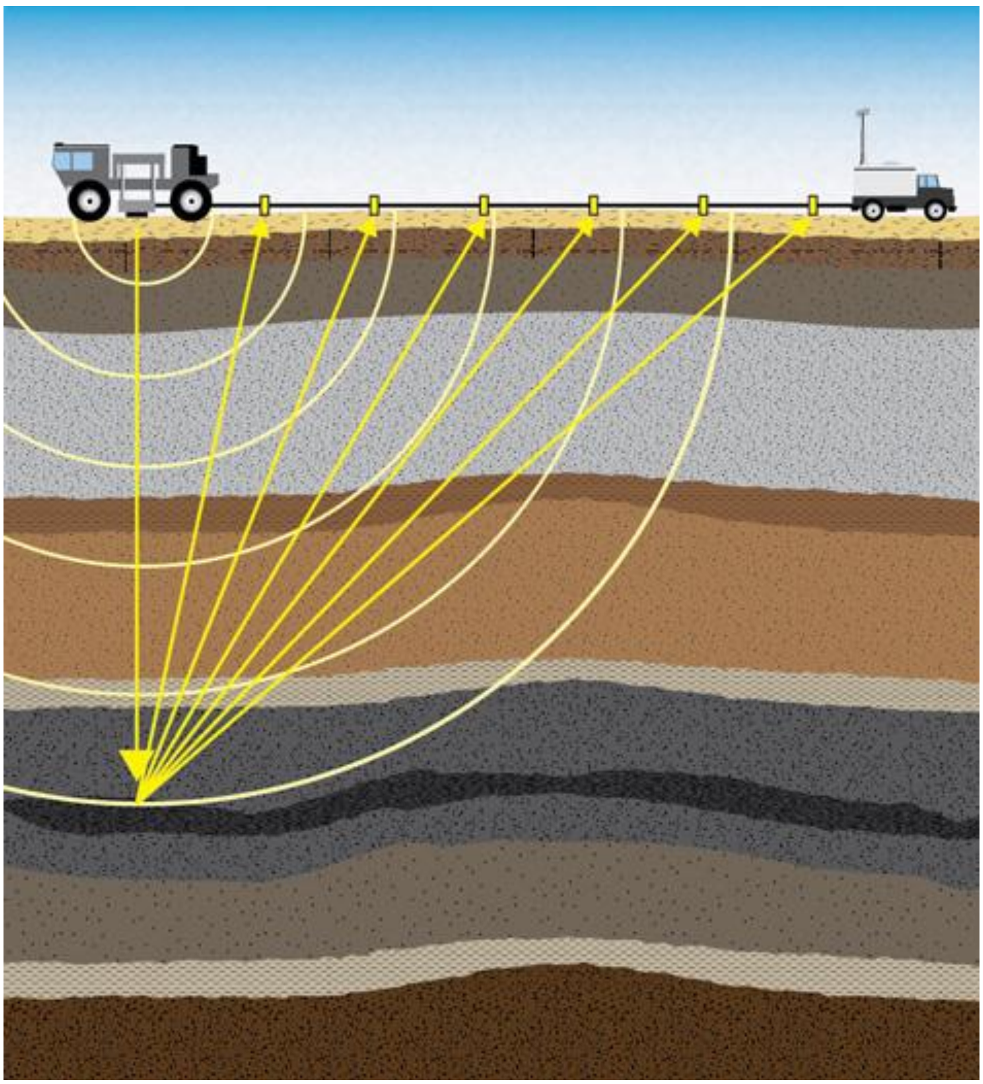
Subsurface Geology

4th Year Geology (All)



Geology Department (2017)

Dr. Abdel Mawgoud

Introduction

When conducting any detailed subsurface geologic study, a variety of maps and cross sections may be required. The numerous techniques available to use in the preparation of these maps and sections are discussed in subsequent chapters.

As mentioned earlier, the primary focus of this book is on the maps and cross sections used to find and develop hydrocarbons. However, the techniques are applicable to many other related geologic fields. The following is a list of the types of maps and sections discussed in this book.

SUBSURFACE MAPS. Structure, structural shape, porosity top and base, fault surface, unconformity, salt, net sand, net hydrocarbon, net oil, net gas, interval isopach, isochore, facies, and palinspastic maps.

CROSS SECTIONS. Structure, stratigraphic, problem solving, final illustration, balanced, and correlation sections. Conventional and isometric fence diagrams and three-dimensional models are also presented.

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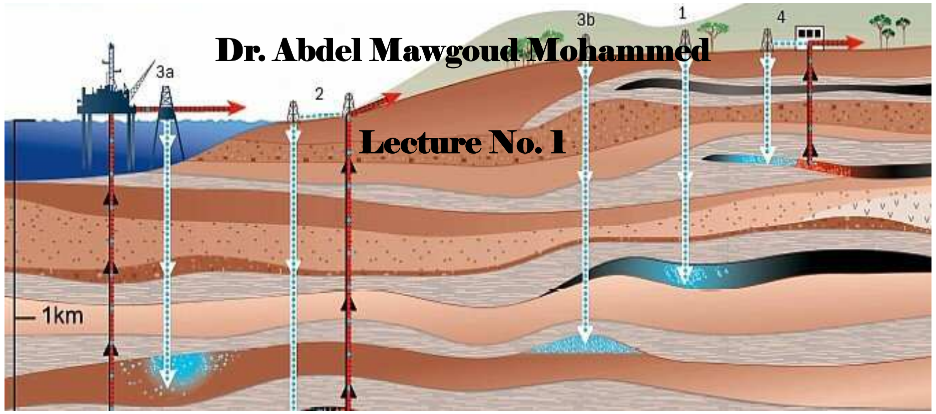
SUBSURFACE GEOLOGY



Dr. Abdel Mawgoud Mohammed

Lecture No. 1

Course Data

Course Code: 440G

Target Group: 4rd year students of GEOLOGY DEPARTMENT, (Geology, Geophysics, Geology and Chemistry)

Course Credits: 1 CTS

Course Material: PPT Presentation on board; books on reference list; Other materials.

Reference Textbooks

Tearpock, D. & Bischke, R. 1991: Applied Subsurface Geological Mapping. Prentice Hall PTR, New Jersey. 676 p.

Furthermore:

Asquith, G. and Krygowski, D. 2004. Basic Well Log Analysis, 2nd edition. AAPG Methods in Exploration Series,28, 244pp.

Jonathan C and Evenick, (2008): Introduction to well logs & subsurface maps. PennWell Corporation. 256 pp.

Course Description

This course aims at introducing the students to the basics of Subsurface Geology, a vast field that includes:

Subsurface geology is the study of the physical properties and location of rock and soil found below the ground surface. One of the most valuable reasons for learning about the **subsurface** is their application to the petroleum industry and understanding the materials below man-made structures.

It is your course

Make the best of it!

Introduction

- ❖ Objectives of subsurface mapping
- ❖ Methods
- ❖ Before you start

Objectives

- **Most of the Earth's structure and stratigraphy are hidden.**
- **Structure/stratigraphy may host features of economic or academic importance.**
- **Need to be able to map/interpret the subsurface.**

- **Petroleum industry**
  Explore for and develop oil and natural gas reserves
- **Mining**
  Explore for and develop minerals and other economic deposits
- **Groundwater**
  Explore for and develop groundwater
- **Waste disposal**
  Find suitable repositories for waste
  Environmental remediation

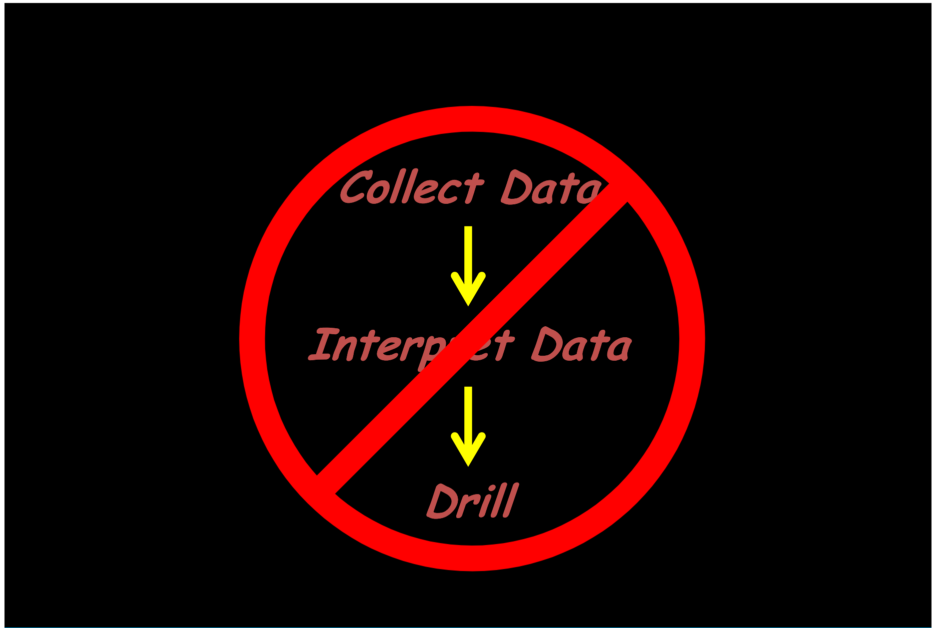
- **Geotechnical engineering**
  Locate and map the distribution of layers with specific properties.
- **Academic studies**
  Structure, stratigraphy
- **Develop the most reasonable subsurface interpretation(s) for the area being studied, even in areas where the data are sparse or absent.**
  Integration of different types of data.
- **Interpretations used to direct future exploration & development.**

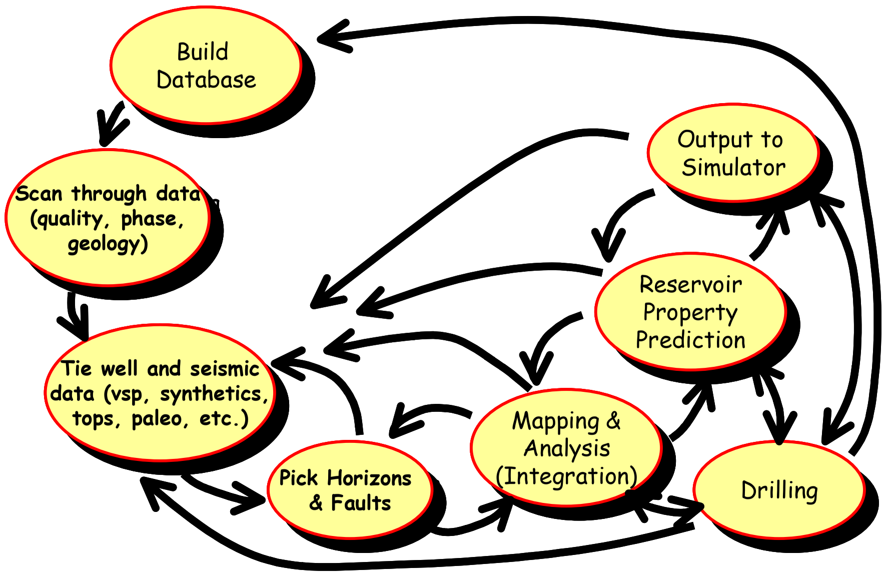
Methods

- **Previous reports**
- **Potential field data (gravity, aeromag)**
- **Seismic data (2-D, 3-D)**
- **Ground-penetrating radar**
- **Core, cuttings ("samples")**
- **Wireline logs**
- **Engineering data (fluids, pressures, etc.)**
- **Etc.**

Methods

- Without understanding what you're doing, you'll get a wrong answer.
- Interpretations (maps, etc.) are working hypotheses, never "final".
  - May need to update, revise as new data become available.
  - Easier with digital data.





Before You Start

- Need clear definition of objectives.
  - Structure? Stratigraphy? Exploration? Development? Etc.
  - Without knowing where you're going, you're unlikely to get there…
- Need good understanding of structural geology, stratigraphy and other related fields.
  - The more geology one knows, the more reasonable the resulting interpretation
- Need good understanding of physical basis for any geophysical methods being used.

Before You Start

- **Use correct mapping techniques and methods.**
  - Prepare reasonable subsurface maps and cross-sections
  - "Maps and cross-sections are the primary vehicles used to organize, interpret and present available subsurface information"
  - Digital products (e.g., volumes) becoming more common
- **Need to define fault behavior in 3-D.**
  - Faults may have important affects on location, movement of fluids
  - Show location of faults on maps, but also map fault surfaces
  - May need to do structural reconstruction to validate accuracy of fault interpretations

Before You Start

- **All subsurface data need to be used to develop a reasonable and accurate subsurface interpretation.**
  - Geologic (including paleontologic), geophysical, engineering.
  - Attention to resolution, accuracy of each type.
  - Integration of different types of data results in more robust interpretation.
- **Need to document the work done.**
  - Lots of data likely to be collected and/or generated – document in a format that may be referenced, used, revised.
  - People working on project may change, may want to "revisit" work many years after it is done.
  - Electronic media (PowerPoint files, hypertext documents, etc.) good vehicles – especially when working with digital data.

