Instructional Objectives

1. Select and appropriate drilling method and drilling and sampling tools given a geological scenario and a design purpose for the investigation.
2. Explain the purpose of drilling mud, and how to adjust the mud density.
3. Explain the principles of sample handling and preservation.
4. Generate a core log from rock core.
5. Predict drilling issues give a geological scenario.

Rotary Drilling

Rotary (direct) Drilling

This method makes use of a constantly rotating bit to penetrate any type of formation to depths that can exceed 1,000 feet. As drilling proceeds, cuttings are removed by a continuous circulation of fluid (either air or water based) that flows down inside the pipe string and up-hole along the annular space between the borehole walls and the pipe string.

- **PROS:**
  - High penetration rate;
  - Drilling operation requires a minimum amount of casing;
  - Rapid mobilization and demobilization;
- **CONS:**
  - Use of a drilling fluid, both in terms of sample contamination and water management (in the case of water-based fluids and air injected by gasoline compressors);
  - Circulation of drilling fluid may be lost in loose/coarse formations, hence making difficult to transport drill cuttings;
  - Difficult to collect accurate samples, i.e. a sample from a discrete zone since the cuttings accumulate at surface around the rim of the borehole.

Reverse Circulation Rotary Drilling

Reverse circulation rotary drilling uses the same principles as direct rotary drilling, except that the flow pattern of the drilling fluid is reversed. In this method, the drilling fluid (air or water) is pushed down in the annular space between the borehole walls and the pipe string, and is expelled upward within the pipe string.

- **PROS:**
  - Applicable to a wide variety of formations;
  - Possible to drill large-diameter holes, both quickly and economically;
  - Minimal disturbance to the formation due to the pressure being applied inside and outside the pipe string;
  - Easier recovery of cuttings since the up-hole velocity is controlled by the size of the drill pipe and less subject to lost-circulation;
  - No casing required during drilling and advantageous when high risks of caving in. If there is a risk of caving, mud should be used as a stabilizer. In the case of air drilling, it presents the same risk than regular air rotary, since the flow is down the annular space.
- **CONS:**
  - High water requirements (not for air drilling);
  - Collection of a representative sample is difficult due to potential material mixing;
  - Rig size can render access difficult;
  - Need for drilling mud management (not for air drilling).
Dual-Wall Reverse Circulation Drilling

Dual-wall reverse circulation is a sub-type of rotary drilling similar to RC, in which two concentric drill pipes are assembled as a unit to create a controlled annulus. This method is widely used in groundwater monitoring work. The drilling fluid (air- or water-based) is pumped through an outer swivel down through the annulus of the bit where it is deflected upward into the center pipe. The cuttings are carried upward through the inner pipe and surface swivel, and can be collected as a sample or pile up on the ground.

**PROS:**
- Good sample recovery due to controlled up-hole fluid velocity;
- Fast penetration in coarse alluvial or broken, fissured rock;
- Possible to obtain continuous representative samples of the formation and groundwater;
- Easy estimate of aquifer yield at many depths in the formation;
- Reduction of lost-circulation problems;

**CONS:**
- Practical borehole diameter limited to 10 inches;
- Maximum depth of ~ 1,400 feet, although greater depths can be achieved in hard rock;
- Possible to dry out or to not detect a thin of low-yield aquifer;
- Possible sample contamination due to the oil used in the air-compressor unless quality air filters are used (this is true for all air methods, unless the contractor uses filters).

http://technology.infomine.com/hydromine/topics/Site_Assessment/Drilling.asp#b1

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Percussive Drilling

Percussive Drilling Bits

Drilling equipment

Down the hole hammer and drill bits
Cable-Tool Percussion Drilling

Cable-tool drilling is a method in which a bit, hammer or other heavy tool is alternately raised and dropped to strike through the formation by breaking the soil or rock. Cuttings are recovered by adding water to the borehole (slurry), which is intermittently bailed out of the borehole. This method is widely used in water wells but of limited application in monitoring work mainly because the method is slow.

**PROS:**
- In situations where the aquifer is thin and yield is low, the method permits identification of zones that might be overlooked by other drilling methods;
- Recovery of representative soil samples at every depth, although samples are disturbed due to the impact of the blow which can affect material several feet below the bottom of the hole;
- Allows well construction with low chance of contamination;
- Borehole can be bailed at any time to determine approximate yield of the formation at a given depth;
- Easy access to rough terrain.

**CONS:**
- Slow penetration rate;
- Due to the constant mixing of water, it is not possible to obtain groundwater samples during drilling;
- Expensive casing for larger diameters;
- Difficult to pull back casing in some geologic conditions.

Air Percussion Casing Hammer Drilling

This method is also called drill through casing driver. It combines the borehole stability of the cable-tool rig and the speed of an air rotary rig. The use of a casing driver permits the casing to be advanced during drilling, but both drilling and driving can be adjusted independently depending on the nature of the formation.

**PROS:**
- Wells can be drilled in unconsolidated materials that could be difficult to drill with cable-tool or direct rotary method;
- No water-based fluid (drilling mud) is required in unconsolidated materials;
- Representative formation and groundwater samples can be collected;
- Borehole is fully stabilized during drilling operations through the use of casing;
- Rapid penetration rates even in difficult drilling conditions;
- Lost circulation problem is rarely a concern, except in very loose materials (e.g. mine waste rock);
- Operates well in cold weather;

**CONS:**
- Method does not permit yield measurements during drilling;
- When groundwater static levels are low, the high air pressure in the hole can prevent water from entering the borehole; a “rest” period is necessary to assess the true static level;
- Relatively expensive method (increased cost of driving casing);
- Borehole diameter limited to 12 inches.

