</th>
</tr>
</thead>
<tbody>
<tr>
<td>nil</td>
<td>0</td>
</tr>
<tr>
<td>weak</td>
<td>1</td>
</tr>
<tr>
<td>fair</td>
<td>2</td>
</tr>
<tr>
<td>strong</td>
<td>3</td>
</tr>
</tbody>
</table>

The colour of the natural oil fluorescence is rated as shown below. The colour approximates to its specific gravity.

<table>
<thead>
<tr>
<th>Colour of natural fluorescence</th>
<th>Code</th>
</tr>
</thead>
<tbody>
<tr>
<td>none</td>
<td>0</td>
</tr>
<tr>
<td>brown</td>
<td>1</td>
</tr>
<tr>
<td>orange, gold, yellow</td>
<td>2</td>
</tr>
<tr>
<td>pale yellow, bluish-white</td>
<td>3</td>
</tr>
</tbody>
</table>

**Colour of cut**  
Place equal volumes of chips and solvent in a non-fluorescing glass test tube. Shake and allow to settle before observing the colour of the solvent in comparison to the chart in Figure 14.

<table>
<thead>
<tr>
<th>Colour of cut</th>
<th>Code</th>
</tr>
</thead>
<tbody>
<tr>
<td>colourless</td>
<td>0</td>
</tr>
<tr>
<td>pale straw</td>
<td>0.5</td>
</tr>
<tr>
<td>straw</td>
<td>1</td>
</tr>
<tr>
<td>dark straw</td>
<td>1.5</td>
</tr>
<tr>
<td>light amber</td>
<td>2</td>
</tr>
<tr>
<td>amber</td>
<td>2.5</td>
</tr>
<tr>
<td>dark brown</td>
<td>3</td>
</tr>
<tr>
<td>very dark brown to opaque</td>
<td>3+</td>
</tr>
</tbody>
</table>
**Show number**

Wyman & Castano (1974) originally proposed that the mathematical averages of the codes for each show (their show number) could be compared as a relative ranking.

**Spurious hydrocarbon indications**

It is easy to mistake other phenomena for indications of hydrocarbons. The NTGS site Representative must be aware of the possibility of false hydrocarbon indications.

**Drill gas**

Drill gas is liberated from rock (generally a rich source rock) as it is crushed during drilling. The low circulating volume of a cored slimhole means that quantities of gas can be sufficient to result in a quite rapid order of magnitude increase above background. A small increase in drilling fluid relative density (RD) while drilling will not decrease drill gas, but if the hole is circulated without drilling ahead, drill gas will decrease rapidly and may disappear entirely. That is, drill gas will not flow from the drillhole.

Numerous slimhole well completion reports have credited drill gas as a show, but it should never be reported as such. As Whittaker (1987) has said: gas flows from a well; it is not mined.

The situation can be further complicated since source rock responsible for drill gas also commonly contains unmigrated oil and the drill gas will occur in association with heavier hydrocarbons that are genuine shows.

**Trip gas and connection gas**

When the circulation pump is stopped for any reason such as trips or connections, a greater amount of gas can flow into the drilling fluid. Upon recommencement of circulation, this gas shows up at the surface as an increase. If such surges can be lagged back to the resumption of circulation, trip gas or connection gas should be suspected. Such increases should be documented but are not gas shows as such. Clear indications of connection gas or an increasing trend in trip gas are a sign of increasing formation pressure and therefore of concern.

---

**Cut fluorescence**

The fluorescence of the cut in the test tube is rated as below. It should reflect the code used above.

<table>
<thead>
<tr>
<th>Cut fluorescence</th>
<th>Code</th>
</tr>
</thead>
<tbody>
<tr>
<td>none</td>
<td>0</td>
</tr>
<tr>
<td>slight (almost transparent when viewed through tube)</td>
<td>1</td>
</tr>
<tr>
<td>medium (translucent when viewed through tube)</td>
<td>2</td>
</tr>
<tr>
<td>strong (opaque when viewed through tube)</td>
<td>3</td>
</tr>
</tbody>
</table>

**Figure 14.** Natural colour of oil and description code.
**Biogenic methane**

A false gas show can occur when methane-bearing groundwater is intersected. As discussed separately in **DRILLING PROBLEMS**, quantities of gas may be sufficient to be a safety concern. A few northern Queensland waterbores have considerable biologically generated flammable headspace gas. Several people have lost a bet with a local publican (and the hair off their arm) when they ignite the gas bubbling from a bore used for the pub ablution block. Since such gas is biogenic, not thermogenic, it is not strictly a gas show in the sense used by petroleum explorers. Isotopes can be used to distinguish the two types of gas.

**Bitumen**

Bitumen, loosely any solid or semisolid hydrocarbon, is arguably a genuine hydrocarbon show and should be recorded. Bitumen usually has nil to moderate-intensity dull brown (commonly spotted) natural fluorescence. It gives nil to moderate streaming white to yellow white cut fluorescence.

**Carbonaceous material**

Carbonaceous matter may have faint natural fluorescence. It will not yield a crush cut with toluene. However, depending on the type of organic matter, some superseded solvents such as acetone and carbon tetrachloride will give misleadingly intense cut fluorescence. These are not shows but may be reported as such in well completion reports, particularly those from the 1960s and early 1970s.

**Stylocumulate**

Carbonate rocks commonly contain organic-rich stylocumulate. Comments similar to carbonaceous material (above) apply. In cuttings, stylocumulate can be mistaken for carbonaceous shale. Stylocumulate can be misleading since it can have mineral fluorescence due to secondary minerals and the organic matter itself may have a faint natural fluorescence. Furthermore, zones of stylocumulate commonly acted as migration pathways and may contain shows of residual hydrocarbons.

**Contamination**

Contamination is a common problem. There are numerous drilling fluid additives, lubricants, corrosion inhibitors and other substances, both downhole and around a rig, which produce spurious hydrocarbon indications. Most insect repellents and sunscreens will contaminate samples. Rod thread grease (pipe dope or DAFF) and core barrel and bit lubricants can be a serious problem. Some hammer oils are especially bad. Drillers may treat tight hole conditions by copious use of drilling lubricant and by greasing the outside of the drillstring. In recent NTGS cored holes, this resulted in averages of 0.13 kg/m of grease and 1.0 L/m of bit lubricant. This is excessive contamination and would have made the onsite detection of any formation hydrocarbons impossible. Historically, diesel has also been added to the drilling fluid to combat various hole problems. When suspended in drilling fluid, diesel can scavenge other organic materials from the system and serious contamination will result. Older organic-based mud additives and any organic-based lost circulation material can become part of a biological cocktail as the drilling fluid ferments and methane is liberated. Bactericide treatment will be necessary. Modern synthetic polymer drilling fluids are less prone to these problems but they do contain C₁₇–C₂₄ hydrocarbons, which are used as biomarkers in oil/source rock matching.

▲ Any possible contamination should be thoroughly documented to avoid later spurious assays. If any contamination problem is suspected, all potential contaminants should be sampled and submitted to the lab doing the organic geochemistry. Hands should be washed before handling core. Check the offside getting the core out of the inner tube! You can almost guarantee that the piece of core he/she has gotten from the lifter will have his/her greasy finger marks on it. If a rack is used to lay out core it should be cleaned regularly. Washing core with a rag will leave fluorescent lint behind and the rag frequently becomes contaminated. The solvent being used to undertake onsite hydrocarbon studies should itself be regularly checked for contamination. A final word of warning: using detergent to clean equipment is also inadvisable, as most detergents fluoresce! Use plain water.

**COLLECTION AND ASSAY OF NON-CORE SAMPLES**

Most non-core lithological samples from NTGS drilling will be from precollars and waterbores. Geochemical samples from RC or RAB, as used for mineral exploration, would also fit into this category. Fluid samples are also important and should not be overlooked.

**Rotary open hole samples**

**Sample collection and labelling**

▲ Open hole samples should be collected at 1 m or 2 m intervals. These samples are normally laid out on the ground by the driller’s assistant in rows corresponding to 10 m intervals.

The large volume of sample (a wheel barrow load per 2 m) from a percussion hole is normally put into large transparent plastic sample bags by the drillers. The NTGS site Representative will subsample this material using either a sample splitter or a hollow spear made from PVC pipe. Subsamples are put into cloth bags and the remainder discarded on site. It is important that the subsample is representative and uncontaminated (see **Sample contamination**). Mud-drilled samples should be washed in a sieve to remove drilling fluid contamination. Cloth bags are used and wet samples should be allowed to dry in the bags.

Individual cloth bags should always be labelled with the hole number and it should be clear what the composite interval is.
Tedious as it is, best practice is to give from and to depths and drillhole name on each and every bag. Cloth bags are put into a polyweave sack for transport. The necks of the polyweave sacks should be fastened with a special wire-twisting tool. On no account should the drillhole name appear only on the polyweave sack. This avoids the problem of mixing of samples from different holes when the cloth bags are removed from the polyweave sack.

NTGS normally provides all bags and ties.

Sample contamination

Some mineral exploration companies are surprisingly casual in the way they treat samples that are expected to be representative at ppm or ppb levels.

▲ Cloth bags containing samples for trace metal assay should not be transported or stored in contact with metal surfaces. There is no point in assaying trace levels of metal in the contents of a sample bag that is rusted to the truck tray floor or in contact with a corroded zinc-plated metal sample drum.

Some mineral exploration companies used plastic sample bags that were stapled shut. However, it was found that metal staples were inadvertently included in the sample, either on site or when the bags were opened in the laboratory, and this resulted in spurious metal assays. In other cases, a zinc anomaly was traced to a cloth sample bag that someone had used to wipe up spilt sunscreen. High lithium levels were found to have come from grease on a sample bag. Even something as seemingly benign as a few stray leaves can, depending on the sample preparation and analytical technique, seriously contaminate a sample. Members of the pea family, for example, contain percentage levels of zinc. Tungsten analyses may be compromised by fragments from the drill bit (most contain tungsten carbide) or if a tungsten mill is used in the laboratory. Diamonds can easily be plucked from a diamond drill bit, especially if it is face-set.

Water samples

Water samples are important for groundwater studies and for the determination of resistivity of water (Rw) for wireline log calibration. Duplicate samples are normally collected in 1 L screw-top plastic bottles. Glass bottles are required for trace hydrocarbon analysis. Water samples have a limited shelf life and should be analysed as soon as possible after collection. Basic measurements such as temperature, conductivity and pH should be made on site.

▲ Before sample collection, all sample bottles should be rinsed with dilute HCl and then repeatedly with the water to be sampled. Samples should be kept cool as high ambient temperatures can influence subsequent hardness measurements. Bottles should be permanently labelled with drillhole, depth, date and sampler’s name. Air drilling is the best way to detect groundwater. Water from the aquifer should be airlifted for sufficient time to enable an uncontaminated sample. If the only sample available is still contaminated, allow it to settle before decanting into the sample container. During coring, it may not be possible to detect minor groundwater influx and an aquifer may even be a lost circulation zone. It may not be practical to collect water samples during continuous coring.

Oil samples

▲ Rinse the sample container repeatedly with the oil to be sampled. If sufficient is available, collect 2 L in glass bottles or tins. McCartney bottles (screw-top bacterial culture bottles with vinyl, not rubber, seals) can be used for smaller quantities. Containers should be permanently labelled with drillhole, depth, date and sampler’s name.