Summery

- Subsurface mapping of important economic & fundamental importance
- Push towards digital, computer-based interpretation
- Need to understand fundamentals – geology, geophysics
- Integration of different types of data results in more robust interpretation

- Drive vehicles according to local conditions and comply with road or site rules.
- Routinely practise good housekeeping.
- Work as part of a team.
- Treat co-workers in a manner that promotes a safe working environment and goodwill.
- Maintain an acceptable level of personal hygiene.
- Comply with any particular directives from the client's representative relating to safety, health, and environmental issues.
- At all times comply with the company's safety and environmental policy, procedures, and practices.
- Report all accidents, incidents and near misses on the day they occur to the correct personnel, so that they can be investigated and do not reoccur.
- Respond to an emergency or potential emergency situation, and perform first aid if required.
- Participate in emergency response drills as required.
- Regularly check site safety boards for notices and safety alerts.
- Cooperate at all times with the client's representative.
- Participate in any inductions and training sessions when requested.
- Attend and participate in toolbox and safety meetings.
- Give/receive and clarify shift handovers.
- Carry out pre-start checks.
- Operate communications equipment (including radios, mobile telephones, and satellite telephones).
- Tag out any faulty equipment and report the problem to the driller so that maintenance can be carried out.
- Correctly maintain PPE as supplied, and check and maintain safety equipment.
- Promote safety and goodwill when clients and third parties visit the drill site.
- Comply with company confidentiality requirements and prohibitions in relation to communicating the status/results of the drill program.
- Participate in internal or external training, as directed by the company.
- Help to control any damage to the environment.
- Clean up oil or chemical spills in accordance with procedures and as recommended by relevant MSDS.

1.4 Drilling industry sectors

Drilling has existed as an industry since the Chinese erected the first cable-tool rig approximately 4000 years ago.

Since the development of drill rigs, techniques and applications have led to the industry's expansion into the following specialised sectors:

- Blast hole
- Environmental
- Foundation and Construction
- Geotechnical (site investigation)
- Geothermal
- Mineral exploration
- Mineral production and development
- Oil and Gas: Offshore
- Oil and Gas: Onshore
- Seismic
- Trenchless technology
- Water well.

Definitions of each drilling sector follow, along with brief outlines of the applications involved. Processes and spheres of influence overlap in many cases.

Blast hole drilling

Holes are drilled for explosives, which are detonated to remove rock, ore, or minerals. The sector covers:

- mines where surface and underground drilling is part of the extraction processing for valuable ore, including the removal of waste to access the ore body
- quarries to produce road or construction materials and dimension stone
- construction of roadworks, dam sites, and breakwaters.

Environmental drilling

This industry sector uses specialised geotechnical drilling and water well drilling methods to:

- monitor the quality of groundwater and assist in the control and remediation of groundwater pollution
- test and monitor landfill sites, pollution of lagoons and sensitive sites (e.g. protected land, water supply well fields, chemical, or hydrocarbon storage sites)
- determine the source or extent of pollution problems
- sample and construct wells for recovering or remediating pollutants in groundwater
- support work at archaeological sites.

Foundation and Construction drilling

This industry sector uses drilling to:

- establish stable foundations
- increase bearing capacity by drilling deeper into stronger rock
- provide shear strength between the rock face and in-situ concrete
- form foundations for buildings or other constructions, such as bridges, railways, factories, processing plants, wharves, and dams
- provide holes and casings that become part of a structure, such as piles or large diameter holes in bedrock/firm ground that are filled with reinforced concrete to become foundations.

Under-reaming and caisson development are specific applications used in this industry sector:

- **Under-reaming** is the process of enlarging a hole beneath the casing to allow the casing to move down the hole – this is extremely useful when drilling ground that is not self supporting and keeps on collapsing.
- **Caisson** is a large watertight structure in which underwater construction work may be carried out.

Geotechnical (site investigation)

This type of drilling is carried out to determine soil and rock characteristics. In some cases, it is also used to gather information about the nature and position of the water table from particular sites. Drilling is conducted to assess potential construction sites and to confirm conditions.

It is important to have detailed information about soil and rock properties obtained from Geotechnical drilling so that buildings or tunnels are not placed on top of, or cut through, unstable or weak material.

Geotechnical drilling precedes construction, and Foundation and Construction drilling.

Geotechnical surface projects include:

- Buildings and storage structures
- Factories and plants
- Dams, bridges, and roads
- Wharves and other civil works.

Below surface projects include:

- Tunnels and shafts
- Access or inspection holes
- Storages
- Underground silos
- Power stations.

Geothermal drilling

This industry sector uses drilling to generate electric power from steam turbines, which are powered by steam that is produced from hot water recovered from the drill holes.

There are two main types of hydrothermal deposits:

- hot water springs
- hot rocks.

Hot rocks require injection wells as well as production wells. Water is injected into the ground, where it is heated by the rocks and then recovered from the production wells.

Mineral exploration drilling

This industry sector uses drilling to search for valuable minerals or materials.

Drilling is conducted to:

- search for new ore bodies
- determine the size and grade of an ore body (resource definition)
- collect stratigraphic information
- carry out geochemical surveys

- perform gravity or magnetic survey interpretation enhancement
- undertake grade control (i.e. determine what is uneconomical to treat, and then drill to identify what can be treated during the mining process)
- check that no economic ore or materials are below sites for a proposed waste dump, dam, plant, or building (sterilisation drilling)
- explore for ore bodies.

Mineral production and development

This industry sector drills holes on the surface and underground to develop mines and to produce ore. It includes drilling for:

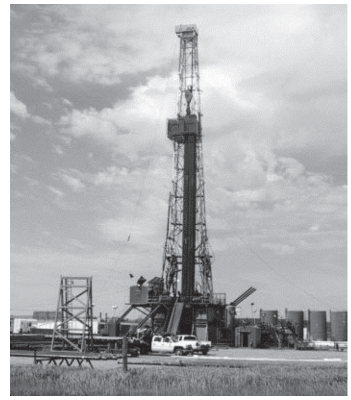
- services in underground mines, such as electric cables, water pipes, or compressed air lines
- access ways, ventilation, or fill-holes for sand or slurry.

Downhole hammer drilling, up-hole hammer drilling, and raise boring are three specific drilling methods used in this sector.

Oil and Gas drilling: Offshore

This sector is similar to Oil and Gas: Onshore, except that holes are drilled using floating platforms and ships.

Oil and Gas drilling: Onshore



In this industry sector the holes are usually relatively deep, involve large equipment, and use drilling mud to stabilise the hole and prevent blow-outs. Drilling processes used in oil and gas drilling include:

- stratigraphic drilling – to improve the understanding of the local geology
- exploration drilling
- building production wells for oil and gas
- building water or gas injection wells for secondary recovery
- coal seam gas drilling.

With coal seam gas drilling, a directionally controlled drill hole is drilled to intersect and travel along the seam until it intersects a vertical production bore. Perforated casing is installed in the hole to enable the gas to travel to and up the production bore when the hydrostatic pressure is lowered by pumping water from the production bore.

Seismic drilling

This industry sector usually operates in remote areas, drilling shallow holes for explosives used in reflection and refraction surveys.

It is usually associated with:

- gaining knowledge of subsurface geology over large areas
- identifying targets for mineral, oil, and gas exploration.

Trenchless technology

In this industry sector:

- directional drilling is used to drill large diameter bores in hard rock or other difficult geology
- guided boring is used to drill small/medium diameter bores in moderate geology
- product pipe is installed in a directionally drilled or reamed/widened hole (e.g. for methane drainage, services and pipes under roads, railways, buildings, dams, lagoons, or lakes).

Water well drilling

This industry sector uses drilling to:

- monitor water levels or wells
- construct production wells
- dewater wells at mine and construction sites
- create injection wells.

Ninety-seven per cent (97%) of fresh water on earth is underground and the water well drilling sector supports sourcing and delivering water for:

- domestic or stock use and irrigation in farming
- town water supplies or industrial/mineral treatment plants.

1.5 Drilling objectives

There are many reasons to drill a hole, For example, to:

- put something in for storage or disposal
- pass through something for access (e.g. shafts, tunnels)
- gain information from the drilling itself, from tests/measurements made in the hole or from formation samples recovered from the hole
- produce oil, gas, steam, water, molten, or dissolved minerals.

The reason for making a hole is called the drilling objective. It consists of four important parts:

- **Statements** — tell the driller what to do and why
- **Standards** — tell the driller the measurement, drilling angle, and drill logging requirements
- **Conditions** — tell the driller how, when, and where the standards apply
- **Checks** — tell the driller the method to use to ensure that the standards are being met.

The **Statements** clearly set out the objective. It is important that statements are clearly worded so that the driller can understand them. After all, he cannot be expected to do a job unless he has a clear picture of what it is he is expected to do.

For example: *Drill an exploratory hole to produce data on the nature and position of the formations; and produce chip samples for laboratory testing.*

The **Standards** tell the driller the precise requirements for drilling. Certain standards will be required for every hole and they must be adhered to exactly. They are a measurement of the work to be performed.

Examples are:

- *The hole to be drilled must be drilled within 0.5 metres (18 in) of the peg*
- *The hole must be drilled to a depth of 100 metres (300 ft)*
- *The minimum hole diameter is to be 125 mm (5 in)*
- *The hole must be within 3 degrees of vertical throughout*
- *The sample interval is to be every 1 metre (3 ft)*
- *Drilling logs must record changes of formation within 0.2 metres (8 in) of the correct position.*

The **Conditions** provide a frame of reference for the work (i.e. how, when, and where the standards apply). They may describe site access or weather conditions and their effect on the drill site or hours of work.

They could comprise the following:

- *Drilling is to be conducted only during the dry season*
- *Drilling will be performed only during daylight hours*

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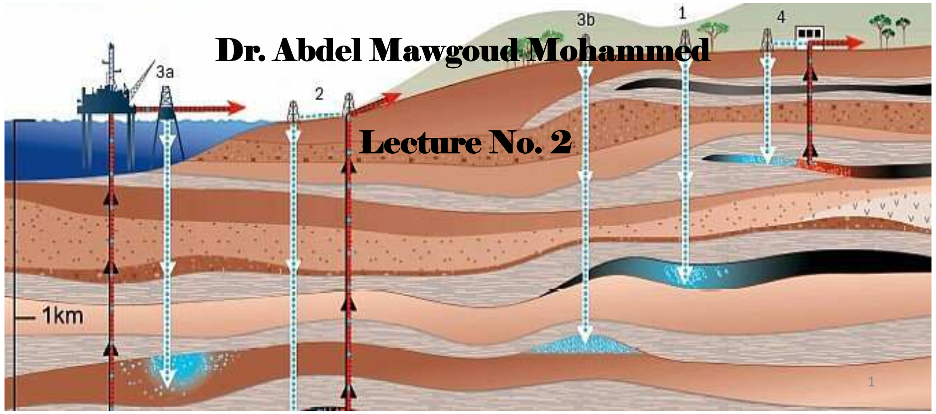


Dr. Abdel Mawgoud Mohammed

Lecture No. 2

Drilling

Drilling occurs in all nations around the world, and in the seas surrounding those nations, using drilling rigs to bore into the earth.

Drilling

- provides information about resources (**minerals, construction material, oil, gas, water**) and also provides access to those resources.
- helps with developing infrastructure in foundations, piling, and constructing dams, and in laying underground cables for energy transmission and communications.
- helps to gather information such as ground strength, ground formations and composition, and the presence and quality of groundwater (geotechnical, seismic, and environmental).
- **deals with a subject which should interest both the geologist and the engineer.**

Introduction to drilling methods

- There are several different types of drilling methods used worldwide.
- Drilling methods describe how holes are made. Different methods have different characteristics and applications.
- The conditions or objectives for drilling usually determine the method to be used.
- Various well drilling methods have developed because geologic conditions range from hard rock such as granite and dolomite to completely unconsolidated sediments such as alluvial sand and gravel.

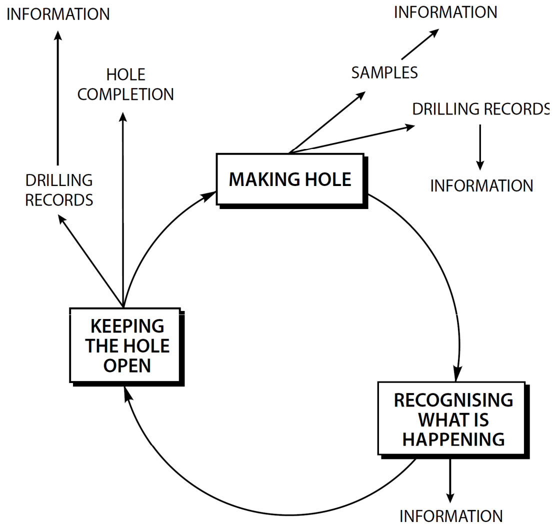


Figure 1–1: The Drilling Process

Drilling methods

1. Cable-tool drilling
2. Auger drilling
3. Rotary drilling

1. Cable-tool drilling

- Cable-tool drilling has its beginnings 4000 years ago in China.
- It was the earliest drilling method and has been in continuous use.
- In 1859 an early form of this type of drilling was used to drill the first oil well (in Pennsylvania, USA).
- Cable-tool rigs are sometimes called pounders, percussion, spudder or walking beam rigs.