ODEX Percussion Down-The-Hole Hammer Drilling

ODEX is an adaptation of the air-operated down-the-hole hammer. It uses a swing-out eccentric bit to ream the bottom of the casing. The percussion bit is a two-piece bit consisting of a concentric pilot bit behind which is an eccentric second bit that swings out to enlarge the hole diameter. Immediately above the eccentric bit is a drive sub that engages a special internal shouldered drive shoe on the bottom of the ODEX casing. The ODEX is thus pulled down by the drill stem as the hole is advanced.

**PROS:**
- Rapid removal of cuttings;
- No use of drilling mud;
- High penetration rate, especially in resistant rock formation (e.g. basalt);
- Easy soil and groundwater sampling during drilling;
- Possible to measure yield estimate at selected depth in the formation;
- Advantageous in unconsolidated formations with a high risk of caving (this is the probably the most important feature);

**CONS:**
- Practically restricted to unconsolidated formations.
- Relatively a more expensive method
Components of Drilling

• Cutting
• Flushing
• Cooling

Drilling Fluid

• Borehole stabilization
• Cooling
• Flushing

Drilling Mud

• Mixture of water and mineral particles in suspension, specific gravity and viscosity greater than water
• Basic clay is bentonite
• Also barite

Drilling and Rock Coring

<table>
<thead>
<tr>
<th>Purpose</th>
<th>Consistency</th>
<th>Proportion Unit of Water to Bentonite</th>
</tr>
</thead>
<tbody>
<tr>
<td>Support of borehole</td>
<td>Very thick cream</td>
<td>27 kg (60 lb.)</td>
</tr>
<tr>
<td>Removal of cuttings</td>
<td>Thick to very thick cream</td>
<td>11–27 kg (25–60 lb.) depending on soil grain size</td>
</tr>
<tr>
<td>Retention of sample in sampler</td>
<td>Thin to thick cream</td>
<td>9–27 kg (20–60 lb.)</td>
</tr>
<tr>
<td>Assist in cutting action of sampler</td>
<td>Thin to thick cream</td>
<td>11–23 kg (25–50 lb.)</td>
</tr>
</tbody>
</table>

* Unit of water is 379 l (100 gal.).
Core bits

Sampling

- Drill Cuttings
- Core Barrels

Core Barrels

- Single tube
- Double tube
- Triple tube
- Oriented core
- Lexan liners

### DIMENSIONS OF CORE SIZES

<table>
<thead>
<tr>
<th>Name</th>
<th>Diameter of Core (in)</th>
<th>Diameter of Reechicle (in)</th>
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<tr>
<td>LDXM</td>
<td>.75 (19.05)</td>
<td>.77 (19.64)</td>
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<tr>
<td>AX</td>
<td>.97 (24.64)</td>
<td>.97 (24.64)</td>
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<tr>
<td>APMN</td>
<td>1.05 (26.71)</td>
<td>1.07 (27.15)</td>
</tr>
<tr>
<td>APMV</td>
<td>1.05 (26.71)</td>
<td>1.07 (27.15)</td>
</tr>
<tr>
<td>AO-Feather AN</td>
<td>1.05 (26.71)</td>
<td>1.07 (27.15)</td>
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<tr>
<td>EZ</td>
<td>1.34 (34.06)</td>
<td>1.34 (34.06)</td>
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<tr>
<td>CTM, CTMD</td>
<td>1.34 (34.06)</td>
<td>1.34 (34.06)</td>
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<tr>
<td>FOB (Feather BUC)</td>
<td>1.66 (42.20)</td>
<td>1.66 (42.20)</td>
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<tr>
<td>HO, Feather BU</td>
<td>1.66 (42.20)</td>
<td>1.66 (42.20)</td>
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<tr>
<td>NIS</td>
<td>1.66 (42.20)</td>
<td>1.66 (42.20)</td>
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<tr>
<td>SOB, Feather NNC</td>
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<td>1.87 (47.51)</td>
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<tr>
<td>NV, Feather SS</td>
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<td>1.87 (47.51)</td>
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<tr>
<td>SPOC (Feather, Reesicle)</td>
<td>3.12 (79.28)</td>
<td>3.12 (79.28)</td>
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<tr>
<td>HO Tube</td>
<td>3.75 (95.25)</td>
<td>3.75 (95.25)</td>
</tr>
<tr>
<td>TP, Poc Stand</td>
<td>3.75 (95.25)</td>
<td>3.75 (95.25)</td>
</tr>
</tbody>
</table>

Single Tube

AASHTO Man. Sub. Inv.
Double Tube

Triple Tube

Lexan
Oriented Core

- Physical alignment
- Paint or acid marking
- Craelius core orientator
- Oriented core barrels

Orienting Core Barrels

Reorienting Core Using a Goniometer

Core Handling

Images from the collection of Dr. J. A. Franklin
Core Logging

Insitu Testing

1. Borehole imaging
2. Downhole geophysics
3. Hydrogeology tests
4. Pointload test
Borehole Optical Imaging

Point Load Test

Images from the collection of Dr. J. A. Franklin

Point Load Testing

Drilling Issues
1. Drilling rates
2. Core photographs
3. Rock classification
4. Recovery
5. RQD (Rock Quality Designation)
6. Fluid loss
7. Core storage and labeling
8. Care and preservation of samples
9. Boring closure

More Drilling Issues
1. Acquire subsurface information required
2. Verify compliance with company policies and contract specifications
3. Coordinate with all subcontractors
4. Examine drilling and sampling equipment for defects
5. Maintain a subsurface information summary
6. Production summary
7. Logs
8. Regular reports
9. Monitor groundwater levels
10. Comply with laws and regulations
11. Communicate with project manager