ENGINEERING

The objective of any drillhole is to penetrate and adequately sample those formations required without risk and to be able to wireline log the hole if so required. It is the Contractor’s responsibility to drill the hole to engineering specifications stipulated in the contract and detailed drillhole plan.

▲ The NTGS Representative is expected to monitor the Contractor and ensure that these objectives are met.

Engineering information in daily drilling reports

▲ The NTGS Representative must ensure that the driller’s daily reports contain sufficient engineering information. This includes details of casing, drilling fluids and hole trajectory. These are described individually below.

Casing

Casing is a hole liner used to curtain off unconsolidated near-surface material, to isolate other formations that cause drilling difficulties, or to separate formations with different water chemistry or significantly different pressure gradients. On a petroleum well or waterbore it also forms the conduit for delivery and supports the surface production equipment. Casing can be suspended from the surface, hung from an outer casing string, sat on the hole bottom, surface clamped, grouted or cemented in place. This will depend on the reasons the casing was run, the depth and pressure requirements.
A conductor is surface casing used to contain unconsolidated material. On holes deeper than about 150 m this is followed by other strings of casing of decreasing diameter nested inside each other. Once casing is run, a smaller-diameter hole is necessary to continue drilling. This change in diameter is referred to as stepping down.

PVC pipe with solvent-cemented belled ends and, less commonly, fibreglass or threaded PVC casing are all used at relatively shallow depths. Generally, steel casing is required elsewhere.

PVC comes in various numbered classes depending on the diameter and wall thickness (Table 5). All such pipe used downhole must comply with AS1477. Heavier duty is indicated by a higher class number. Class 9 can be used with care in shallow situations such as a ≤ 6 m conductor, but Class 12 is preferable elsewhere. Only Type P primer and solvent is to be used (AS3879). PVC casing joins can be secured with self-tapping screws while waiting for the solvent cement to cure. Care must be taken to ensure that the screws do not protrude internally and only stainless steel screws are permissible in waterbore casing. Normally, all PVC casing used in stratigraphic and exploration drilling is disposable and, subject to abandonment procedures (see COMPLETION AND ABANDONMENT), is not retrieved. However, special threaded PVC casing may be run in multihole downhole geophysical surveys so it can be reused in the next hole. Always carry extra PVC pipe to allow for damage in transit.

There are many different types of steel casing appropriate to various applications. Butt-welded steel casing, compliant with AS1396, 1579 and 1836, is used in waterbores, but is non-retrievable and too labour intensive for stratigraphic drilling. Cored mineral exploration and shallow stratigraphic holes are typically cased with retrievable threaded steel casing (Table 6) that comes in 3 m lengths, or by using drill rods without a bit, or both (see Engineering design of typical cored stratigraphic drillholes). Cored holes usually have proportionately more casing than conventional holes. Aside from the engineering aspects, casing points depend on the rig capacity in each diameter and costs per metre.

A rule of thumb for a typical cored stratigraphic hole in an unknown area is that after the conductor, casing should be run in intervals of thirds of the proposed total depth (PTD).

Threaded heat-treated steel casing is used in oilfield and deep mineral holes where pressure-rating is a major issue in hole engineering. This casing should only be transported with thread protectors and may not be cut or welded. Each section of casing has a unique length and will be branded with this and API specifications including various grade designations. Pressure-rated casing is most commonly referred to using a code in which a letter refers to the tensile strength (eg H indicates 60 000 psi; J, 75 000 psi and N, 100 000 psi). A number indicates the minimum yield strength. For example, Grade J55 and K55 casing both have a yield strength of 55 000 psi, whereas N80 designates 80 000 psi yield strength. There are numerous thread types, given three-letter codes (eg EUE, LTC, BTC). The casing is also designated by its weight in lb/ft. In contrast to non-oilfield applications, drift ID (ie actual ID as measured by prescribed tools) rather than nominal ID is commonly specified. Adequate casing and a screen will be required if a hole is to be completed as a waterbore. If converting a slimhole to a waterbore, bear in mind that casing used in waterbores less than 50 m deep must be a minimum of 100 mm diameter; deeper bores require a minimum diameter of 125 mm.

NTGS should ensure that the driller is carrying adequate casing for both waterbores and stratigraphic holes and that holes are cased according to best practice as described above. All casing used in a drillhole must be described in the Daily Operations Report and recorded in the Drillhole Completion Report. This should clearly indicate casing specifications, shoe depth and which casing was retrieved and which was abandoned.

<table>
<thead>
<tr>
<th>Nominal size (mm)</th>
<th>Class</th>
<th>ID (mm)</th>
<th>OD (mm)</th>
<th>OD bell</th>
</tr>
</thead>
<tbody>
<tr>
<td>100</td>
<td>9</td>
<td>104.6</td>
<td>114.3</td>
<td>124</td>
</tr>
<tr>
<td></td>
<td>12</td>
<td>101.7</td>
<td>114.3</td>
<td>125</td>
</tr>
<tr>
<td>125</td>
<td>9</td>
<td>128.4</td>
<td>140.2</td>
<td>152</td>
</tr>
<tr>
<td></td>
<td>12</td>
<td>124.9</td>
<td>140.2</td>
<td>155</td>
</tr>
<tr>
<td>150</td>
<td>9</td>
<td>146.85</td>
<td>160.25</td>
<td>170</td>
</tr>
<tr>
<td></td>
<td>12</td>
<td>142.65</td>
<td>160.25</td>
<td>177</td>
</tr>
<tr>
<td></td>
<td>18</td>
<td>134.65</td>
<td>160.25</td>
<td>188</td>
</tr>
<tr>
<td>155</td>
<td>9</td>
<td>154.45</td>
<td>168.25</td>
<td>184</td>
</tr>
<tr>
<td></td>
<td>12</td>
<td>151.65</td>
<td>168.25</td>
<td>187</td>
</tr>
<tr>
<td>175</td>
<td>9</td>
<td>185.15</td>
<td>200.25</td>
<td>222</td>
</tr>
<tr>
<td>177</td>
<td>12</td>
<td>158.3</td>
<td>177.0</td>
<td>195</td>
</tr>
<tr>
<td>200</td>
<td>6</td>
<td>213.8</td>
<td>225.5</td>
<td>236</td>
</tr>
<tr>
<td></td>
<td>9</td>
<td>208.5</td>
<td>225.3</td>
<td>243</td>
</tr>
<tr>
<td></td>
<td>12</td>
<td>203.1</td>
<td>225.3</td>
<td>248</td>
</tr>
<tr>
<td>225</td>
<td>12</td>
<td>225.75</td>
<td>250.37</td>
<td>275</td>
</tr>
<tr>
<td>250</td>
<td>12</td>
<td>252.9</td>
<td>280.4</td>
<td>310</td>
</tr>
<tr>
<td>300</td>
<td>12</td>
<td>284.45</td>
<td>315.46</td>
<td>345</td>
</tr>
</tbody>
</table>

Table 5. Specifications of commonly used solvent weld-join PVC casing. ID = inner diameter; OD = outer diameter. Data from Sinclair Plastics.
Table 6. Specifications of common steel casing. ID = inner diameter; OD = outer diameter.

<table>
<thead>
<tr>
<th>Steel casing size</th>
<th>ID (mm / inch)</th>
<th>OD (mm / inch)</th>
</tr>
</thead>
<tbody>
<tr>
<td>AW</td>
<td>48.4</td>
<td>57.1</td>
</tr>
<tr>
<td>AX</td>
<td>50.8</td>
<td>57.1</td>
</tr>
<tr>
<td>BW</td>
<td>60.3</td>
<td>73.0</td>
</tr>
<tr>
<td>BX</td>
<td>62.7</td>
<td>73.0</td>
</tr>
<tr>
<td>EW</td>
<td>38.1 / 1.5</td>
<td>46.0</td>
</tr>
<tr>
<td>EX</td>
<td>41.3</td>
<td>46.4</td>
</tr>
<tr>
<td>H</td>
<td>100.0</td>
<td>114.3</td>
</tr>
<tr>
<td>HW</td>
<td>101.6 / 4.0</td>
<td>114.3</td>
</tr>
<tr>
<td>N</td>
<td>77.8</td>
<td>88.9</td>
</tr>
<tr>
<td>NW</td>
<td>76.2 / 3.0</td>
<td>88.9</td>
</tr>
<tr>
<td>PF</td>
<td>101.6</td>
<td>114.3</td>
</tr>
<tr>
<td>PW</td>
<td>127.0 / 5.0</td>
<td>139.7</td>
</tr>
<tr>
<td>RW</td>
<td>30.1</td>
<td>36.5</td>
</tr>
<tr>
<td>SW</td>
<td>152.4 / 6.0</td>
<td>168.2</td>
</tr>
<tr>
<td>XRT</td>
<td>28.8</td>
<td>30.2</td>
</tr>
<tr>
<td>API 5.5” K55 LTC 15.5 lb/ft</td>
<td>125.73 / 4.95 (4.85 drift)</td>
<td>139.7 / 5.5</td>
</tr>
<tr>
<td>API 2.375” J55 4.7 lb/ft</td>
<td>50.55 / 1.995 (1.901 drift)</td>
<td>60.325 / 2.375</td>
</tr>
</tbody>
</table>

Drilling fluids

The drilling fluid (loosely called ‘mud’) performs the following functions, many of which are critical to the drilling process:

- Aid formation stability and productivity
- Clean the bottom of the hole
- Lift formation cuttings to the surface
- Suspend cuttings while circulation is stopped (eg trips)
- Permit cuttings removal at surface
- Control subsurface pressures
- Deposit a wall cake through porous and permeable formations to aid hole stability
- Cool the bit
- Lubricate the drillstring
- Assist in corrosion control of the drillstring
- Allow electrical logs to be run
- Limit any environmental damage caused by the discharge of the drilling fluids themselves or other materials in them

The selection of appropriate drilling fluids and maintenance of optimum fluid properties are essential to technical success, safety and cost effectiveness.

Drilling fluid parameters

On a deep hole, the following drilling fluid parameters may need to be routinely monitored:

- Relative density (RD), sometimes referred to as specific gravity (SG)* or mud weight (ppg is the API standard), which is measured using a mud balance
- Filtration properties, measured with a standard API filter press (only for water-based muds)
- Flow properties, loosely termed ‘viscosity’, measured using the resistance to flow through a standard Marsh funnel with the result reported in seconds, or by using a rotating rheometer that gives readings at different rotation speeds from which ‘plastic viscosity’ and ‘yield point’ are determined
- Gel development, measured with a rheometer
- Chemical composition and cation exchange capacity, measured as methylene blue capacity
- pH, measured with test papers or a meter
- Chlorides, measured with sulfuric acid, silver nitrate, phenolphthalein and potassium chromate

It is the responsibility of the driller (or specialist Contractor) to monitor and manage the drilling fluids within the parameters set by NTGS. ▲ NTGS should ensure that adequate tests are undertaken and that the results are reported on the Daily Operations Report and recorded in the Drillhole Completion Report.