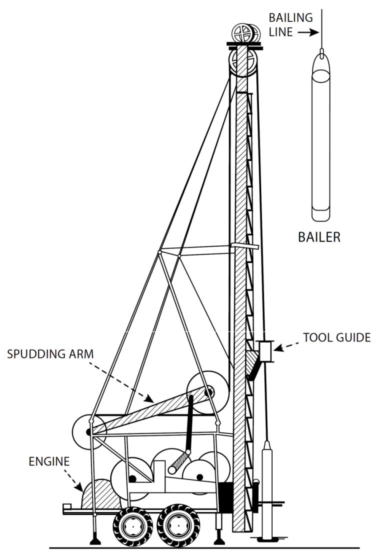


Figure 3–27: Cable-tool drill rig

A string of Cable-tool consisting of:

1) a rope socket
2) a set of jars
3) a drill stem
4) a drilling bit

Total weight of the above is several thousand kilograms.

Drilling bit alone weight 1500 kg and 1 to 3 m length.

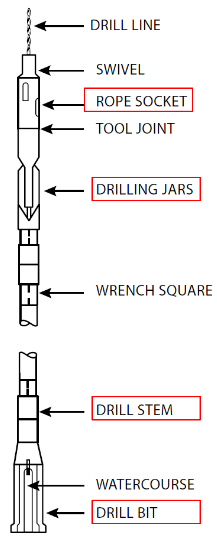


Figure 3–28: Drill string

Advantages of cable-tool drilling

- Low capital investment and cheap maintenance.
- Produces high-quality samples in unconsolidated.
- Particularly suitable for water well work.
- Suited to remote area operation. Fuel consumption is about 15–20 litres (4–5 US gal) per day.
- Can drill economically and obtain samples in cavernous formations.
- In general, with a single tool string it can drill in a greater variety of lithologies than other drill types.

Disadvantages of cable-tool drilling

- Productive output measured in hole produced per day is relatively low in most cases.
- Rock penetration rates may be extremely low.
- When casing is required, deep drilling presents problems in keeping the casing free.
- The heavy hammering action causes disturbance and damage in some formations, resulting in mixed samples.
- Geophysical logging of a cased hole is restricted to neutron and gamma logs.

2. Auger drilling

In soils or unconsolidated formations, auger drilling provides the advantages of low capital and operating costs.

Mechanical clearing of the hole also eliminates any need for pumps or compressors.

A tractor-mounted auger drill

Types of auger drilling

1. Continuous flight augers

- **Small diameter holes, continuous flight augers are supported by the hole.**
- **Cuttings are carried to the surface on the helical flights.**

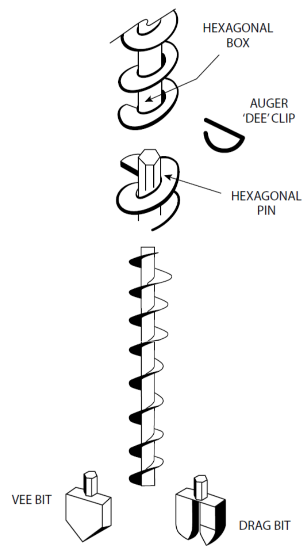


Figure 3–74: Continuous flight auger drill string and bits

2. Hollow augers

- Are continuous flight augers that have a hollow centre tube.
- They are normally used with a **plug bit** held in place by a secondary internal rod string, or simply by friction.
- Water sampling can also be conducted in the auger string, or using small-diameter wells set through the inside of the string.

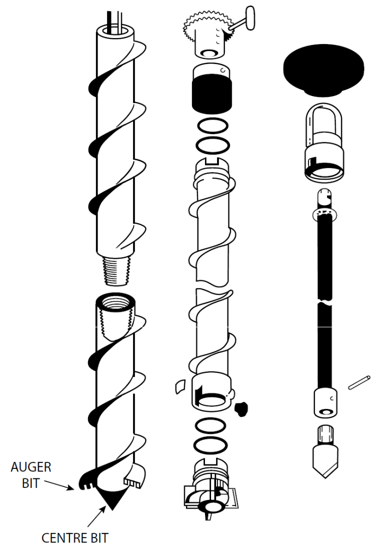
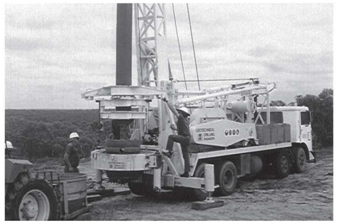


Figure 3–75: Hollow auger components

3. Bucket augers

Figure 3–77: Auger bucket [2]

The cuttings are picked up in the bucket, hoisted to the surface and dumped through the hinged bottom of the bucket.



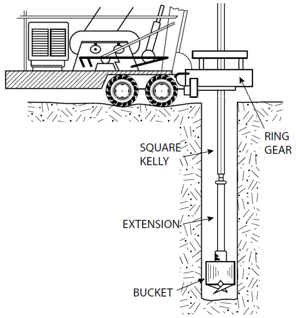


Figure 3–78: Table drive bucket auger drill

Applications of auger drills

Auger drills find their main application in soil and unconsolidated groundwater investigations, and in drilling for construction in soils and very soft rock. When a boulder is encountered make it hard for augers themselves.

Auger drills used for:

- Site investigation.
- Geochemical sampling.
- Environmental drilling and sampling.
- Alluvial mineral investigations.
- Electrode holes.
- Holes for cast in situ foundation piers.
- Mineral sampling.
- Access holes.

3. Rotary drilling

- What is rotary drilling?
- Forms of rotary drive
- Rotary mud drilling
- How the rotary drill string works
- Rotary drill string components
- Suspension and drive components
- Drill collars or stabiliser bars
- Reamers and drill collar stabilisers.

Drilling Rig Components

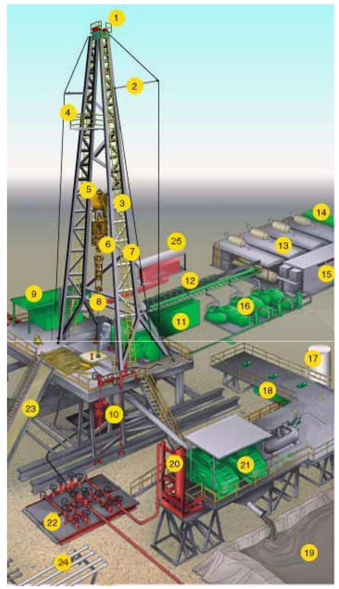
Drilling Rig Components

Click on the name below or a number on the graphic to see a definition and a more detailed photo of the object.

1. Crown Block and Water Table
2. Catline Boom and Hoist Line
3. Drilling Line
4. Monkeyboard
5. Traveling Block
6. Top Drive
7. Mast
8. Drill Pipe
9. Doghouse
10. Blowout Preventer
11. Water Tank
12. Electric Cable Tray
13. Engine Generator Sets
14. Fuel Tank
15. Electrical Control House
16. Mud Pumps
17. Bulk Mud Component Tanks
18. Mud Tanks (Pits)
19. Reserve Pit
20. Mud-Gas Separator
21. Shale Shakers
22. Choke Manifold
23. Pipe Ramp
24. Pipe Racks
25. Accumulator

Additional rig components not illustrated at right.

26. Annulus
27. Brake
28. Casing Head
29. Cathead
30. Catwalk
31. Cellar
32. Conductor Pipe
33. Degasser
34. Desander
35. Desilter
36. Drawworks
37. Drill Bit
38. Drill Collars
39. Driller's Console
40. Elevators
41. Hoisting Line
42. Hook
43. Kelly
44. Kelly Bushing
45. Kelly Spinner
46. Mousehole
47. Mud Return Line
48. Ram BOP
49. Rathole
50. Rotary Hose
51. Rotary Table
52. Slips
53. Spinning chain
54. Stairways
55. Standpipe
56. Surface Casing
57. Substructure
58. Swivel
59. Tongs
60. Walkways
61. Weight Indicator



Equipment used in drilling

What is rotary drilling?

- Rotary drilling is any form of drilling that makes a hole by **turning the bit** on the bottom of the hole.
- It involves rotation as opposed to the up and down action of percussion drilling.
- Rotary drill bits are usually considerably larger in diameter than the drill pipe.
- Fluid circulation is used to clear the cuttings.

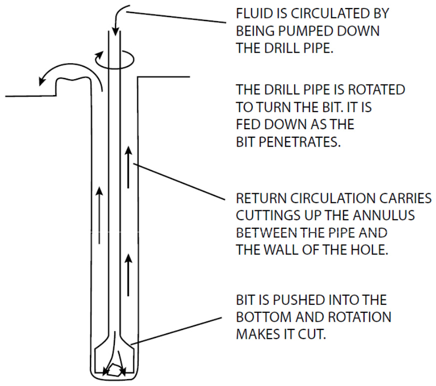


Figure 3–86: Standard circulation rotary drilling

Rotary bits and tools

- The rotary bit drive
- Rotary blade bits
- Rotary roller bit design
- Chip clearing with roller bits
- Bits for soft formations
- Bits for medium formations
- Roller bits for hard formations
- IADC Roller cone bit classification
- Maintaining tricone bits
- Rotary undercutters and hole openers
- Overburden drilling methods.

Rotary blade bits

Unconsolidated formations: These formations are cut with bits having a forged or hard-faced edge suited to stirring. Circulation fluid is directed towards the bottom of the hole through the bit nozzle.

In contrast, **hard clays and consolidated formations** are cut better if a sharp cutting edge is provided. The edge is usually hard faced or fitted with carbide inserts to resist wear. Some formations form better chips if a ploughing action is provided using a finger type drag bit.

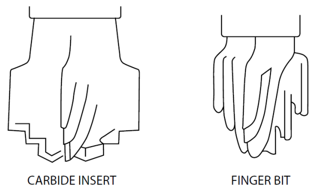


Figure 3–105: Drag bits

Figure 3–106: Drag bits with tungsten carbide inserts

Rotary roller bit design

Roller bits offer many variations, and notable design differences include:

- tooth material, shape, height, and spacing
- cone rolling patterns resulting from changes in shape of the cone and in alignment of the cone axes
- placement, size, and direction of the openings or nozzles directing flow of the circulation fluid
- types of bearings, with differing provision for bearing lubrication.

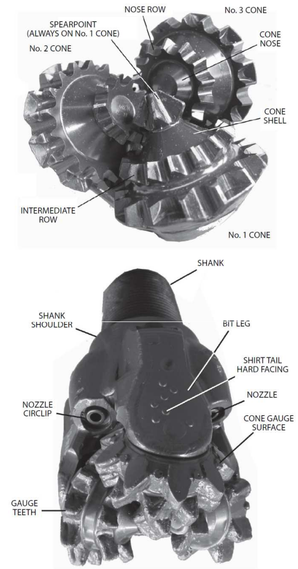


Figure 3–110: Roller bit components

Bits for soft formations

- A roller bit for soft formations with low compressive strength (e.g. calcite, shale, clay) is designed with long teeth to give large penetration and large 'rolling chips', but with comparatively light weight and downwards pressure.
- Widely spaced teeth allow for easier clearing of the 'sticky' chips typical of clay and shale.
- Normally, soft formation bits are run with relatively low weight, for example, ranging from 500 to 1400 kg (1100 to 3000 lb) per inch of bit diameter.

Figure 3–111: Soft formation roller bit

Bits for medium formations

- Bits for medium formations will have a greater number of shorter, more closely spaced teeth, as this design change provides a more chipping-crushing action.
- Bits with teeth comprising chisel-shaped tungsten carbide inserts and carbide gauge and shoulder facings are available.
- Weights generally range from 500 to 2300 kg (1100 to 5000 lb per inch bit diameter) and rotation can range from 60 to 100 rpm.

Figure 3–112: Medium formation roller bit

Bits for hard formations

- Hard rock cannot be torn or cut – it must be fractured.
- High thrust loading is required (e.g. 1800 to 3000 kg, or 4000 to 6000 lb per inch bit diameter).
- The teeth in hard formation bits are either case-hardened steel or tungsten carbide inserts with conical or hemispherical ends.
- To avoid slipping or skidding on the bottom, the bits are rotated at low speeds (e.g. 40–80 rpm).

Figure 3–113: Hard formation button roller bit

Drill collars or stabiliser bars

When a bit is connected directly to the drill pipe, the bending of the pipe allows the hole to deviate severely.
Sometimes a **bit stabiliser** is run to control the bit. The bit stabiliser is a large diameter, thin-walled tube. It provides direction control but not weight. The drill pipe still runs in compression.

Care of drill collars:
The drill collars themselves are in compression and will buckle. But since the tube itself is stiffer than the tube in a drill pipe, the bending occurs at the joint. Tool joints in the drill collars must be given even greater care than the drill pipe joints.

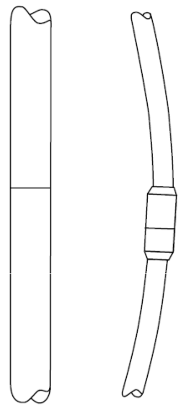
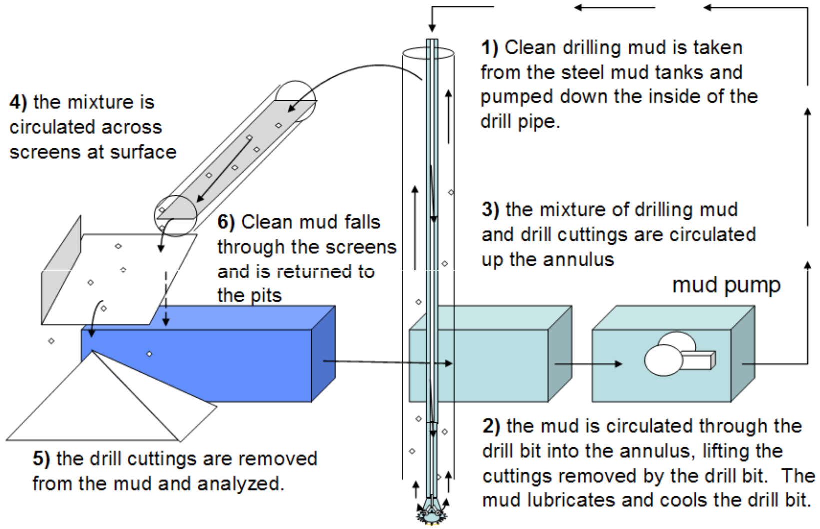


Figure 3–99: Drill collar (left) and drill pipe (right)

○ Rotary mud drilling

- ○ Drilling muds have evolved enormously since 1901, when the first major petroleum discovery using rotary drilling and circulating mud was made at Spindletop, near Beaumont, Texas, USA.
- ○ The Spindletop mud was simply water made viscous by hydrating clay cuttings.
- ○ Today, mud are complex mixtures of bentonite, polymers, thinners, barite and a host of other ingredients that must accomplish several tasks.

Fluid Circulation System



Drilling fluid roles

The drilling fluid plays several functions in the drilling process.

The most important are:

- ○ **clean the rock fragments from beneath the bit and carry them to surface.**
- ○ **exert sufficient hydrostatic pressure against the formation to prevent formation fluids from flowing into the well.**
- ○ **maintain stability of the borehole walls.**
- ○ **cool and lubricate the drillstring and bit.**

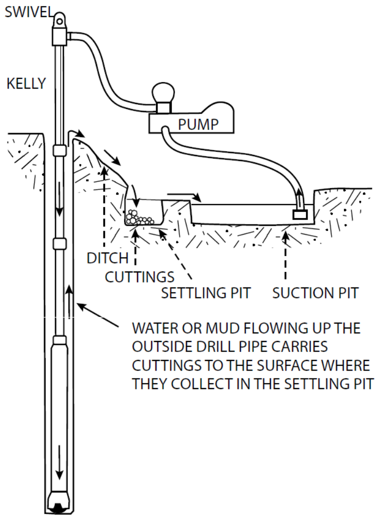
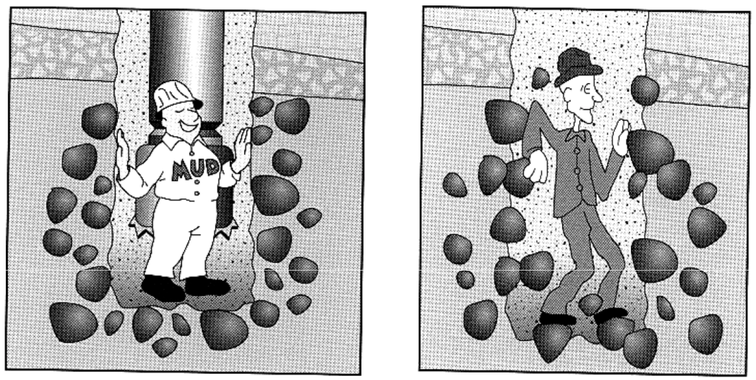


Figure 3–91: Rotary mud/water circulation

2 Support of the Borehole Wall – Balancing Formation Pressures



While Drilling Open Hole
Mud Column should act as „Hydraulic Casing“

Sufficient Mud Density
Good Filtration Properties

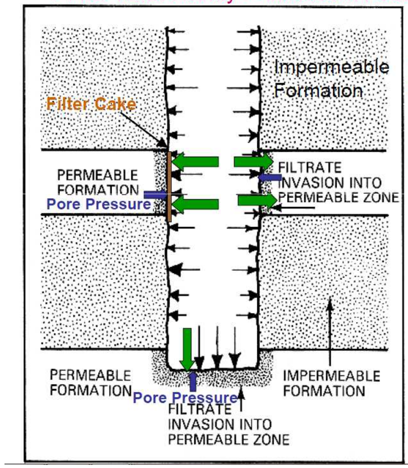
Insufficient Mud Density
Bad Filtration Properties

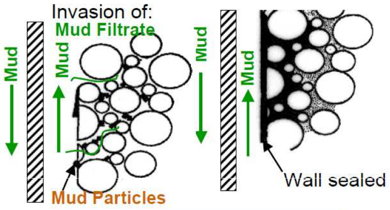
-Uncontrolled Fluid Entry
-Borehole Instabilities
-Differential Sticking

Supporting the Borehole Wall – Hydraulic Casing Effect

Mud Properties

- Mud Density -> Pressure Support
- Filtration Characteristics -> Wall Sealing
- Free Water Activity -> Interaction Rock





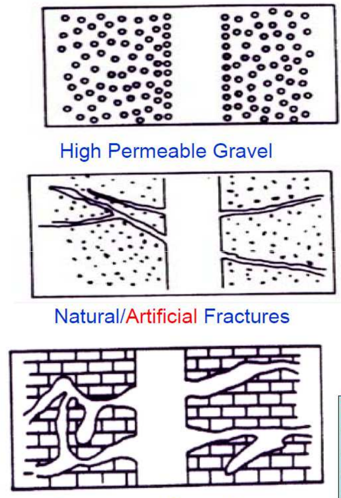
Good Filtration Characteristics

- Quick Filtercake Buildup
- Low Filtration Rate
- Filtercake
  - -thin
  - -impermeable
  - -slick

Minimizing Formation Damage

Prevention of Lost Circulation – Factors to Consider

Types of Lost Circulation Zones

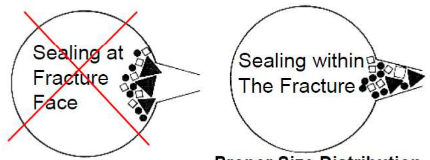


Preventive Methods

- Reducing Mud Density
- Avoiding Pressure Surges
- Lowering Gel Strength
- Lowering Equivalent Circulation Density (ECD)

Fighting Against Lost Circulation

Application of Sealing Material



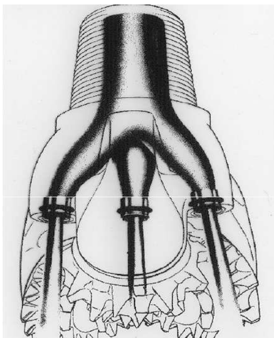
Types of Materials used:

- **Fibrous (Raw Cotton, Mineral Fibers, Glass Fibers)**
- **Flaky (Cellophane, Mica, Cotton Seed Hulls)**
- **Granular (Perlite, Ground Plastic, Nut Shells, Wood)**
- **Thick Slurry Pills (Bentonite/Polymer, Cement)**

Drilling fluid in wellbore

In wellbore:

- The drilling fluid then flows down the rotating drillstring and jets out through **nozzles** in the drill bit at the bottom of the hole.
- The drilling fluid picks the rock cuttings generated by the drill bit action on the formation.
- The drilling fluid then flows up the borehole through the annular space between the rotating drillstring and borehole wall.



Jet Nozzles in a Roller Cone Bit

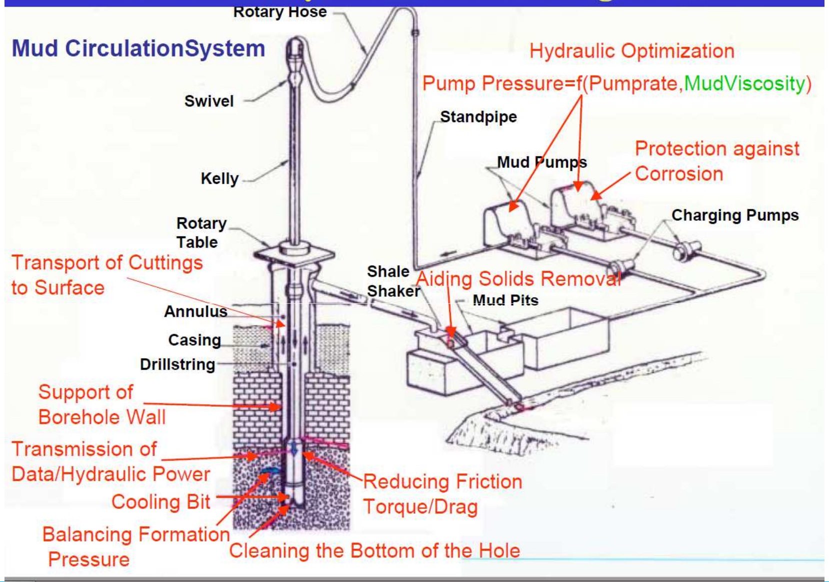
Drilling fluid at surface

At surface:

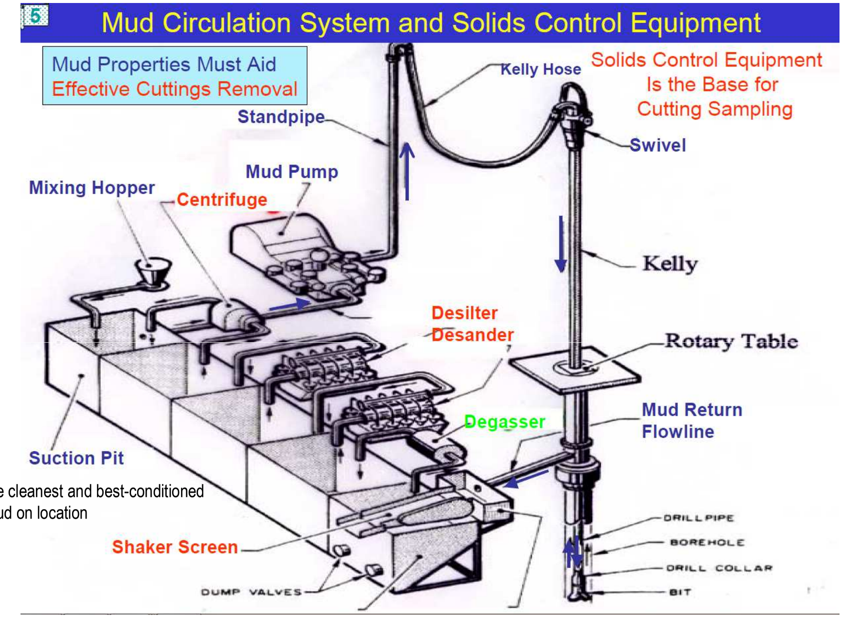
At the top of the well (and above the tank level), the drilling fluid flows through the flow line to a series of screens called the shale shaker.

- The shale shaker is designed to separate the cuttings from the drilling mud.
- Other devices are also used to clean the drilling fluid before it flows back into the drilling fluid pits.

Technical Key Functions of Drilling Fluids



Mud Circulation System and Solids Control Equipment



Fundamentals of Cutting Transport

Drilling/Mud Circulation

Transporting of Cuttings to Surface

↑V_{ann}: Mud Velocity in Annulus depends on:

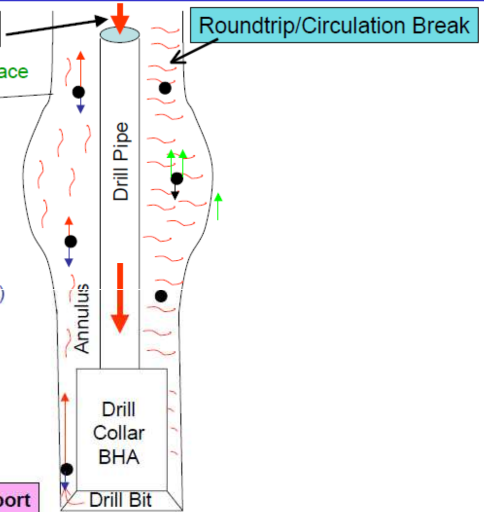
- •Pumprate,
- •Annular Geometry

↓V_{sett}: Cutting Settling Velocity depends on:

- •Mud Parameters
  - Rheology (Viscosity)
  - Density
- •Cutting Parameters
  - -Density
  - -Diameter
  - -Shape

$V_{ann} >> V_{sett}$

Basic Law of Cuttings Transport
$(V_{ann} - V_{sett})/V_{ann} > 50\%$



Single Tube Reverse Circulation:

- Reverse circulation (RC) moves the fluid down the borehole outside the drill pipe, into the bit, and up the inside of the drill pipe.
- This technique was originally developed to drill large diameter bores (up to 1.2 m) in unconsolidated formations efficiently, but has since been adapted for many purposes.
- Most RC drilling of this type is done with water rather than with an engineered mud, or with a very light mud.
- RC requires very large mud pits that must be transported or dug by dozer.