* To convert ppg (lbs/US gallon; API standard) to SG multiply by 0.12
Drilling fluid additives

The numerous categories of drilling fluid additives are:

- Bactericides
- Calcium removers
- Corrosion inhibitors
- Defoamers
- Emulsifiers
- Filtrate reducers
- Flocculants
- Foaming agents
- Lost circulation materials
- Lubricants
- pH control additives
- Shale control agents
- Surfactants
- Thinners, dispersants
- Viscosifiers
- Weighting materials

It is the responsibility of the driller (or specialist Contractor) to maintain adequate stocks on site. NTGS should monitor the inventory. The classifications, the proprietary name and the quantities used should be noted in the Daily Operations Report and recorded in the Drillhole Completion Report. Such information is critical to assessment of drilling engineering, possible sample contamination, environmental impact and cost control.

Engineering design of typical cored stratigraphic drillholes

The exact configuration of each hole will depend on the near-surface conditions, the nature of the formations to be intersected, groundwater, depth, rig capacity, drillstring and bits available. Even when these are determined, multiple engineering solutions are often possible. A typical cored stratigraphic slimhole (Figure 15a and b) drilled with a multipurpose rig would be:

- Auger or air drill into consolidated material (say, 3-6 m) and run a disposable conductor. Cement conductor in place if necessary but bear in mind that abandonment procedures (see COMPLETION AND ABANDONMENT) mean that no concrete or casing can be left within 30 cm of the surface
- Step down and air drill through the weathered zone into competent rock (say, 60-100 m). If sufficient water is found this hole can be developed as an onsite waterbore; the rig is then moved slightly and the precollar repeated, or the stratigraphic hole may be recommenced in PQ core if the ground is found to be suitable
- Run retrievable threaded steel HW casing in the stratigraphic hole
- Begin HQ3 coring, checking recovery; the driller may switch to normal HQ if there are no problems and if HQ offers a cost advantage. Take HQ or HQ3 to about one third of PTD, or no more than 90% rig capacity
- Run NW casing or open-ended HQ drillstring as casing
- Core NQ, or preferably NQ2, to PTD (600-1000 m)
- Retrieve steel casing
- Abandon hole in accordance with regulations

Hole orientation and deviation

The objective is to drill a straight hole but hole orientation will invariably change as drilling progresses. Variance from the planned trajectory is recorded with respect to both horizontal and vertical frames of reference multiple times during drilling. Such directional surveys are mandatory at intervals of not more than 200 m in petroleum wells in the NT and, as described below, NTGS has its own specifications for stratigraphic holes.

Terminology can be confusing. The preferred terms are: ‘azimuth’, which is recorded as the horizontal direction of the hole relative to magnetic north, and ‘declination’, which is the angle with horizontal. Declination may be expressed as a negative number of degrees, a vertical hole having a declination of -90°. Unintentional changes in azimuth and declination are best known as drift and deviation respectively. Figure 16 provides examples. Deflection, or deliberate directional drilling, uses these terms in a different sense. Killeen et al (1995) gives a good review of hole orientation methods.

Don’t expect a perfectly straight, perfectly vertical drillhole. There is no such thing. By virtue of the drilling process, all holes tend to spiral. Even under ideal circumstances, rotary drilled holes will spiral clockwise (‘walk to the right’ in drilling parlance) and flatten (trend towards vertical) with depth. Abrupt changes in drilling parameters or lithology can cause sudden changes in deviation and drift. Maximum deviation will occur if the hole intersects a rock fabric (bedding, foliation) at about 40°. A ‘dogleg’ is usually defined...
Figure 15a

Figure 15. Cross-sections of typical cored slimhole stratigraphic drillholes. Horizontal scale is accurate 1:1. Actual engineering will depend on surface conditions, nature of rocks to be drilled, PTD, abandonment requirements, rig capacity and specifications of bits and tubular elements. (a) A 6" OD 20 lb/ft steel pipe conductor in a 6.25" hole, followed by HW casing in a 5" hole that could be hammer, blade or air drilled, open-ended HQ rods used as casing in the HQ core section, and NQ2 core to TD. (b, overleaf) A 125 mm Class 9 PVC conductor, followed by PQ cored section cased with HW, HQ cored section cased with NW, and NQ core to TD.
Figure 15b

<table>
<thead>
<tr>
<th>Depth (m)</th>
<th>HQ Core DIA</th>
<th>NQ Core DIA</th>
<th>PQ Core DIA</th>
</tr>
</thead>
<tbody>
<tr>
<td>34</td>
<td>158.75 (6.25&quot;) h</td>
<td>140.2 OD</td>
<td>152 bell</td>
</tr>
<tr>
<td>122.6 h</td>
<td>114.3 OD</td>
<td>101.6 (4.0&quot;) ID</td>
<td>85.0 PQ Core</td>
</tr>
<tr>
<td>96.0 h</td>
<td>88.9 OD</td>
<td>76.2 (3.0&quot;) ID</td>
<td>63.5 NQ Core</td>
</tr>
<tr>
<td>75.7 h</td>
<td>63.5 NQ Core</td>
<td>47.6 NQ Core</td>
<td></td>
</tr>
</tbody>
</table>
as any deviation >3º/30 m. Rotary holes will steepen with less weight on the bit and flatten with high weight on the bit. A dull bit will deviate more from vertical than a new bit. The high rotation speeds and less pendular weight involved in coring mean that deviation is more of a tendency than with conventional drilling and that deviation becomes a more serious problem with decreasing hole diameter. Deviation in excess of 10º is quite common in NQ cored holes in excess of 800 m and Hartley (1994) cites examples of up to 10º deviation over 30 m for BQ in schist. Significant deviation means that the drillhole may:

- Miss the target (especially important in mineral exploration)
- No longer intersect bedding at 90º (not true stratigraphic thickness)
- Contain sections of tight hole and doglegs that increase drag and wear on the drillstring and lead to further drilling problems

All stratigraphic holes must be surveyed for deviation and preferably for drift. The NTGS contract stipulates that readings should be taken no more than 30 m apart. The actual depths will have to correspond to the end of core runs, and depending on the lengths of collars, rods, subs and core barrel, this may not be exactly at absolute depths of 30 m, 60 m and so on. A good rule of thumb is that the difference in declination between adjacent readings should not exceed 2º. Any more than 3º in 30 m is considered a dogleg. Insist that any spurious reading is repeated, if not before drilling is resumed, then no later than the end of the next run. If deviation becomes a problem, surveys should be more closely spaced while remedial action is underway. Penalties will apply if deviation from the proposed program is excessive. Typical penalties are shown below:

<table>
<thead>
<tr>
<th>Depth interval</th>
<th>Deviation from planned vertical trajectory</th>
<th>Penalty</th>
</tr>
</thead>
<tbody>
<tr>
<td>0-300 m</td>
<td>greater than or equal to 5º</td>
<td>5% of metreage rate until the hole is within specification or enters another category</td>
</tr>
<tr>
<td>300-600 m</td>
<td>greater than or equal to 7º</td>
<td>10% of metreage rate until the hole is within specification or enters another category</td>
</tr>
<tr>
<td>&gt;600 m</td>
<td>greater than or equal to 10º</td>
<td>20% of metreage rate until the hole is within specification or enters another category</td>
</tr>
<tr>
<td>any 30 m interval</td>
<td>greater than or equal to 3º from previous reading</td>
<td>20% of metreage rate for the next 120 m</td>
</tr>
</tbody>
</table>

Since this is part of monitoring the driller’s obligations under the contract, NTGS personnel must be familiar with how deviation surveys are done and should check all measurements. These must be documented in the Daily Operations Report.

Hole orientation can be recorded by numerous devices. These range from crude downhole acid-etch tubes (note that NTGS forbids hydrofluoric acid (HF) on site), through combined compass and gravity tools and gyroscopic devices to continuous computer telemetry. The recommended types of equipment are described below.

**Electronic memory tools**

Several tools have been developed to record hole azimuth and declination electronically. This information can be viewed on a hand-held field computer and downloaded to a PC. The Flexit Multismart tool, for percussion holes, uses two non-magnetic stainless steel drill rods located behind the hammer and an electronic-memory survey tool in an inner tube. Data are recorded in 3 m increments as the rods are retrieved. Each reading takes less than 10 seconds. The Ranger survey system is similar. The Tensor tool uses three magnetometers and two accelerometers to record hole declination, azimuth and magnetic tool-face readings. It can be run in both rotary and diamond core holes and operated either in single-shot or continuous mode. Electronic multishot surveys are the preferred technique to survey percussion precollars since correct precollar alignment is critical for the diamond tail. Such tools are usually only operated by a specialist Contractor and would not normally be required on fully cored NTGS holes.

**Eastman camera**

The single-shot Eastman camera is the most widely used in coring. This is a downhole wireline photoclinometer that incorporates a timer, camera, compass and inclinometer. Rubber fingers are used to centre the instrument and it is seated downhole in a special non-magnetic collar. The type employed in near-vertical holes uses a battery-powered light to expose a small disc of photographic film resembling a compass face, which is developed back at the surface as a permanent record of azimuth and declination. Although a special magnification device is available, few drillers have one and the charts should be read with either a hand lens or a binocular microscope. Declination can be read to the nearest degree and estimated to 0.1º. Azimuth is read to the nearest 5º and can be estimated to the nearest degree. Be wary when reading the azimuth as most cameras photograph the card from underneath and so a reading east of north is read in a counterclockwise direction (Figure 17). Some discs have 0-90º for each quadrant; others have a 0-360º compass scale. Note that the
Figure 16. Explanation of hole orientation terminology. (a) This drillhole was intended to be vertical (90°), but at 300 m it has a declination of -75°. This equates to a deviation, or build, of +15°. By 800 m, the deviation has increased to +25° (declination -65°). The azimuth of the hole, towards 165°, is also the drift direction since the hole was planned to be vertical. Most operators would consider such variance from planned as unacceptable. (b) In this example, the hole was planned for a declination of -70° (20° from vertical) and a heading of due south (azimuth 180°). At 800 m, the hole was actually -65° from horizontal and so has a deviation from planned of +5° vertical. Its azimuth is 165° instead of 180°, so it has drifted +25° and is eastnortheast of where it should be. Depending on the size of the target, this may be acceptable.
exposed discs should be retained by NTGS in their individual envelopes and should not be exposed to sunlight and high temperature.

Multishot Eastman cameras used in Australia are of the same vintage as the single-shot cameras and operate similarly but are usually run at the completion of the hole. The multishot tool uses a timer to activate the camera and this requires considerable skill by the driller to reposition the tool between readings.

Both multiple and single-shot Eastman survey tools can be equipped with angle units for use in holes closer to horizontal. The declination is read from the long crosshair on a drum scale and the short crosshair records the azimuth on a circular compass scale (Figure 17).

▲ Experience has shown that the Eastman camera is prone to failure. NTGS contracts stipulate that there should be two cameras on site for deep holes. It is prudent to test both instruments at the surface and establish their relative precision. Remember that, at surface, the compasses will be affected by any nearby metal. Downhole, magnetic interference means that it is pointless taking a reading within 10 m of steel casing. Ensure that there are spare batteries, discs and developer and that the developer is kept refrigerated.