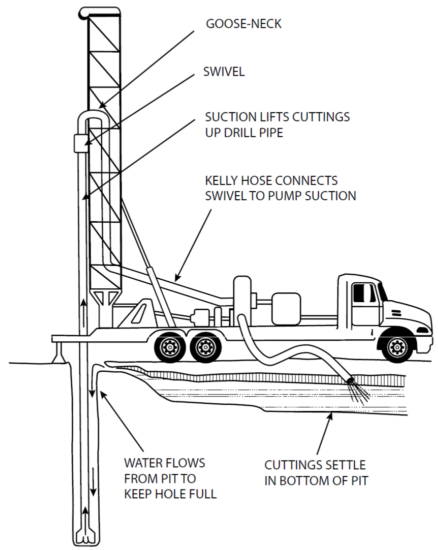


Figure 3–92: Single tube reverse circulation

Drilling Fluids

Drilling fluids include both gases and liquids, liquids are called drilling mud, where the drilling mud is one of the most important elements of any drilling operation. The mud has a number of functions which must all be optimized to ensure safety and minimum hole problems. Failure of the mud to meet its design functions can prove extremely costly in terms of materials and time, and can also jeopardise the successful completion of the well and may even result in major problems such as stuck pipe, kicks or blowouts. There are basically two types of drilling mud: water-based and oil-based, depending on whether the continuous phase is water or oil. The water-base mud is the most commonly used. The use of oil-base mud is usually limited to drill extremely hot formations or formations that are affected adversely by water-base muds. Where the use of gasses is limited to formations that are competent (hard) and impermeable. Gas–liquid mixtures can be used when only a few formations capable of producing water at significant rates are encountered. Then there are a multitude of additives which are added to either change the mud density or change its chemical
properties.

Drilling mud selection: (Data REQUIREMENTS)

The following information should be collected and used when selecting drilling fluid or fluids for a particular well. It should be noted that it is common to utilize two or three different fluid types on a single well.

1. The range of temperature, strength, permeability, and pore fluid pressure exhibited by formations (Pore pressure /fracture gradient plots to establish the minimum / maximum mud weights to be used on the whole well).
2. Offset well data (drilling completion reports, mud recaps, mud logs etc.) from similar wells in the area to help establish successful mud systems, problematic formations, potential hazards, estimated drilling time etc.
3. Types of formations to be drilled.
4. Casing design program and casing seat depths. The casing scheme effectively divides the well into separate sections; each hole section may have similar formation types, similar pore pressure regimes or similar reactivity to mud.
5. The water quality available.
6. Restrictions that might be enforced in the area i.e. government legislation in the area, environmental concerns, etc.

Drilling Fluid Functions:

The drilling mud must perform the following functions:

1. **cool the drill bit and lubricates its teeth**: one of the prime functions of the drilling fluid or mud is to cool the drill bit and lubricate its teeth. The drilling action requires a considerable amount of mechanical energy in the form of weight on bit, rotation, and hydraulic energy. A large proportion of this energy is dissipated as heat, which must be remove to allow the drill bit to function properly, the drilling mud also helps the removing of the rock cuttings from the space between the bit teeth, thereby preventing **bit balling** which is one of the common problems in drilling process.

2. **lubricates and cool the drillstring:** a rotary drillstring generates a considerable amount of heat which must be dissipated outside the hole. The drilling mud helps to cool the drillstring by absorbing the heat and releasing it, by convection and radiation, to air surrounding the surface mud tanks (pits). The mud also, provides lubrication by reducing friction between drillstring and borehole walls. Lubrication is usually achieved by the addition of bentonite, oil, graphite, etc.
3. **control formation pressure:** for safe drilling, high formation pressure must be contained within the hole to prevent damage to equipment and injury to personnel. The drilling mud achieves this by providing a hydrostatic pressure just greater than the formation pressure. For effective drilling, the difference between the hydrostatic pressure and formation pressure should be zero. The hydrostatic pressure depends on the mud weight which, in turn, depends on the type of solids added to the fluid making up the mud and the density of the continuous phase. In practice, an overbalance,(Where the pressure in the wellbore in higher than the pressure in the formation), 100 to 200 psi (trip margin) is normally used to provide an adequate safe guard against well kick. The pressure overbalance sometimes referred to as chip hold down pressure (CHDP), and its value directly influences penetration rate. In general, penetration rate decreases as (CHDP) increases. When an abnormally pressured formation is encountered, the (CHDP) becomes negative and sudden increase in penetration rate is observed. This is normally taken as an indication of a well kick.
4. **carry cuttings out of the hole:** for effective drilling, cuttings generated by the bit must be removed immediately. The drilling mud carries these cuttings up the hole and to the surface, to be separated from the mud. The removal of cuttings depends on the viscous properties called "Yield Point" which influences the carrying capacity of the flowing mud and "gels" which help to keep the cuttings in suspension when the mud is static to prevent them from accumulating on the bottom of the hole and causing pipe sticking. The flow rate of mud is also critical in cleaning the hole.
5. **stabilize the wellbore and prevent it from caving in:** the formation of a good mud cake helps to stabilize the walls of plaster to interior walls (like plastering a room walls to keep them from flaking). The pressure differential between hydrostatic pressure of mud and that of the wellbore stable. Shale stability is largely dependent on the type of mud used to minimize the swelling stresses caused by the reaction of the mud with the shale formations. This reaction can cause hole erosion or cavings resulting in an unstable wellbore. Minimization of wellbore instability is provided by the "inhibition" character of the drilling mud.. At last it should be noted that the best way to keep a hole stable is to reduce time during which the hole is kept open.
6. **helps in the evaluation and interpretation of well logs:** wire line logs are run in mud-fills holes in order to ascertain the existence and size of hydrocarbons zones. Open hole logs are also run to determine porosity, boundaries between formations, location of geopressured (or abnormally pressured) formations and the site for the next well.

   Hence, the drilling mud must possess such properties that it will aid the production of good logs (Log response may be enhanced through selection of specific fluids and conversely, use of a given fluid may eliminate a log from use. Drilling fluids must be evaluated to assure compatibility with the logging program).
7. **limiting the corrosion of drilling equipment:** the drilling mud in most cases will have water that contains dissolved salts as its base liquid. This serves as a medium in which corrosion takes place. If corrosion is suspected, then the cause should be determined and steps taken to prevent damage

of the equipment. It has been found that in muds containing oil as the continuous phase, little or no corrosion occurs.

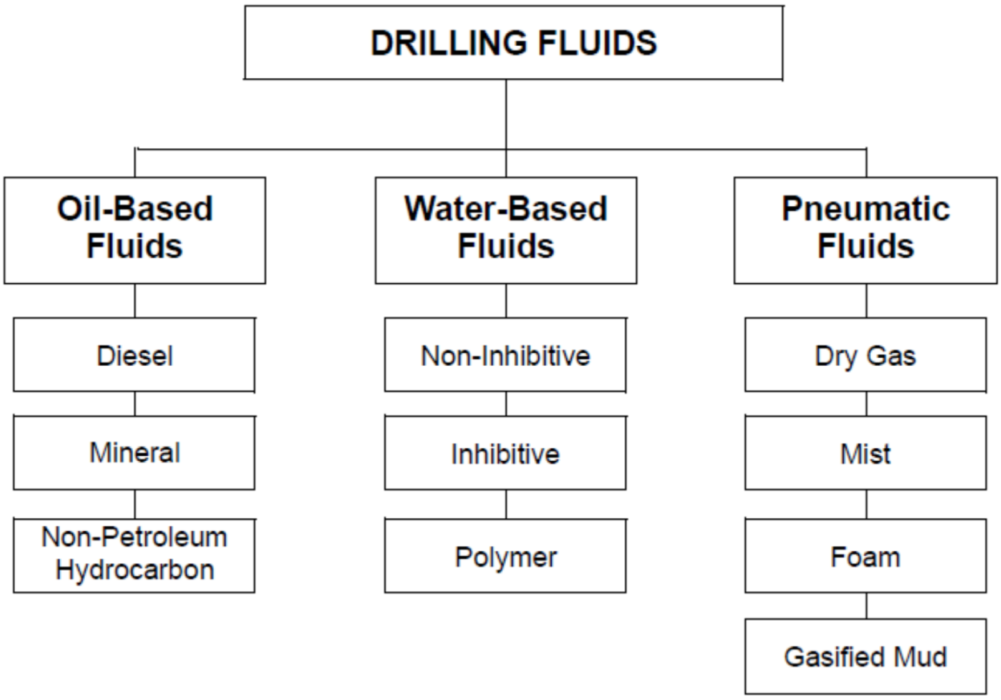
8. **Transmit Hydraulic Horsepower to Bit:** Hydraulic horsepower generated at the bit is the result of flow volume and pressure drop through the bit nozzles. This energy is converted into mechanical energy which removes cuttings from the bottom of the hole and improves the rate of penetration.

Drilling Fluid Classifications:

Drilling fluids are separated into three major classifications (Figure below):

A. Pneumatic.
B. Oil-Based.
C. Water-Based.

Drilling Fluids Classification



A. Pneumatic drilling fluids:

Pneumatic (air/gas based) fluids are not common systems as they have limited applications such as the drilling of depleted reservoirs or aquifers or areas where abnormally low formation pressures may be encountered where normal mud weights would cause severe loss circulation.

An advantage of pneumatic fluids over liquid mud systems can be seen in increased penetration rates. Cuttings are literally blown off the cutting surface ahead of the bit as a result of the considerable pressure differential. The high pressure differential also allows formation fluids from permeable zones to flow into the wellbore. Air/gas based fluids are ineffective in areas where large volumes of formation fluids are encountered. A large influx of formation fluids requires converting the pneumatic fluid to a liquid-based system as their properties tends to break down in the presence of water. As a result, the chances of losing circulation or damaging a productive zone are greatly increased.

consideration when selecting pneumatic fluids is well depth. They are not recommended for wells below about 6-8000 ft (1800-2400 m) because the volume of air required to lift cuttings from the bottom of the hole can become greater than the surface equipment can deliver.
Penetration rate: is the speed at which a drill bit breaks the rock under it to deepen the borehole. Also known as penetration rate or drill rate. It is normally measured in feet per minute or meters per hour, but sometimes it is expressed in minutes per foot. Generally, ROP increases in fast drilling formation such as sandstone (positive drill break) and decreases in slow drilling formations such as shale (reverse break). ROP decreases in shale due to diagnesis and overburden stresses.

B. Oil-based mud:

An oil based mud system is one in which the continuous phase of a drilling fluid is oil. When water is added as the discontinuous phase then it is called an invert emulsion. A primary use of oil-based fluids is to drill troublesome shales and to improve hole stability. They are also applicable in drilling highangle/ horizontal wells because of their superior lubricating properties and low friction values between the steel and formation which result in reduced torque and drag and ability to prevent hydration of clays. These fluids are particularly useful in drilling production zones, shales and other water sensitive formations, as clays do not hydrate or swell in oil.. They may also be selected for special applications such as high temperature/high pressure wells, minimizing formation damage, and native-state coring. Another reason for choosing oil-based fluids is that they are resistant to contaminants such as anhydrite, salt, and CO_2 and H_2S acid gases.
Cost is a major concern when selecting oil-based muds. Initially, the cost per barrel of an oilbased mud is very high compared to a conventional water-based mud system. However, because oil muds can be reconditioned and reused, the costs on a multi-well program may be comparable to using water-based fluids. Also, buy-back policies for used oil-based muds can make them an attractive alternative in situations where the use of water-based muds prohibit the successful drilling and/or completion of a well.
Today, with increasing environmental concerns, the use of oil-based muds is either prohibited or severely restricted in many areas. In some areas, drilling with oil-based fluids requires mud and cuttings to be contained and hauled to an approved disposal site. The costs of containment, hauling, and disposal can greatly increase the cost of using oil-based fluids.

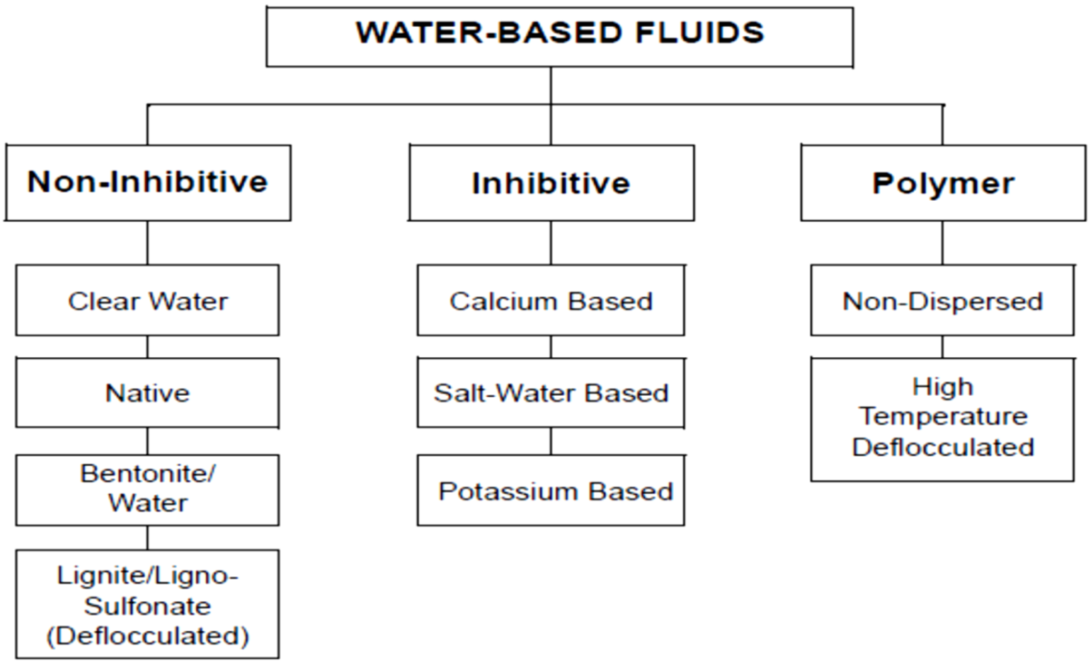
There are two types of oil based muds:

- Invert Emulsion Oil Muds.
- Pseudo Oil Based Mud.

C. Water-Based Fluids:

These are fluids where water is the continuous phase. The water may be fresh, brackish or seawater, whichever is most convenient and suitable to the system or is available. Water based fluids are the most extensively used drilling fluids. They are generally easy to build, inexpensive to maintain, and can be formulated to overcome most drilling problems. In order to better understand the broad spectrum of water-based fluids, they are divided into three major subclassifications:

Water-Based Fluids



1. Non-Inhibitive Fluids

Those which do not significantly suppress clay swelling, are generally comprised of native clays or commercial bentonites with some caustic soda or lime. They may also contain deflocculants and/or dispersants such as: lignites, lignosulfonates, or phosphates. Non-inhibitive fluids are generally used as spud muds. Native solids are allowed to disperse into the system until rheological properties can no longer be controlled by water dilution.

2. Inhibitive Fluids

Those which appreciably retard clay swelling and, achieve inhibition through the presence of cations; typically, Sodium (Na^+), Calcium (Ca^{++}) and Potassium (K^+). Generally, K^+ or Ca^{++}, or a combination of the two, provide the greatest inhibition to clay dispersion. These systems are generally used for drilling hydratable clays and sands containing hydratable clays. Because the source of the cation is generally a salt, disposal can become a major portion of the cost of using an inhibitive fluid.

3. Polymer Fluids

Those which rely on macromolecules, either with or without clay interactions to provide mud properties, and are very diversified in their application. These fluids can be inhibitive or noninhibitive depending upon whether an inhibitive cation is used. Polymers can be used to viscosify fluids, control filtration properties, deflocculate solids, or encapsulate solids.

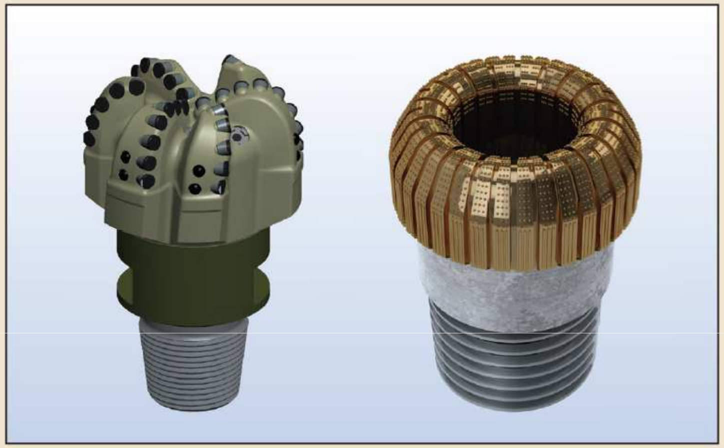
The thermal stability of polymer systems can range upwards to 400˚F. In spite of their diversity, polymer fluids have limitations. Solids are a major threat to successfully running a cost-effective polymer mud system.

4. Core drilling

The core is an intact sample of the underground geology, which can be examined thoroughly by the geologist to determine the exact nature of the rock and any mineralization.

Core drilling, yields a solid cylinder shaped sample of the ground at an exact depth.

Core drilling is also used to define the size and the exact boundaries of mineralization. This is important for determining ore grades being handled, and vital for calculating the mineral reserves that will keep the mine running in the future.



^ Bits for drilling versus coring. Whereas a drill bit (*left*) is designed to grind away rock at the bit face, the toroidal face of the coring bit (*right*) employs a fixed cutter design that leaves the center of the borehole untouched. This hollow bit creates a cylindrical core of the formation that passes through the middle of the bit to be retained within a liner inside the BHA.

Core barrels

- ○ The core barrel is sandwiched between the drill rods and the diamond bit.
- ○ Most conventional barrels as well as wireline barrels incorporate a stationary inner tube to contain and protect the core.
- ○ Its length varies from 0.5 to 3 m.
- ○ There are three types of core barrel in use:
  - The single tube core barrel, and
  - Double tube core barrel.
  - Triple tube core barrel

Core barrels (Double tube core barrel)

- ○ **Double tube core barrel is the standard**

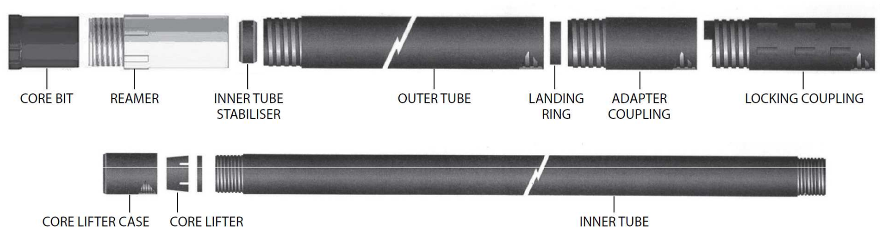
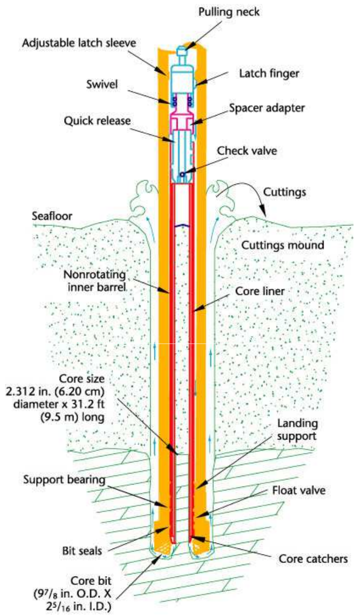


Figure 3–140: Barrel outer and inner tube

- Outer tube barrel rotates with cutting bit.
- Inner barrel is either fixed or swivel type (with bearing) that retains core sample.
- Core diameters generally range from 21 to 85 mm (0.85 to 3.35 inch).



Core sample quality

- Make sure that the barrel and inner tube are in good condition.
- Select the correct bit for the ground conditions.
- Make sure that the inner tubes are the correct length.
- Make sure that the inner tube is seated in the barrel correctly each time a new tube is required. When in doubt pull out and reseat.
- Check the core lifter regularly to prevent a core drop or excessive stick up on the bottom of the hole.
- Vibration can cause core loss, so ensure the drill fluid lubricates the drill string.
- Make sure that the core trays are numbered and labeled correctly.
- Be careful not to drop core trays when they are being transported.

Sonic drilling

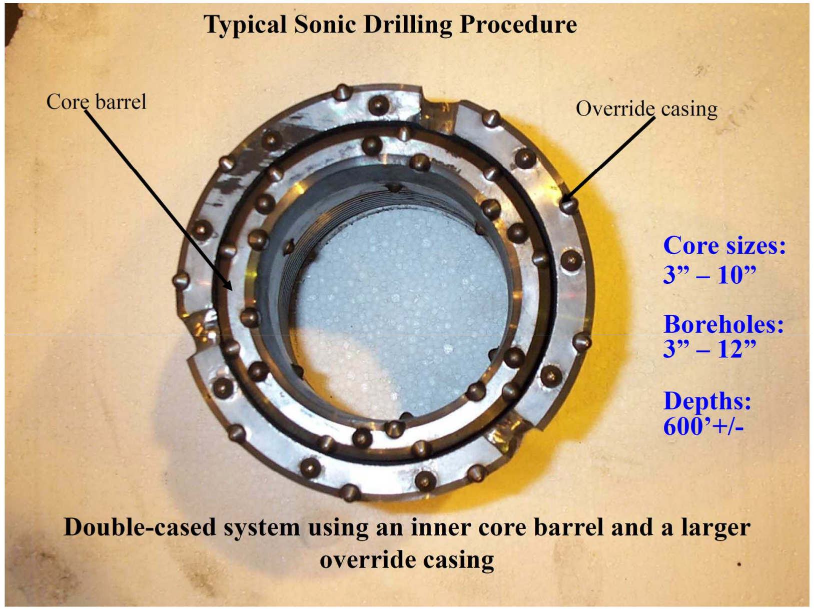
A SONIC drill is more precisely identified as a rotary vibratory drill. It is capable of high drilling speeds as well as accomplishing tasks, such as continuous coring that cannot be carried out by any other equipment.

At first glance, a SONIC drill rig looks very much like a conventional air or mud rotary drill rig. The biggest difference is in the drill head, which is slightly larger than a standard rotary head. The head contains the mechanism necessary for rotary motion, as well as an oscillator, which causes a high frequency force to be superimposed on the drill string. The drill bit is physically **vibrating up and down** in addition to being **pushed down** and **rotated**. These three combined forces allow drilling to proceed rapidly through most geological formations including most types of rock.

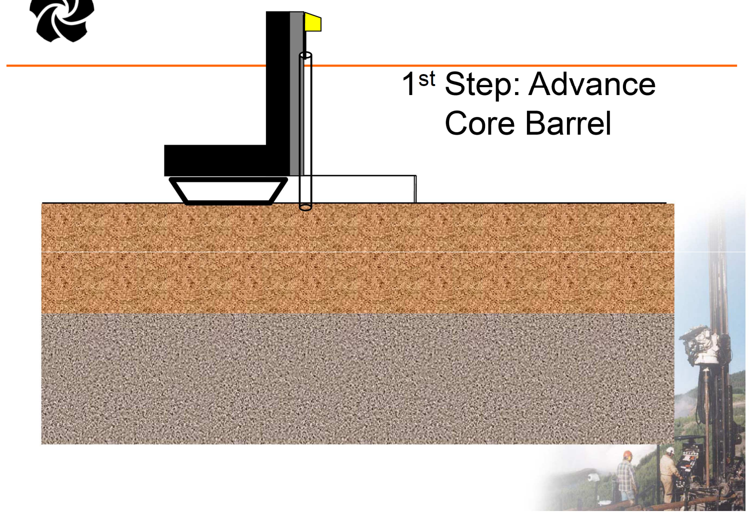
Sonic drilling head

rotary motion
as well as
an oscillator

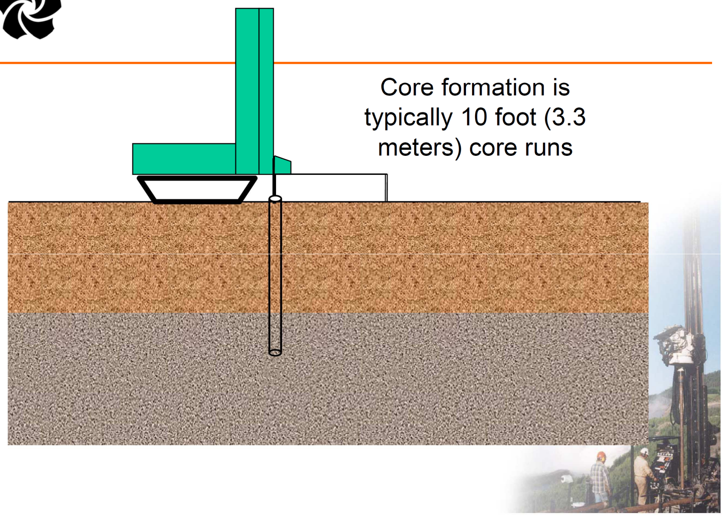
Drilling Technology for **High-Quality**
Continuous Soil Sampling and
Efficient Borehole Drilling
Utilizing High Frequency Resonant Energy