Mechanical controlled vertical drift indicators

Although very outdated technology, these inclinometers are more robust and reliable and less heat sensitive than Eastman cameras, but only measure deviation from vertical and not the azimuth of the hole. They are lowered into the hole on a wireline. The most common, a Totco, is routinely used for the upper section, at least, of onshore Australian petroleum wells. It uses a plumb bob to mark a paper bullseye. A timer activates the plumb bob twice, 60 seconds apart, and the bullseye is rotated 180° between the readings. If the survey was successful, both readings should be within 0.5° of each other (the precision) and exactly 180° apart. Instruments and bullseye charts are available in 0-1°, 3°, 5°, 7°, 8°, 14°, 16°, 21°, 24°, and 90° values. Accuracy is commonly taken to be ± 0.75°, but it decreases as the hole deviates further from vertical.

▲ Be sure whether each concentric circle represents 0.5°, 1.0° or 2.0° etc deviation from the vertical.

Electric wireline surveys

Some wireline logging companies specialise in downhole surveying while others will offer it as part of one of their suites (commonly with the dipmeter). Data should only be recorded on the uphole (not downhole) run.

Plotting azimuth and declination / drift and deviation

The older convention was to plot declination (or deviation) and azimuth as being constant over the interval between the midpoints of adjacent surveys. For example:

<table>
<thead>
<tr>
<th>Depth (m)</th>
<th>Deviation (degrees from vertical)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Reading at 30</td>
<td>5</td>
</tr>
<tr>
<td>Plot 0-45</td>
<td>7.5</td>
</tr>
<tr>
<td>Reading at 60</td>
<td>10</td>
</tr>
<tr>
<td>Plot 45-75</td>
<td>12.5</td>
</tr>
<tr>
<td>Reading at 90</td>
<td>15</td>
</tr>
<tr>
<td>Plot 75-90</td>
<td>15</td>
</tr>
</tbody>
</table>

A better technique is to honour the readings and interpolate between them. There are various computer methods, including the Angle Averaging Method, Balanced Tangential Method, Radius of Curvature Method (preferred by most petroleum operators) and Minimum Curvature Method, details of which can be found in BIBLIOGRAPHY.

Calculating true vertical depth and horizontal displacement

▲ True vertical depth (TVD) and horizontal displacement in a planned vertical hole are calculated as follows:

\[
\text{TVD} = \text{Driller's Depth} \times \cos (\text{deviation})^\circ \\
\text{HORIZONTAL DISPLACEMENT} = \sin (\text{deviation})^\circ \times \text{TVD}
\]

As most holes are spiralled, the calculated TVD and horizontal displacement will be maximum values.

➡ Example 3

A drillhole with a driller’s depth of 1000 m and a deviation of 10° from vertical has a TVD of 984.81 m and a horizontal displacement of 171.1 m.
Figure 17. Reading hole orientation and deviation surveys. Note that all are shown enlarged about four times actual size. (a) Eastman surveys from a planned vertical hole. In the diagrammatic representation (left), deviation is read from the crosshair on the bullseye (5° from vertical). Azimuth is read from the projection of the crosshair onto the circular compass scale around the circumference (058° NE). Note that the compass face is reversed because the instrument photographs the disc from below and that the quadrants are, somewhat confusingly, each numbered 0-90°. The example of an actual Eastman film (right) has a normal compass face with north at zero; concentric circles indicate 1° increments, and displacement of the crosshair is in the direction of the deviation. The indicated deviation is therefore 2° and azimuth 245°. (b) Eastman survey in an inclined hole. The long crosshair on the drum scale shows the angle relative to vertical (38°). Azimuth is read from the short crosshair on the circular compass scale (due N in this case). (c) Chart from a double-acting mechanical drift indicator. The two readings (arrowed dots) are 180° apart, indicating a successful survey. Assuming a vertical hole was planned, a deviation of 1.25° is read on the bullseye scale. Adapted from ADITCL (1997).
Survey data presentation in NTGS reports

▲ The original survey discs are to be retained by NTGS. The NTGS Technical Note and Drillhole Completion Report will each have tabulated data and a graphical representation of hole trajectory.

DRILLING PROBLEMS

Drilling problems specific to coring are discussed in DRILLING PROBLEMS WHILE CORING; others are discussed below.

DRILLING PROBLEMS ASSOCIATED WITH THE FORMATION

▲ Under the terms of the contract, NTGS is liable for the extra costs these problems cause, so the Geologist has to be familiar with them. Unless otherwise specified, remedial action is at the discretion of the driller and this is not a good time to harass the Contractor.

Taking a kick and a blowout

The first influx of overpressured liquid or gas into a drillhole is termed taking a kick. Any uncontrolled flow of hydrocarbons from the drillhole is termed a blowout. Unexpectedly intersecting shallow gas has caused blowouts even on well engineered petroleum wells. It is disastrous in an inadequately cased hole with a rig that has no blowout preventer, spark arrestors and no kill mud on site. The risk of shallow gas can be evaluated from the overall petroleum prospectivity, the density of nearby waterbores and other drillholes that have not intersected shallow gas.

Although shallow gas is a worst-case scenario, the same can be said for the potential of intersecting hydrocarbons (oil or gas) under pressure at any depth. A diamond core rig also runs the risk of inducing a blowout if the inner tube is retrieved at excessive speed. The lowered pressure inside the drillstring will allow the influx of formation fluid. This is termed swabbing.

▲ No NTGS drillhole will be knowingly located on a potential structural or stratigraphic trap and particular attention must be paid to any hole proposed to intersect known or suspected hydrocarbon reservoir. The final responsibility for site location with respect to the risk of blowout rests with the Director NTGS.

Abnormal formation pressure

Intersecting rock that is under abnormally high formation (as opposed to hydrostatic) pressure can never be treated lightly. Worldwide, nearly one half of all onshore petroleum wells and more than one third of offshore wells have experienced trouble of one type or another by drilling through overpressured formations. Although mostly confined to Mesozoic and younger sedimentary rocks, the notion that overpressure doesn’t affect ‘old’ rocks is a fallacy. In addition, basins of any age that contain sulphate evaporites must be treated with extra caution.

Abnormal pressure can be generated in several ways:

Compaction: pore water expands with increasing burial depth and increasing temperature, whereas the pore space is reduced by increasing geostatic load. If pore water is prevented from escaping, the pore water will become overpressured. This is usually a problem in thick, young shales. Compaction effects can be compounded by tectonic stress, salt or shale diapirism, etc.

Diagenesis: the following processes can all release free water, which if trapped in pore spaces, will give rise to abnormal pressure: smectite to illite clay diagenesis, recrystallisation of carbonates, gypsum to anhydrite transformation and diagenesis of volcanic ash (which also produces CO₂ and CH₄). In addition, diagenesis can produce impermeable barriers (eg stylolites) to further confine formation fluids.

Differential density: when a pore fluid present in any non-horizontal structure has a density significantly less than the normal pore fluid density in the area, abnormal pressures can be encountered in the updip portion of the structure.

Fluid migration: the upward migration of fluids can result in a shallow formation becoming pressured (or ‘charged’). The path for such migration can be natural or man-made (eg casing leaks, bad cement jobs).

Thermal cracking of hydrocarbons: approximately 85 m³ of gas can be generated from the thermal cracking of one barrel of oil (Barker, 1990). The by-product organic compounds degrade further and become concentrated in the pore spaces, thus occluding permeability and further contributing to the overpressure.

Tectonic effects: associated with faults.

Detecting overpressure

Detecting overpressure while drilling involves monitoring changes to lithology, drilling and circulation parameters as a transition zone is intersected. The most obvious changes are:

- An increase in penetration rate, torque and drag through the transition zone into an overpressured shale
- An increase in drilling fluid density and viscosity
- Rotary drilling of an overpressured ('sloughing') shale will result in long crescent-shaped cuttings and a volume of cuttings seemingly greater than the volume drilled
Cored shale will swell and jam in the inner tube or swell and rapidly disintegrate into splinters in the core tray; it may cause tight hole conditions or disintegrate and cause a washout.

A noticeable increase in flowline temperature

Overpressure problems will get worse the longer the formation is exposed to the drilling. A polymer and/or saline (usually KCl) drilling fluid may inhibit shale expansion. Where the problem is serious, the formation may need to be cased off.

The site Geologist should be aware of this problem and inform the driller if overpressure is suspected.

Artesian water

Several basins in the NT contain artesian aquifers. Water may be under considerable pressure and it is not uncommon for a fountain higher than the mast when open hole drilling. Some artesian water is also very hot (may boil at the surface), which poses an additional threat.

The smaller annulus and higher pump pressure on a diamond core rig mean that the majority of pressure is contained inside the drillstring. Water pressure may piston the inner tube up uncontrolled after the core is broken at the end of a run.

Check nearby waterbores for the possibility of artesian water. If there is a possibility, ensure that the driller has the appropriate licence and training and is informed in advance.

Lost circulation

Lost circulation is the most common and one of the most expensive drilling problems. Aside from the loss of expensive downhole fluids, it frequently results in the drillhole being terminated prematurely and/or the loss of downhole equipment. This section deals with a loss of returns to the formation and does not necessarily imply a total loss of returns; it includes partial and seepage losses. Lost circulation is usually thought of as loss of the drilling fluid, but it also includes loss of cement when cementing casing. Zones of lost circulation pose special problems in pressure control. There is the potential of an underground blowout and, since no fluid level can be seen, it is impossible to detect swabbing (inducing a blowout).

Some instances of loss to porous formations are unavoidable. In other cases, lost circulation can be artificially induced due to negligence. The causes of lost circulation can be grouped into the following categories:

- Natural formation porosity, especially in unconsolidated, cavernous or naturally fractured formations
- Artificially fractured formation, which can result from excessive drilling fluid RD, excessive pump pressure, a formation integrity test taken too far, a poor cement job or pressure surges associated with drillstring movement (running in the hole too fast or pulling out too fast with a blocked bit)

In both rotary drilling and diamond coring, lost circulation may be treated with various lost circulation materials (eg mica), grouts and expanding foam fillers designed to occlude porosity and permeability. Lost circulation is often more difficult to treat in diamond cored holes. Drilling ahead with no returns due to lost circulation is certainly not a desirable practice, but fairly commonly undertaken (especially by mineral drillers) for short distances in the hope of regaining circulation. Water, rather than drilling fluid, is generally used once the decision has been taken to drill blind. It may be necessary to run casing if it is critical to penetrate below a major lost circulation zone.

It is up to the driller to decide how best to treat lost circulation, but all action must be taken in consultation with the NTGS site Representative.

Differential sticking

If the drilling fluid pressure exceeds the pore pressure of a permeable formation, mud filtrate is lost to the formation and excessive mud filter cake builds up. Differential pressure sticking occurs when the drillstring adheres to the wall of the hole through this zone. The drill string usually becomes stuck after having been stationary. The driller will be unable to rotate or move the string up or down but circulation will not be restricted. The slick rods used in continuous diamond coring and collars used in other drilling are much more prone to differential sticking than pipe with upsets. On continuously cored holes, the drillstring is left stationary in the hole proportionately longer (while retrieving the core), which increases the risk. Only a few tens of centimetres of bad formation can cause differential sticking and the situation will only get worse with time. Typical delays are 24-36 hours. Prevention is far better than cure. Diamond drillholes add special lubricants to the drilling fluid as a preventative measure. Do not allow drilling fluid RD to become excessive through porous and permeable formations and maintain optimal hydraulic parameters.