SONIC Drilling Process

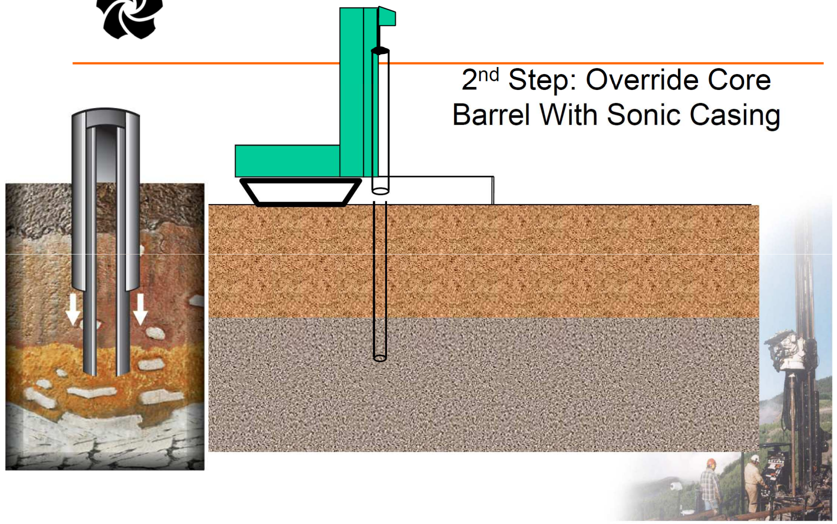


SONIC Drilling Process



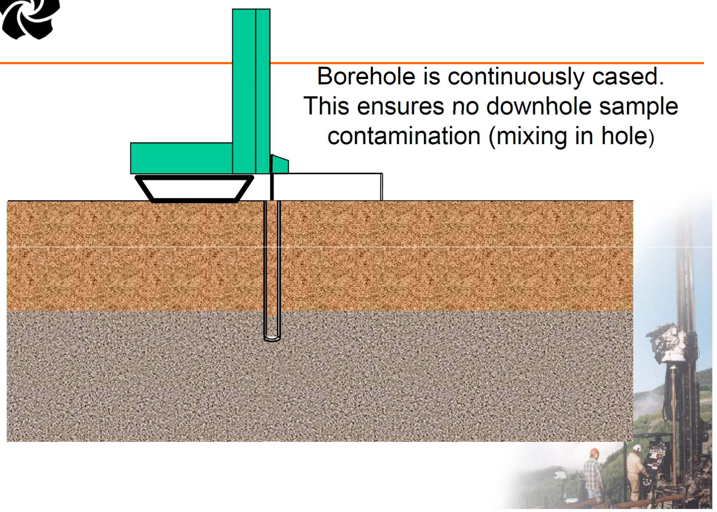
Core formation is typically 10 foot (3.3 meters) core runs

SONIC Drilling Process



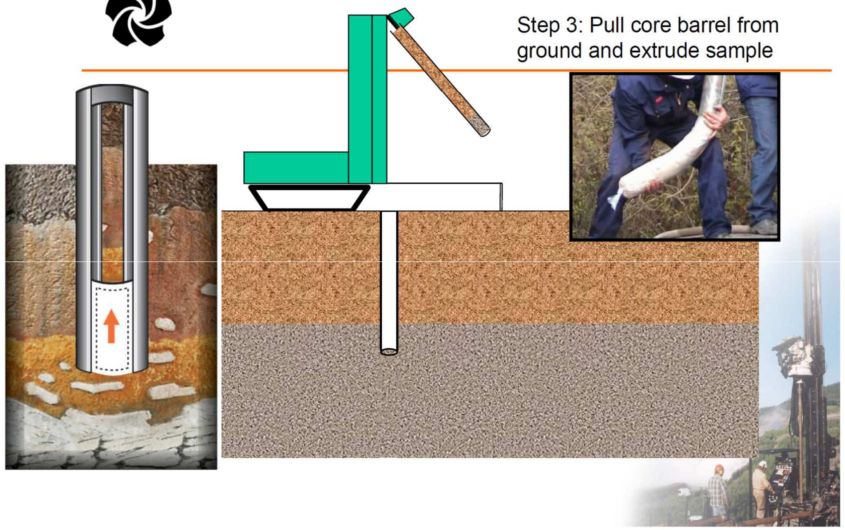
2^{nd} Step: Override Core Barrel With Sonic Casing

SONIC Drilling Process



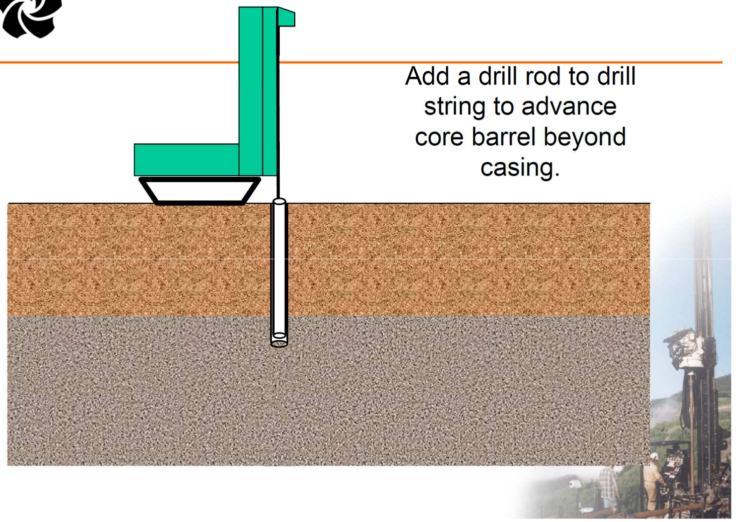
Borehole is continuously cased. This ensures no downhole sample contamination (mixing in hole)

SONIC Drilling Process



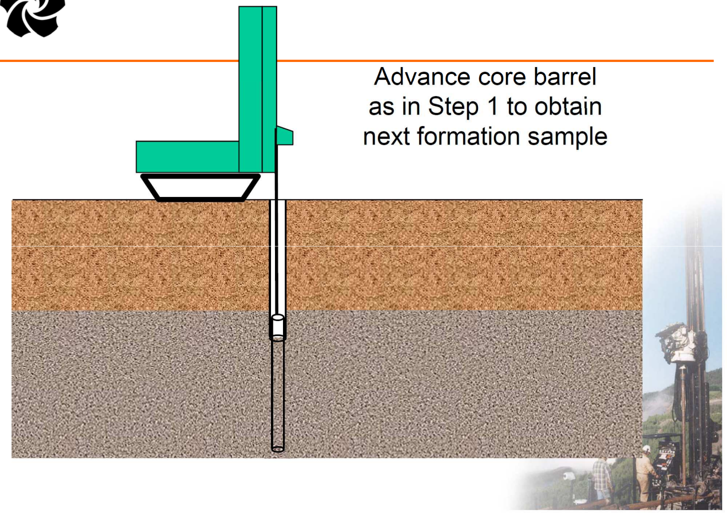
Step 3: Pull core barrel from ground and extrude sample

SONIC Drilling Process



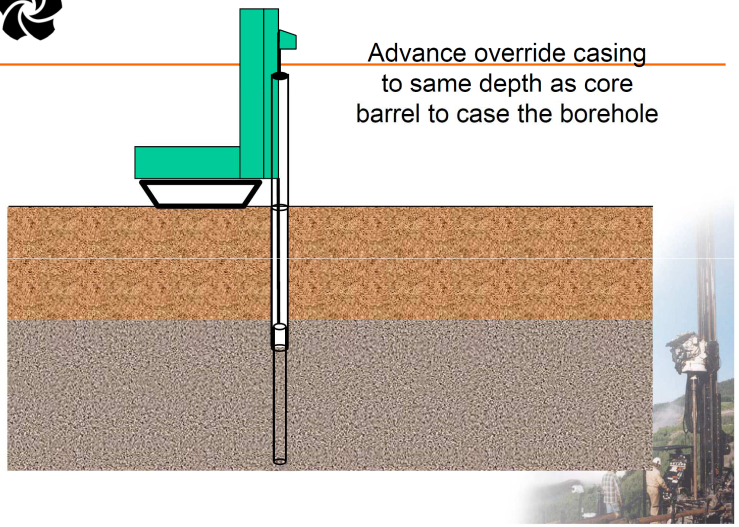
Add a drill rod to drill string to advance core barrel beyond casing.

SONIC Drilling Process



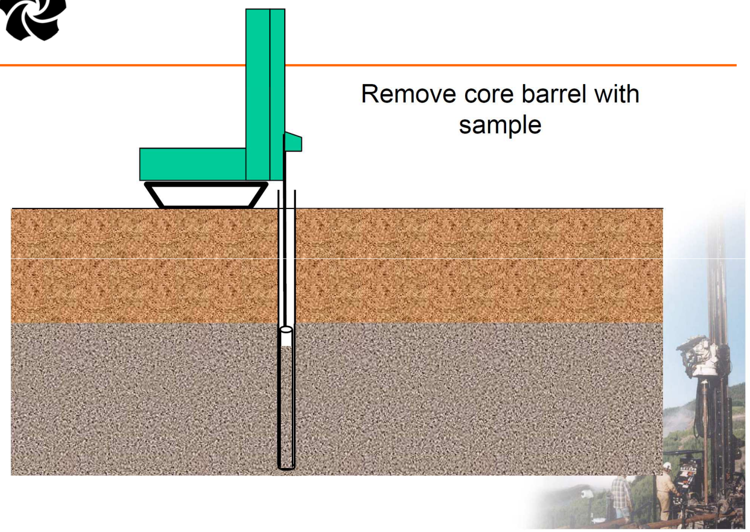
Advance core barrel as in Step 1 to obtain next formation sample

SONIC Drilling Process



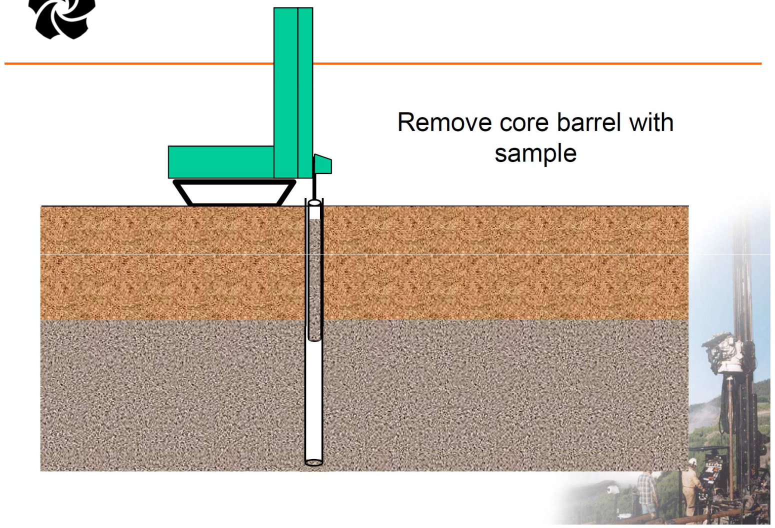
Advance override casing to same depth as core barrel to case the borehole

SONIC Drilling Process

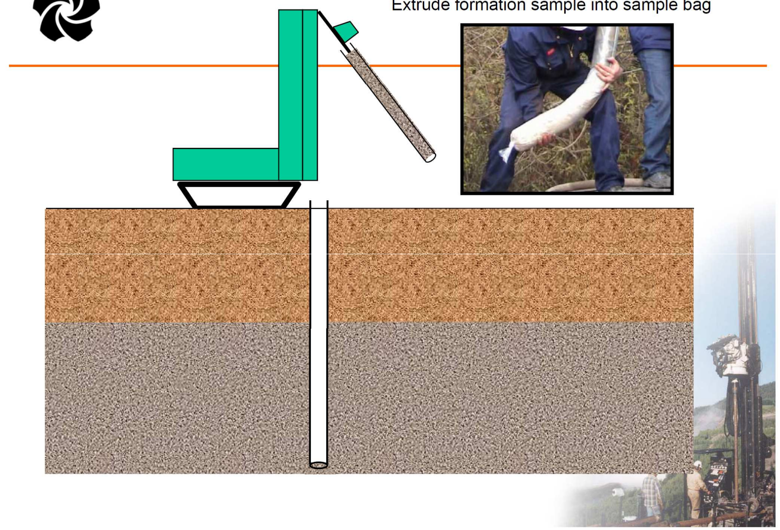


Remove core barrel with sample

SONIC Drilling Process

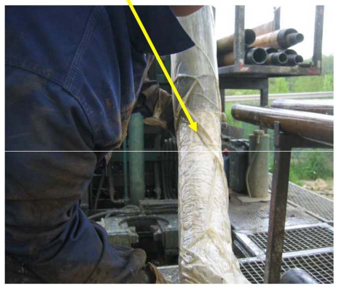


SONIC Drilling Process



Continuous Core Sample Production

Core extrusion into plastic sleeve



Core samples opened for inspection

Geologic Applications

- All unconsolidated formations, including: sand (including heaving); gravel; clay; hard till; cobbles and boulders.
- Fill and construction debris.
- Any formation known as "difficult" for conventional methods.
- Some bedrock formations, typically softer, porous and weathered: shale; sandstone; limestone; basalt; etc.
- SONIC is not typically cost-effective drilling large amounts of very dense/hard bedrock.

Potential SONIC Advantages

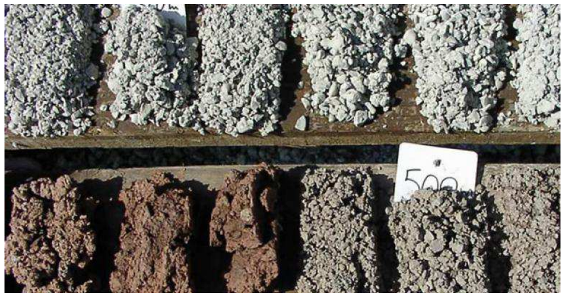
- Faster drilling.
- The lack of any need to introduce fluid into the hole makes this method an ideal drilling method when contamination is potentially a problem.
- Less mess.
- Wider range of ground can be drilled.
- No large mud pits or compressor required for cutting removal.
- Accurate information obtained where other methods fail.