Once the string is differentially stuck, there are several options. Because delays will exacerbate the situation, many drillers will use brute force as the first option. A conventional petroleum drillstring incorporates ‘jars’ that hammer the string up or down a short distance specifically for this reason. Petroleum drillers may also ‘spot a pill’, meaning that they pump a slug of specially mixed fluid so that it rests within the zone of differential sticking. The pill is designed to break down the filter cake, thus reducing the bond between the pipe and the wall of the drillhole. There are no jars on a diamond core rig and differential sticking can be a costly delay. The driller uses specialist drilling fluid additives, often treating the whole mud system rather
than the specific target zone. The drillstring stick-up is marked and the driller attempts to work free, being careful not to exceed the allowable stretch and torque. Excessive overpull is to be avoided. Some drillers will use the powerful rig leg jacks to lift the entire rig (masts and drillstring get bent doing this!). If the first few attempts fail, the best solution is to reduce the hydrostatic pressure (assuming that it is safe to do so, ie no hydrocarbons or abnormally pressured formations). This can be done by reducing the RD of the drilling fluid, by swabbing and if necessary, by removal of fluids from the annulus. Although counterintuitive, it helps if the drillstring is in compression, not tension, because this tends to move the effect of greatest stress to the stuck point. Alternatively, differential sticking may be overcome by reverse circulation if this is possible with the hardware available.

Spin out

A combination of formation amenable to the development of a thick mud cake, poor drilling fluid parameters, low fluid velocities and the centrifugal effect resulting from the high rotation speed used in diamond coring can cause the mud cake to become overly thick. The drillstring then differentially sticks. This has caused holes to be prematurely abandoned, with loss of downhole equipment. The risk increases with depth. Experience has shown that problems can arise at only 130 rpm if the drilling fluid is below par (Dunster 1991), and drilling fluid properties should be carefully monitored to avoid spin out. In a conventional petroleum well, barite is added to the mud when a gas kick occurs (ie gas under pressure flows into the well). This is a last resort in cored slimholes because the barite would spin out and prevent the resumption of drilling.

Solids in the annulus

Solid particles such as cuttings and cavings which are too large or too dense to be carried out of the annulus may wedge between the drillstring and the walls of the hole. The main symptom is the inability to move the string up. It may be able to be moved down (if off bottom), but then cannot be moved up as far as previously. This occurs in combination with rotation becoming increasingly difficult. Circulation may also be compromised. Chert from near the surface and pebbles plucked from a soft matrix conglomerate (especially tillite) are common sources of problems. Diamond cored holes are also prone to ‘sanding in’, whereby unconsolidated sand or poorly consolidated sandstone builds up above the core barrel and wedges it in the hole. The drilling fluid should be conditioned to increase its lifting capacity, drilling lubricant should be added, the hole flushed and surged, while working the drillstring. If equipment is available, reverse circulation is another option.

Salt

Intersecting a substantial thickness of NaCl poses several problems. Firstly, it dissolves, meaning reduced or no core recovery and an out-of-gauge hole. Secondly, it may deleteriously affect the drilling fluid. Polymer systems are generally tolerant to salt contamination, but salt will reduce the yield point, meaning higher concentrations of polymer are required. Tens of metres of salt have been cored satisfactorily by supersaturating the drilling fluid with KCl or NaCl.

DRILLING PROBLEMS ASSOCIATED WITH DOWNHOLE EQUIPMENT

These problems are the sole responsibility of the driller and, under most contracts, any delays they cause will be at no expense to NTGS.

Key seating

This occurs where the drillstring wears into the wall of the hole at one or more doglegs or ledges. On a conventional rotary hole, upsets or larger diameter tools such as collars, stabilisers or the hammer get stuck when being pulled out. Key seating is less likely to be a problem on a diamond cored hole with a slick drillstring, but it does occur. Key seats need to be reamed out.

Drillstring washout

The abrasion of slick drillstring against casing or the hole wall (particularly at a dogleg) can weaken the walls or joints of drill rods to the point of leakage. Of all the cored petroleum slimholes >1000 m deep drilled in Australia prior to 1991, one fifth experienced at least one drillstring washout and several had multiple washouts (Dunster 1991). Drillstring washout reduces circulation to the bit and the driller must be vigilant to detect the decrease in pump pressure, in order to avoid the more catastrophic downhole problems outlined below. Drillstring washout can be confirmed by circulating a tracer that will return to the surface prematurely. A washout necessitates an immediate and very careful trip so as not to further compromise a weakened drillstring.
Rusty drillstring

An inappropriately stored drillstring will rust, particularly internally. When such drillstring is used, rust flakes from the inside of the string will block the jets and waterways of the bit or may stop the overshot attaching to the inner tube.

Bent rods or drillpipe

A slightly bent drill string will cause unacceptable whip and wobble and be abraded against the side wall of the drillhole. This is especially true at the high rotation speed used in diamond coring. If the bend occurs while drilling, it may be difficult to detect which element(s) of the string are at fault.

Parted drillstring

The drillstring may part by ‘twisting off’ when a tubular element shears or if a joint comes loose or breaks (Figure 18). If joints are not correctly tightened (make-up torque too low), the pin (male thread) typically fails at about one third from the widest point of the thread. Overtightened threads (make-up torque too high) can break at either the pin, the box (female thread) or both. Diamond drill rods are particularly prone to twisting off because of the combination of thin walls and damage to the outside of the female threaded ends by tongs. If one length is faulty, it is likely that others are too and multiple twist-offs can and do occur.

Figure 18. A twist off. Even the thickest-walled tubular elements, in this case a drill collar with hardened steel walls >3.0 cm thick, can fail. This was one of many such drillstring failures encountered in this conventional petroleum well. X-rays of the drillstring subsequently found numerous cracked and fatigued collars and heavy weight pipe that resulted from abuse on a previous contract. A new drillstring had to be mobilised for the next well in the program.

Figure 19. A new diamond drill bit (left) and a damaged counterpart (right) showing what happens when the bit it is not adequately cooled. Two simultaneous washouts in the drillstring meant that insufficient mud was passing through the bit and within a few metres it had lost its crown and was worn back to the shell. Friction generates considerable heat. The material shown between the bits is a piece of melted matrix fused to dropped core of shale which itself has become hot enough to be deformed like plasticine before resolidifying. It is normally impossible to retrieve the damaged bit in this situation and the hole would have to be sidetracked or abandoned.
Undergauge hole

Undergauge hole can be caused by a worn bit, formations that swell or splinter, or excessive wall cake. Remedial reaming back to bottom can be time consuming, especially when diamond coring, as the bit is not designed to function in this way and reaming will cause premature wear of the gauge diamonds. Undergauge hole may also cause problems with running casing or wireline logging.

Bit failure

A diamond bit can become ‘polished’ if the diamonds do not protrude from the matrix sufficiently to cut cleanly. This can be caused by inappropriate bit selection, excessive rotation speed or too little weight on the bit. Reaming, fractured ground or overpressured formation will cause excessive wear on the outer edge of a diamond bit. Overdrilling dropped core will prematurely wear the inner diamond pads. Blocked waterways are another common cause of diamond bit failure. This can usually be remedied by better bit selection. Diamond bits will fail catastrophically if for some reason (such as drillstring washout) they are not cooled (Figure 19). Roller bits can fail due to blocked jets, or the jets may wash out. Bearings are another weak point on roller bits and can fail before the bit wears to the point it would normally be pulled. A worst-case scenario is for bearing failure to result in the loss of one or more cones downhole.

Wireline breakage

The wireline that retrieves the core is run thousands of metres every shift. It is prone to kink and fray and has to be replaced regularly as part of preventative rig maintenance. Broken wirelines are not unusual. They are designed to part at a weak point at the connection with the overshot.

Fishing

A fish is any undesirable object in the hole that impedes further drilling, the running of casing or wireline logging. Common fish include a parted drillstring, a failed drill bit, a wireline logging tool (see Wireline Logging) or foreign object (‘junk’) in the hole. Broken overshot jaws can be a problem in diamond coring. Even a tiny fragment of metal can ring or wipe the face of a diamond bit. Attempting to drill ahead without knowing there is junk in the hole is responsible for over half of the premature deaths of diamond bits. The attempted retrieval of a fish (fishing) has been required on up to 20% of all petroleum drilling jobs and 80% of all workovers up to the mid-1980s (Kemp 1990). Basic fishing tools designed to tap into, or over, each of the diameters of casing and drillstring tubular elements should be carried as part of the rig inventory on deep drillholes. These taps and other useful fishing tools are shown in Figure 20.

It will be up to the NTGS Representative to decide when to cut losses and abandon fishing attempts. This should be agreed with the driller before commencing fishing operations.

Surface equipment failure

The most common surface equipment failures on a multipurpose rig include mechanical breakdown, blown hydraulic or air hoses, leaks in the top drive swivel and worn pump liners.

Wireline logging and vertical seismic profiling

Wireline logging

Wireline logging normally accounts for about 10-20% of the total cost of a petroleum well and can be as high as 30% of the cost of a mineral exploration hole. While it can be argued that fully cored holes obviate the need for sophisticated wireline logs, a minimum suite is probably still necessary to facilitate drillhole-to-drillhole correlation, especially to uncored petroleum wells. It is recommended that caliper, gamma and resistivity, at least, be run in all deep stratigraphic holes in petroleum basins and that logging be undertaken with the rig still over the hole. Gamma logging of core at surface (for example, with Geoscience Australia’s shielded twin detector logger) is a poor substitute for downhole logs but, depending on freight costs, may be a cheaper alternative.

The downhole wireline logging equipment chosen will depend on the quality of the logs (a function of the Contractor’s hardware and software), cost, length of the cable, diameter of the tools relative to the hole, and access to the site. Downhole temperature may also be a limiting factor in unusual circumstances. Waterbore and coal logging equipment will be limited by depth. Most conventional petroleum logging tools will not fit into narrow-diameter slimholes, but several service companies have special small-bore tools. Large petroleum logging units are usually mounted on conventional-drive highway trucks, but slimhole units are typically on multiwheel drives.

The NTGS site Representative is expected to QC the wireline logging operations.
Preparations

Wiper trip

A wiper trip or dummy trip means pulling the string at least part way out, running back in, then pulling out completely. It is used routinely by some operators in the oil industry in the belief that this removes any obstructions in the hole, creates a uniform mud cake and increases the chances of getting to bottom. This practice is unusual in cored drillholes in hard rock. Recommended NTGS procedure is to wiper trip through any of the following:

- Lost circulation zones
- Thick porous and permeable elastic zones
- Tight hole (doglegs, sloughing shale, etc)
- Where any nearby drillholes experienced trouble wireline logging.

Figure 20. Fishing tools. (a) Carrot tap designed to screw into the drillstring to retrieve pipe or rods. (b) Bell tap that screws over tubular elements. (c) Reverse circulation junk basket for retrieval of small metal objects. Once the tool is in position, a steel ball is dropped inside the drillstring. It seats in the tool and reverses the circulation at the face of the bit. Face-set tungsten carbide is used to mill over the junk, which is flushed into one or more internal basket catchers. A magnet can also be incorporated into the catcher. (d) Poor-boy fishing tool that can be fabricated on site using the pin on a sub and piece of slotted casing. It is designed to twist down over the fish and the fingers bend closed underneath it. Images (a)-(c) courtesy of Diamond Boart, Gotco International and Logan Oil Tools.
**Conditioning and sampling the drilling fluid prior to wireline logging**

Correct sampling and analysis of the drilling fluid in the hole during logging is critical to the evaluation of resistivity and self-potential (SP) logs. The drilling fluid is sometimes ‘sweetened up’ (particularly in terms of viscosity) prior to logging. This practice should be resisted for the following reasons:

- If the drilling fluid could be improved, it should have been done during active circulation while drilling
- Changes to the physical properties of the drilling fluid are invariably accompanied by chemical changes
- Downhole conditions will still be equilibrating when logging commences and will vary during logging
- The drilling fluid that has penetrated the formation may not be physically displaced by any newly conditioned drilling fluid, but cation exchange will be operating

The recommended drilling fluid preparation prior to logging is simply to circulate bottoms up, preferably twice. The time circulation stopped and the final flowline temperature should appear on log headers. The last mud sample circulated off bottom should be sampled for filtrate and mud cake evaluation. Mud resistivity measurements should be made twice, once immediately after collection and again about midway through the entire logging process. Ensure that the correct mud data, including the temperature, appear on the log header. A quick check for unweighted mud is:

\[ \text{Rmf} \text{ should be } 0.75-0.88 \times \text{Rm} \]
\[ \text{Rmc} \text{ should be } 1.11-1.50 \times \text{Rmf} \]

where the various resistivities are: \text{Rm} - mud, \text{Rmf} - filtrate and \text{Rmc} – mud cake.

**Recording datum and depth**

The header should show the datum being used and both driller’s and wireline total depths. These depths are rarely the same. The wireline depth is usually less, often because savings prevent the tool getting to bottom. There are other reasons for discrepancy. Even assuming that the measuring wheel is accurately calibrated and there is no slippage, twisting can shorten the cable by a few percent. In the opposite sense, cable has an elastic stretch of up to 0.8 m per 1000 m. The wireline depth should be calibrated against casing shoe depth. In the case of oilfield API casing, the casing depth will be known to within millimetres and should be more precise than the wireline.

**SAFETY**

⚠️ If logging is to be undertaken with the rig still over the hole, ensure that the work area is free of obstructions. The drillers will assist the logging Contractor to rig up. All other personnel not directly involved must be kept away from the area around the drill floor and from any logging tools laid out on the surface. The hole shall be covered at all times unless there is a tool in the hole and a slotted cover should be used while logs are being run. All sheaves should be properly guarded and loads must be moved across the cable when logging operations are underway. Other general safety procedures outlined in **SAFETY AND EMERGENCY PROCEDURES** shall be followed.

**Logging suite**

Most operators will be able to provide preliminary hard copy and final digital data on site. Typical vertical scales generated on site are 1:200 and 1:500. It is handy to have a hardcopy at the same vertical scale as the site lithological log. The digital version should include LIS and/or LAS ≥1.0 format.

Tools with a radioactive source are **never** to be the first logs run. Logs which do not read through casing need only be run 5-10 m into it. Repeat intervals vary from tool to tool but 5-10 m should be considered a minimum.

There are dozens of ever-changing, impressive-sounding proprietary names for the various wireline logging tools. The basic generic types are described below.

**Mechanical caliper**

**Principle**

Measures the vertical change in diameter and sometimes shape of hole with mechanical arms; holds other instruments against the hole wall

**Uses**

- QC of depth on other wireline logs, detection of tight hole or washouts in hole wall that might compromise quality of other log data,
- calculation of hole volume for cementing

**Display**

Use metric even if the bit is in inches; the bit diameter may be shown as a dotted line for comparison with hole gauge
Calibration
Calibrated against rings of known diameter or casing ID

Limitations
Low repeatability, particularly of single arm tool, because of elliptical hole; badly out of gauge holes will exceed caliper reach

Checks
Check casing reads correctly

Natural gamma ray

Principle
Scintillometric measurement of natural radioactivity, usually as total counts; spectral tools will record separate K, Th and U

Uses
Definition of bed boundaries, lithological identification, correlation, establishment of ‘shale’ base line, detection of radioactive ore deposits and feldspathic sandstones, matching of separate logging runs

Display
API units, 0-100 API or 0-200 API units, linear, increasing to left

Calibration
Test pit

Limitations
Tool must be centred; absolute reading will depend on detector type, logging speed and time constant; thick mud cake may influence readings; largely unaffected by caving and will read through casing, but is attenuated; barite, KCl and/or mica (added to combat lost circulation) in drilling fluid will affect readings, subject to temporal variation (drift); vertical resolution of a basic tool is about 0.5 m so thin beds tend to ‘smear’ and inflection points appear displaced

Checks
Be sure that logging speed is recorded and that the time constant used was appropriate for that speed; repeatability varies by lithology and due to random drift; some detectors are temperature sensitive; zero readings are impossible (lowest in evaporites)

Spontaneous potential (SP)

Principle
Measures difference between the electrochemical potential of a downhole movable electrode and another fixed at the surface to detect relative difference in salinities of connate water (Rw) and mud filtrate (Rmf). Uses the same geometry as the resistivity tool and is commonly run in combination

Uses
Detect permeable beds, bed boundaries; determine Rw and Rmf, definition of shale base line; gives qualitative indication of ‘shaliness’

Display
Millivolts (mV), 10 mV per division, linear scale, negative to left

Limitations
Limited by salinity of fluids, if water salinity and mud filtrate are close, as normally is the case in a freshwater aquifer; the SP curve will be too flat and of limited use; some filtrate invasion must be present; useless in cased hole; needs correction for bed thickness, resistivity and hole diameter; sensitive to electrical interference

Checks
Must have good earth connection for surface electrode; check for unacceptable baseline drift and cycling due to magnetism and bimetallism, telluric affects and cable noise
Resistivity and conductivity

**Principle**
Aside from some ore minerals, there are relatively few highly conductive materials in the subsurface, so the conductivity of sedimentary formations is often a function of the salinity of the formation fluid. Various types of tools have been designed to measure the comparative resistivities (the inverse of conductivity) at different depths of wall invasion. Electrical conductivity is usually measured with an induction probe.

**Uses**
Resistivity is a good direct indicator of hydrocarbons, to obtain numerical measures of $R_w$ and $R_t$ for use in the Archie equation to determine $S_w$ (water saturation), determine oil/water contacts; short-spaced tools good for drillhole-to-drillhole correlation. Conductivity measurements are important for calibrating airborne EM data.

**Display**
Resistivity 0.2-200 or 0.2-2000 ohm, four-decade logarithmic, shallowest reading shown as a solid line, intermediate as dashed and deep as dotted.

**Calibration**
Precision resistors

**Limitations**
Dependant on instrument pad/mud cake contact; has to be corrected for temperature, hole and adjacent bed effects; useless in air-filled hole, in non-conductive fluids (use IP instead) or cased hole; long- and short-spaced resistivity have different vertical resolution and respond differently to borehole effects; tool is physically long and needs significant sump.

**Checks**
All resistivity readings should be at or near zero in casing; run repeat section over zones of interests.

**Induced polarisation (IP)**

**Principle**
A transmitter loop charges the formation with a high alternating current. Any conductive particles will become the most highly charged with eddy currents. The magnitude of the currents, proportional to the media conductivity, is monitored using a detector loop. Modern tools have four or more transmitter/receiver pairs. May be run with resistivity tool.

**Uses**
Primarily used in minerals exploration for disseminated sulfides such as volcanic-hosted massive sulfides and porphyry copper deposits; also used in coal exploration. Some application to uranium exploration in detecting zones of alteration and redox fronts. Downhole IP may help calibrate surface IP surveys, although it can be difficult to detect if a drillhole targeted on an IP anomaly has actually intersected it.

**Display**
Various, normally inverted and displayed on a logarithmic scale.

**Limitations**
Will not work in casing; will work in air and non-conductive fluids; temperature dependant.

**Checks**
Compare with other electrical tools, particularly resistivity.

**Magnetic susceptibility**

**Principle**
Measures the ratio of the intensity of natural magnetisation to the intensity of an applied magnetic field; operates in a similar way to an IP tool; maghemite, ilmenite and pyrrhotite will all register high responses.

**Uses**
Mineral exploration, detecting palaeochannels, crude lithology determination.

**Display**
Since it is a ratio, it is strictly dimensionless.
Limitations
Measurements in highly conductive material need to be corrected for conductivity affects

Checks
Compare with electrical tools

Sonic

Principle
Measures the speed of pulsed compressional sound waves in subsurface formations (acoustic travel time); both first arrival and full waveform tools are available. The tool usually comes in two parts, with a lower transmitter separated from one or more upper receivers

Uses
Lithology determination, especially in carbonate and evaporite rocks; porosity evaluation; generation of synthetic seismograms; abnormal pressure indicator

Display
Delta t microseconds/metre, range 500-100 μsec/m, usually linear, Φ,45 to -15 percent porosity

Calibration
Calibrated against a quartz crystal clock, function checked at surface, but a bent tool could pass all checks and produce erroneous logs

Limitations
Tools are usually compensated for changes in hole size and tool tilt; assumes uniform intergranular porosity; cannot recognise secondary porosity; may not show gas in consolidated rock; useless in casing; not a pad-type tool so will work in out of gauge holes but may cycle-skip

Checks
Look for cycle skipping or spurious spikes and slow the tool if more than two spikes per 50 m; sonic in liquid-filled casing should read 187.0 μsec/m (= 57 μsec/ft); values <131 μsec/m or >623 μsec/m are unusual; sonic should register closely with gamma

Density

Principle
Measurement of radioactivity loss between an emitting source (usually 2 curie 137Cs) and return of gamma rays to one or more detectors. Loss of energy is by collision with electrons, the electron density being proportional to the bulk density. Compensated tools use short- and long-spaced detectors to correct for mud cake. Both source and detectors are heavily shielded to minimise borehole effects

Uses
Porosity evaluation; determination of absolute bulk density, shale content; gas detection

Display
1.90-2.90 g/cm³ or 1.95-2.95 g/cm³, linear; may be displayed relative to the selected matrix (limestone or sandstone)

Calibration
Shop calibrated in blocks of known density; onsite tool verification using two small gamma sources

Limitations
Residual hydrocarbons, especially gas, will give erroneously high porosity; susceptible to shaliness; grain density must be known quite accurately to calculate porosity, eg a variation of ±0.05 g/cm³ can produce an error of 2.6% porosity; is a pad tool and so dependant on hole gauge; relatively slow logging speed so be wary in unstable holes - not a tool to get stuck in the hole!

Checks
Confirm logging speed; repeat section in good hole should be within 0.05 g/cm³; check for drift; check density of known uniform lithology (eg halite 2.032 g/cm³, granite 2.5-2.8 g/cm³)
Neutron

Principle
A neutron source (commonly 20 curie AmBe) bombards the formation with neutrons which are captured by atoms in both the formation fluid and matrix. Because of the similarity in mass, most neutrons are captured by hydrogen atoms in water or hydrocarbons which in turn reflect formation porosity. The compensated neutron tool uses two thermal detectors as sensors.

Uses
Delineation of porous zones, determination of formation fluid type, direct indication of gas, evaluation of shale content; in combination with density to identify lithology

Display
Either limestone, sandstone or less commonly dolostone porosity units; usually displayed with density

Calibration
Shop calibration in water-filled tank; on site using two small radioactive sources

Limitations
Elements such as Cl, B and Li interfere; cannot distinguish between water and medium density oil; is influenced by changes in hole diameter; will work through steel casing but PVC (which contains H) will cause a problem; temperature dependant; shale content needs to be verified using another log; not a tool to get stuck in the hole!

Checks
Cross-check with density and gamma

Dipmeter

Principle
Shows bedding by comparing the depth shift in four or more microresistivity sensors

Uses
Dip determination, fracture identification; can replace other microresistivity tools

Display
Needs onsite processing to generate tadpole diagrams

Calibration
As per resistivity

Limitations
One or more arms not contacting the wall (floating arm problem)

Checks
As per resistivity

Downhole temperature

Principle
Record sufficient downhole temperature data for correction of wireline logs and drilling fluid resistivity and allow estimation of geothermal gradient

Uses
Many of the wireline logs, notably resistivity, vary as a function of temperature. Correct values of Rm, Rw, Rmf, Rmc and K all require the temperature of the zone under investigation. Flowline temperature should have been recorded prior to cessation of circulation. Digital temperature logs, where available, are usually run on the way down as one of the first logs and again as one of the last runs. Normal procedure is to record the bottom hole temperature using a maximum reading thermometer on each run. Simple as this may sound, experience has shown that up to a quarter of such readings are unreliable. Failure to reset the thermometer after leaving the tool sitting in the sun doesn’t help. Downhole temperature should be recorded at every opportunity and the time since circulation stopped is also important to calculate a time-dependant correction.
Display
---
Degrees Celsius

Calibration and checks
It is recommended that several downhole thermometers be available on site and that they are cross-checked at the surface

Limitations
Will not work in an air-drilled hole and unreliable inside casing

Velocity survey and vertical seismic profiling
These techniques, and variations of them, measure acoustic waves between a surface source and a wireline geophone/hydrophone at various depths in the drillhole. These data are used to establish a tie between subsurface stratigraphy and a surface reflection seismic section. Downhole techniques are higher resolution than surface seismic. The most basic survey is termed a Velocity Survey or a Check Shot Survey. These only record first-breaks (first arrival signals). Recording depths are chosen from variations in the sonic log and are typically dozens or hundreds of metres apart. Vertical seismic profiles (VSPs) are much higher resolution and record the full wavelet signature of both downgoing and upgoing wavelets and include reflections below the total depth of the drillhole. Receiver spacing is typically a few tens of metres or less.

These surveys are normally very expensive and undertaken by a specialist contractor. GSWA has undertaken VSPs in some of its stratigraphic holes. It would only be required in NTGS drillholes that have a sophisticated downhole logging suite (a high-resolution sonic log is required) and where such drillholes are located on seismic lines. A review of the VSP technique is listed among the online resources (Appendix 1).

DOWNHOLE LOSS OF WIRELINE EQUIPMENT
Loss of a wireline logging tool is a special case of fishing. The wireline logging contractor should carry a cable spear and a fishing tool specially designed to tap onto the top of the wireline logging tool. Downhole loss of a tool with a radioactive source is a worst-case scenario.

COMPLETION AND ABANDONMENT
A stratigraphic drillhole may be completed as a waterbore or, after appropriate plugs etc, may be abandoned. Current NT Government recommendations for waterbore construction and the abandoning of drillholes are quite onerous and described below.

▲ The NTGS site Representative must ensure that the drillers leave the hole in an appropriate condition.

Subsurface plugs
Subsurface plugs are necessary to partition aquifers, hydrocarbon-bearing formations or formations that have different hydrostatic pressures. They also prevent reentry of the drillhole. The plugging program will be specific to each drillhole and both waterbore and petroleum drilling regulations may be applicable.

Most drillholes will require more than one plug. In general, each aquifer is to be cement capped if the hole is to be abandoned. Tens of metres of cement are required for each plug. For plugs placed off bottom in an open hole (balanced cement plugs), the caliper log should be used to locate an in-gauge portion of hole. Displacement, bridge, van Ruth, CW or bull nose plugs may be used in addition to cement in special applications.

▲ NTGS must ensure that the drillers put adequate subsurface plugs in place and that these are properly documented.

Surface plugs for open holes
All holes are to be capped. Stratigraphic holes will have a permanent marker.

Open holes, collared or uncollared, particularly if eroded and cratered, are a danger to wildlife, livestock and vehicles. The Department requires that all drillholes shall be closed and that the closure shall be permanent. Hence, holes as a minimum must be plugged with concrete in the manner described in the cross-section diagrams (Figure 21), or backfilled completely using drill chips or concrete. Note that the use of plastic or PVC caps or plugs such as ‘occy’ plugs is not allowed.

▲ NTGS must ensure that the drillers put adequate surface plugs in place and that these are properly documented.

Surface plugs for collared drillholes including NTGS stratigraphic holes
Holes are to be plugged with concrete at least 0.3 m below ground level using a concrete cone plug. The plug will be fitted with a length of wire rope that extends to the surface, and a labelled metal tag as an indicator. The hole above the plug is to be filled with compacted earth (Figure 21a). Be wary of concrete too near the surface on land that is likely to be cultivated or graded. Plugs may be made in moulds such as polyethylene flowerpots or ‘witch’s hats’. Flowerpot moulds may be reused if the
drainage holes are blocked with masking tape and the inside wiped with diesel or the mould may be left on the plug. PVC collars may be readily cut below ground level using a powered brushcutter modified with a diamond masonry blade. If necessary, the cut section of collar may be removed from the hole using chain tongs or an oil filter remover.

**Plugs for uncollared RAB holes**

Holes are to be plugged at least 1.0 m below ground level with a concrete cone plug. The plug is to be at least 50 mm larger than the diameter of the original drillhole but, depending on the nature of the ground, must be of sufficient size as to remain firmly in position. To enable the placement of the plug the hole may be reamed out with hand tools or counterbored by the drillrig with a larger drill bit. The hole above the plug is to be backfilled with compacted earth and mounded over at the surface. (Figure 21b). The intention is that water shall not enter the hole and cause it to erode and reopen, and particular care is required to ensure the long-term effectiveness of the plug.

**Waterbore completion**

Waterbore completion must follow NT Government recommendations. The top of the production casing must be a minimum 500 mm above ground level. Should any other casing be installed it must be a minimum 300 mm above ground level. The waterbore will be completed with a locked cap. A reinforced concrete slab surrounds the base of the casing(s). The concrete slab must have a minimum thickness of 100 mm and a minimum diameter of 1 m. The bottom of the cement must be a minimum of 25 mm below the natural ground surface and the top level 75 mm above the natural ground surface. The concrete must be a suitable mix of cement, gravel and sand. The surface of the slab must slope away from the casing(s). A bore marker post 2.3 m long and ≥50 mm diameter must be placed approximately 6 m from the completed or abandoned bore. This post will be inserted to a depth of 450 mm and cemented. The bore marker shall have the Registered Number welded clearly on the post and the post shall be painted white.

▲ NTGS must ensure that the drillers complete waterbores in accordance with the appropriate legislation as described above.

![Figure 21. Hole abandonment details. (a) PVC-collared drillhole with concrete plug. (b) Uncollared drillhole with subsurface concrete plug.](image)

**SITE RESTORATION**

▲ NTGS is responsible for site restoration. The site should be restored to its original contours except that the area around the collar must not be a depression. If runoff could erode the site, it should be ripped along the contours and spoon drains constructed. It is not normally necessary to replant the site, except on agricultural land. The NTGS site Representative must obtain before and after photographs of the drill location for inclusion in the Drillhole Completion Report.

**ACKNOWLEDGEMENTS AND DISCLAIMERS**

This manual is intended for informal internal use within NTGS and comes with a standard disclaimer found at the start of this document. Figures and photographs reproduced here are with the permission of the relevant agencies. This does not mean that NTGS or the NT Government endorses these products or suppliers. This manual was proofread by Masood Ahmad and Tim Munson. The layout owes much to comments by James Groombridge. Figures were prepared by Richard Jong and Marianne Fuller.
BIBLIOGRAPHY

A comprehensive drillers’ textbook relevant to Australian equipment; covers all types of drilling.


A basic manual on core logging and handling, mainly directed at the oil industry.

Very dated overview of diamond core drilling written by the Geological Survey of India.

Comprehensive wells site manual for onshore conventional petroleum drilling, used by several international joint ventures.

A succinct text from the United Kingdom that provides a good overview of petroleum drilling operations.

A very useful Australian overview of drilling with good treatment of continuous diamond coring, aimed at wellsite geologists.

A comprehensive, well illustrated and well written textbook on coring; some engineering aspects are unique to South Africa.

Historical interest.

The classic reference to fishing operations in the petroleum industry.

Available at: http://www.mgls.org/95Sym/Papers/Killeen/ Includes a comparison of five different techniques in the same hole.

A practical guide that includes core logging, orientation and sampling; evolved from the Australian Manual of geological practise used in many university courses.

A basic, very practical wells site guide for petroleum drilling.

A standard text directed at conventional rotary petroleum drilling; numerous worked examples of calculations.

A manual for petroleum mudlogging.

An ex-Shell manual that became the AAPG industry standard for the collection and presentation of data on a conventional petroleum wells site.


Reviews common methods of testing for shows in cores, sidewall samples and ditch samples, together with a simple method of recording these observations in a consistent manner.
APPENDIX 1 – ONLINE RESOURCES

GLOSSARIES OF DRILLING TERMS

General

Glossaries of oilfield and drilling terms
http://www.glossary.oilfield.slb.com/
http://www.ukooa.co.uk/ukooa/glossary.htm
http://www.mms.gov/glossary/index.htm

Ocean Drilling Program dictionary
http://www.odp.tamu.edu/publications/dictionary/dict-intro.html

Drilling for groundwater
http://www.agwt.org/info/R_Terms.asp

Glossary of casing and pipe terms
http://www.inter-mountain.com/glossary.htm

SAFETY MANUALS

Diamond drilling safety manual

Geotechnical drilling operations and inspection
http://www.doh.dot.state.nc.us/safety/wpsm/ch11b/37.html

Queensland exploration safety guidelines

WIRELINE LOGGING

Wireline logging and log analysis
http://www.reeves-wireline.com/pdfmineralscatalog/LogAnalMinApps.PDF

Vertical seismic profiling
http://www.mines.edu/students/p/pjbrown/vsp_paper.pdf (and links therein)
## APPENDIX 2 – GLOSSARY OF COMMONLY USED ABBREVIATIONS

<table>
<thead>
<tr>
<th>Abbreviation</th>
<th>Definition</th>
</tr>
</thead>
<tbody>
<tr>
<td>AAPG</td>
<td>American Association of Petroleum Geologists</td>
</tr>
<tr>
<td>AFE</td>
<td>authorisation for expenditure</td>
</tr>
<tr>
<td>API</td>
<td>American Petroleum Institute</td>
</tr>
<tr>
<td>BBL</td>
<td>US barrel (approximately 159 L); BBL is API standard, bbl is preferred by most journals</td>
</tr>
<tr>
<td>BHA</td>
<td>bottom hole assembly</td>
</tr>
<tr>
<td>BHT</td>
<td>Broken Hill-type</td>
</tr>
<tr>
<td>BOP</td>
<td>blowout preventer</td>
</tr>
<tr>
<td>C&amp;C</td>
<td>condition and circulate</td>
</tr>
<tr>
<td>C&amp;F</td>
<td>cartage and freight</td>
</tr>
<tr>
<td>CIF</td>
<td>cartage, insurance, freight</td>
</tr>
<tr>
<td>CIRC</td>
<td>circulate</td>
</tr>
<tr>
<td>CSD</td>
<td>casing shoe depth</td>
</tr>
<tr>
<td>DC</td>
<td>drill collar</td>
</tr>
<tr>
<td>DCDMA</td>
<td>Diamond Core Drill Manufacturers Association</td>
</tr>
<tr>
<td>DEMOB</td>
<td>demobilisation</td>
</tr>
<tr>
<td>DDR</td>
<td>daily drilling report</td>
</tr>
<tr>
<td>DOR</td>
<td>daily operations report</td>
</tr>
<tr>
<td>DP</td>
<td>drillpipe</td>
</tr>
<tr>
<td>DST</td>
<td>drillstem test</td>
</tr>
<tr>
<td>ECD</td>
<td>equivalent circulating density</td>
</tr>
<tr>
<td>EOH</td>
<td>end of hole</td>
</tr>
<tr>
<td>EMW</td>
<td>equivalent mud weight</td>
</tr>
<tr>
<td>F</td>
<td>filtrate</td>
</tr>
<tr>
<td>F</td>
<td>formation factor</td>
</tr>
<tr>
<td>FIS</td>
<td>free in store</td>
</tr>
<tr>
<td>FIT</td>
<td>formation integrity test</td>
</tr>
<tr>
<td>FLT</td>
<td>flowline temperature</td>
</tr>
<tr>
<td>FW</td>
<td>freshwater</td>
</tr>
<tr>
<td>GL</td>
<td>ground level</td>
</tr>
<tr>
<td>GNC</td>
<td>gross nominal capacity</td>
</tr>
<tr>
<td>ID</td>
<td>inside diameter</td>
</tr>
<tr>
<td>IP</td>
<td>induced polarisation (log)</td>
</tr>
<tr>
<td>K</td>
<td>absolute permeability</td>
</tr>
<tr>
<td>KB</td>
<td>(depth below) Kelly bushing</td>
</tr>
<tr>
<td>LC</td>
<td>lost circulation</td>
</tr>
<tr>
<td>LCM</td>
<td>lost circulation material</td>
</tr>
<tr>
<td>MIRU</td>
<td>move in, rig up</td>
</tr>
<tr>
<td>MOB</td>
<td>mobilisation</td>
</tr>
<tr>
<td>NB</td>
<td>new bit</td>
</tr>
<tr>
<td>NFG</td>
<td>not functional</td>
</tr>
<tr>
<td>NR</td>
<td>no returns</td>
</tr>
<tr>
<td>OD</td>
<td>outside diameter</td>
</tr>
<tr>
<td>OH</td>
<td>open hole</td>
</tr>
<tr>
<td>P&amp;A</td>
<td>plugged and abandoned</td>
</tr>
<tr>
<td>PBTD</td>
<td>plugged back total depth</td>
</tr>
<tr>
<td>PDC</td>
<td>polycrystalline diamond compact</td>
</tr>
<tr>
<td>PDQ</td>
<td>pretty damn quick</td>
</tr>
<tr>
<td>POOH</td>
<td>pull out of hole</td>
</tr>
<tr>
<td>ppf</td>
<td>pound per foot (use lb/ft)</td>
</tr>
<tr>
<td>ppg</td>
<td>pounds per gallon (ppg is API standard)</td>
</tr>
<tr>
<td>PTD</td>
<td>proposed total depth</td>
</tr>
<tr>
<td>PV</td>
<td>plastic viscosity (mud)</td>
</tr>
<tr>
<td>QC</td>
<td>quality control</td>
</tr>
<tr>
<td>RC</td>
<td>reverse circulation</td>
</tr>
<tr>
<td>RD</td>
<td>relative density</td>
</tr>
<tr>
<td>RDMO</td>
<td>rig down, move out</td>
</tr>
<tr>
<td>REC</td>
<td>recovered / recovery</td>
</tr>
<tr>
<td>RIII</td>
<td>run in hole</td>
</tr>
<tr>
<td>Rm</td>
<td>resistivity of mud</td>
</tr>
<tr>
<td>Rmc</td>
<td>resistivity of mud cake</td>
</tr>
<tr>
<td>Rmf</td>
<td>resistivity of mud filtrate</td>
</tr>
<tr>
<td>Ro</td>
<td>residual oil saturation</td>
</tr>
<tr>
<td>ROP</td>
<td>rate of penetration</td>
</tr>
<tr>
<td>RPM</td>
<td>revolutions per minute</td>
</tr>
<tr>
<td>Rt</td>
<td>resistivity of invaded zone</td>
</tr>
<tr>
<td>RTSTM</td>
<td>rate too small too measure</td>
</tr>
<tr>
<td>Rw</td>
<td>formation water resistivity</td>
</tr>
<tr>
<td>Rxo</td>
<td>resistivity of flushed zone</td>
</tr>
<tr>
<td>SG</td>
<td>specific gravity</td>
</tr>
<tr>
<td>Sw</td>
<td>water saturation</td>
</tr>
<tr>
<td>SW</td>
<td>saltwater</td>
</tr>
<tr>
<td>SWC</td>
<td>sidewall core</td>
</tr>
<tr>
<td>SWL</td>
<td>standing water level</td>
</tr>
<tr>
<td>SX</td>
<td>sacks</td>
</tr>
<tr>
<td>TCI</td>
<td>tungsten carbide insert (bit)</td>
</tr>
<tr>
<td>TD</td>
<td>total depth</td>
</tr>
<tr>
<td>TDS</td>
<td>total dissolved salts / solids</td>
</tr>
<tr>
<td>TOC</td>
<td>total organic carbon</td>
</tr>
<tr>
<td>Tr</td>
<td>trace</td>
</tr>
<tr>
<td>TS</td>
<td>thin section</td>
</tr>
<tr>
<td>TSTM</td>
<td>too small too measure</td>
</tr>
<tr>
<td>TVD</td>
<td>true vertical depth</td>
</tr>
<tr>
<td>TWT</td>
<td>two-way time</td>
</tr>
<tr>
<td>UDR</td>
<td>universal drill rig</td>
</tr>
<tr>
<td>US</td>
<td>unservicable</td>
</tr>
<tr>
<td>UV</td>
<td>ultraviolet</td>
</tr>
<tr>
<td>VSP</td>
<td>vertical seismic profile</td>
</tr>
<tr>
<td>WL</td>
<td>water loss (mud)</td>
</tr>
<tr>
<td>WOB</td>
<td>weight on bit</td>
</tr>
<tr>
<td>WOC</td>
<td>wait on cement</td>
</tr>
<tr>
<td>WOD</td>
<td>wait on daylight</td>
</tr>
<tr>
<td>WOO</td>
<td>wait on orders</td>
</tr>
<tr>
<td>WOT</td>
<td>wait on tools</td>
</tr>
<tr>
<td>WOW</td>
<td>wait on weather</td>
</tr>
<tr>
<td>WTS</td>
<td>water to surface</td>
</tr>
<tr>
<td>X/O</td>
<td>crossover (in drillstring)</td>
</tr>
<tr>
<td>Y/P</td>
<td>yield point (mud)</td>
</tr>
</tbody>
</table>
APPENDIX 3 – DAILY OPERATIONS REPORT

The following form is for use on deep cored stratigraphic holes. It can be modified to suit other types of drilling. ▲ This or a similar form must be completed and dispatched to the office every 24 hours for the time the rig is on site or in transit to another NTGS drillhole. If no fax is available, normal practice is to dictate the contents of the form over the phone.

Cum = cumulative  
Est = estimated  
PTD = proposed total depth
<table>
<thead>
<tr>
<th>Drillhole:</th>
<th>Date:</th>
<th>Shift Hrs:</th>
<th>Shift m:</th>
<th>Cum Depth:</th>
</tr>
</thead>
<tbody>
<tr>
<td>Contractor:</td>
<td>Cum Days:</td>
<td>Cum Hrs:</td>
<td>Cum m:</td>
<td>PTD:</td>
</tr>
<tr>
<td>Core Dia:</td>
<td>Core Recovery:</td>
<td>Deviation:</td>
<td>Water Truck:</td>
<td>$(\text{hrs})(\text{km})$</td>
</tr>
<tr>
<td>Consumables:</td>
<td>Other Charges:</td>
<td>Est Cum Cost:</td>
<td>Budget Remaining:</td>
<td></td>
</tr>
<tr>
<td>Safety Issues:</td>
<td>NTGS Personnel:</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

**Summary of Activities:**

---

**Geological Report**

<table>
<thead>
<tr>
<th>Current Formation:</th>
<th>Prognosed Top: m</th>
<th>Actual Top: m</th>
</tr>
</thead>
<tbody>
<tr>
<td>Prognosed Base: m</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

**Maximum dip in core:**

**Formation Problems:**

**Lithological Summary:**

**Mineral / Petroleum Occurrences:**

---

**Other Remarks**

---

**Report Prepared By:**

**Sent/Relayed By:**
APPENDIX 4 – NTGS DRILLING LOG

This is a simple generic form. It can be modified to suit the needs of specific projects.
<table>
<thead>
<tr>
<th>i</th>
<th>Metres</th>
<th>Lithology &amp; Grainsize</th>
<th>Recovery</th>
<th>Dip</th>
<th>Bed TK</th>
<th>Description and Comments</th>
<th>Sample/Photo Box No.</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>P G V C M F V Z C</td>
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<td></td>
</tr>
<tr>
<td>Depth Interval (m)</td>
<td>Morphology</td>
<td>Mobility</td>
<td>%Stain</td>
<td>Colour</td>
<td>% Fluor</td>
<td>Intensity</td>
<td>Colour</td>
</tr>
<tr>
<td>-------------------</td>
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</tr>
</tbody>
</table>

**Key**

- **0**: none
- **0**: nil
- **none**: none
- **none**: none
- **none**: none
- **0**: none

- **0-40**: slight
- **0-40**: weak
- **brown**: brown
- **pale straw**: pale straw
- **straw**: straw
- **almost transparent**: almost transparent

- **40-85**: fair
- **40-85**: fair
- **orange, gold**: orange, gold
- **yellow**: yellow
- **dark straw**: dark straw
- **light brown**: light brown
- **translucent**: translucent

- **86-100**: good
- **86-100**: strong
- **near yellow, blue-white**: near yellow, blue-white
- **amber to opaque**: amber to opaque
- **opaque**: opaque
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