Well logging

- **Well logging**, also known as **borehole logging** is the practice of making a detailed record (a *well log*) of the geologic formations penetrated by a borehole.
- The log may be based either on visual inspection of samples brought to the surface (*geological* logs) or on physical measurements made by instruments lowered into the hole (*geophysical* logs).
- Well logging is performed in boreholes drilled for the oil and gas, groundwater, mineral and geothermal exploration, as well as part of environmental and geotechnical studies.

Geological logs

DRILL CUTTINGS are the broken bits of solid material removed from a borehole drilled by rotary, percussion, or auger methods.



Boreholes drilled in this way include oil or gas wells, water wells, and holes drilled for geotechnical investigations or mineral exploration.

CORING is the process of obtaining an actual sample of a rock formation from the borehole. Full coring', in which a sample of rock is obtained using a specialized drill-bit as the borehole is first penetrating the formation.

Sand and gravel

Example Strip Log

Graham & Bird #7 Rubey
Sec 6 24N-10E

Pershing Field
Osage County, Oklahoma

Bartlesville Producer (2,100')

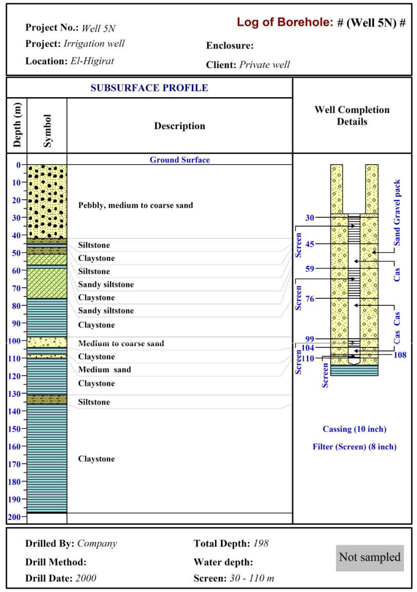


Figure (42): lithologic log of well 5N of the study area.

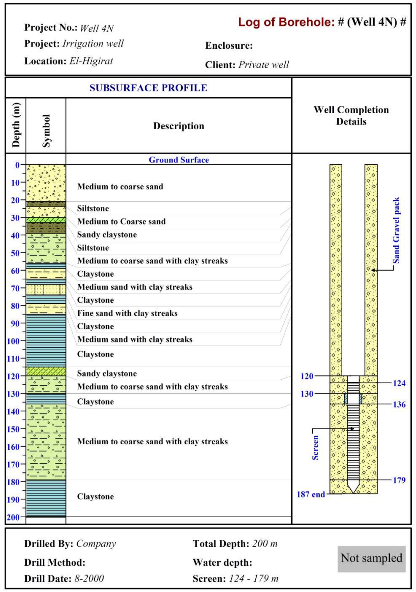


Figure (41): lithologic log of well 4N of the study area.

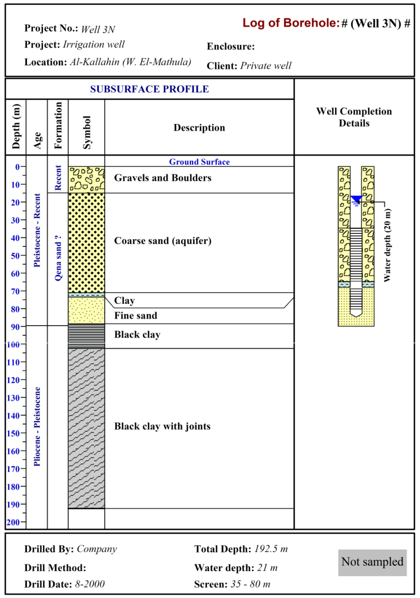
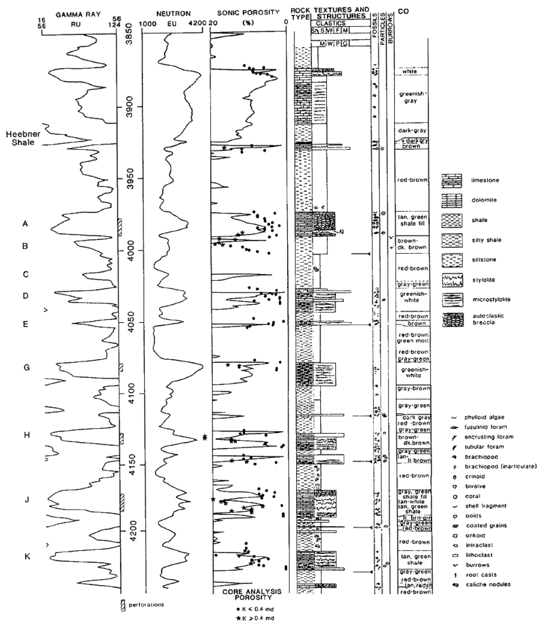


Figure (40): lithologic log of well 3N of the study


GAMMA RAY
RU
NEUTRON
EU
SONIC POROSITY
(%)
ROCK TYPE
TEXTURES AND STRUCTURES
CLASTICS
FOSSILS
PARTICLES
BURROWS
CO
Heebner Shale
A
B
C
D
E
G
H
J
K
3850
3900
3950
4000
4050
4100
4150
4200
perforations
CORE ANALYSIS POROSITY
limestone
dolomite
shale
silty shale
siltstone
stylolite
microstylolite
autoclastic breccia
phylloid algae
fusulinid foram
encrusting foram
tubular foram
brachiopod
brachiopod (articulate)
crinoid
bivalve
coral
shell fragment
ooids
coated grains
onkoid
intraclast
lithoclast
burrows
root casts
caliche nodules

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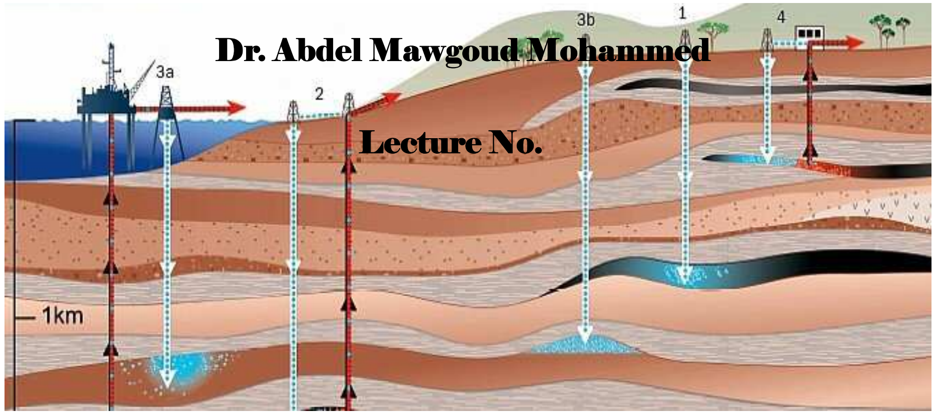
Faculty of Science
Geology Department

SUBSURFACE GEOLOGY



Drilling

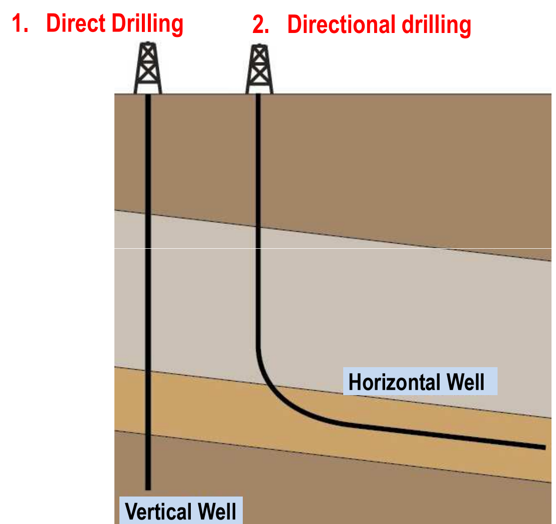
Drilling occurs in all nations around the world, and in the seas surrounding those nations, using drilling rigs to bore into the earth.

Drilling

- provides information about resources (**minerals, construction material, oil, gas, water**) and also provides access to those resources.
- helps with developing infrastructure in foundations, piling, and constructing dams, and in laying underground cables for energy transmission and communications.
- helps to gather information such as ground strength, ground formations and composition, and the presence and quality of groundwater (geotechnical, seismic, and environmental).
- **deals with a subject which should interest both the geologist and the engineer.**

Introduction to drilling Techniques

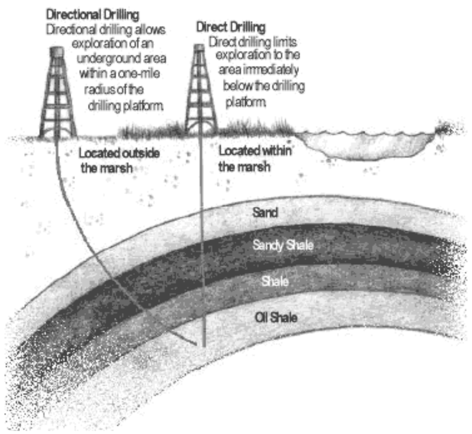
1. Direct Drilling
2. Directional drilling



1. Direct drilling

Most wells drilled for water, oil, natural gas, information or other subsurface objectives are vertical wells - drilled straight down into the earth.

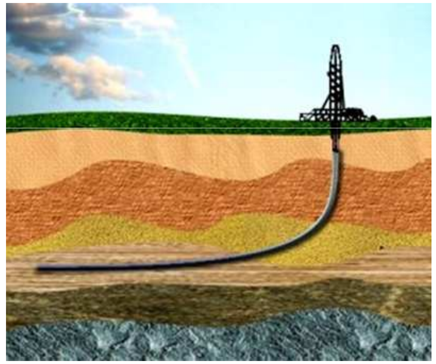
- **Direct drilling limits exploration to the area immediately below the drilling platform.**



2. Directional drilling

While attempting to drill straight down, boreholes have a natural tendency to deviate from a vertical path.

Directional drilling is defined as an art and science involving deflection of a well bore in a specified direction in order to reach a predetermined object below the surface of the earth that cannot be achieved with a vertical well.

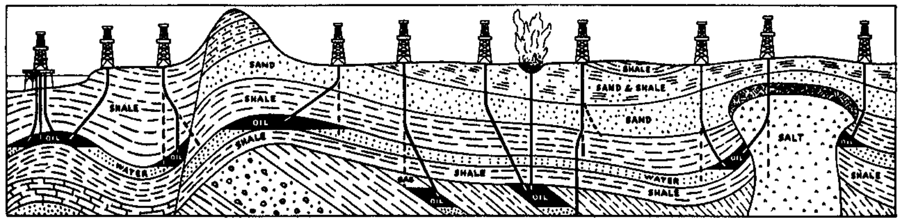


Directionally drilled wells

- A directionally drilled or deviated well is defined as a well drilled at an angle less than 90 deg to horizontal.
- The technique of controlled directional drilling began in the late 1920s on the US Pacific coast (LeRoy and LeRoy 1977).
- Most directional wells begin as vertical wellbores. At a designated depth, known as the Kickoff point (KOP), the directional driller deflects the well path by increasing well inclination to begin the build section.
- Through the use of controlled directional drilling, a wellbore is deviated along a preplanned course to intersect a subsurface target horizon at a specific location.
- Directionally drilled wells have a good application to subsurface mapping.

Application of directionally drilled wells

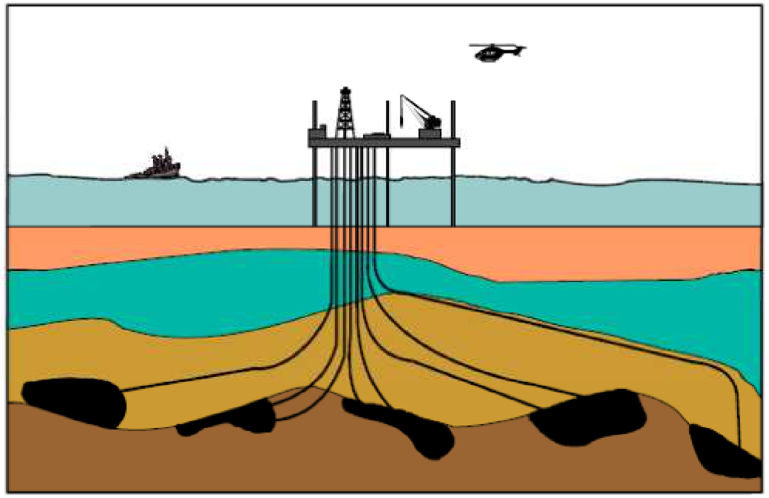
- There are a number of reasons to drill a directional well.
- The most common application is the drilling of offshore wells from a single platform location.
- Onshore, wells are commonly deviated due to inaccessibility to the surface location directly over the subsurface target. Buildings, towns, cities, rivers, and mountains are the kinds of surface obstructions that require the drilling of a deviated well.
- One very important safety application of a deviated well is the drilling of a relief well to kill a well that has blown out.



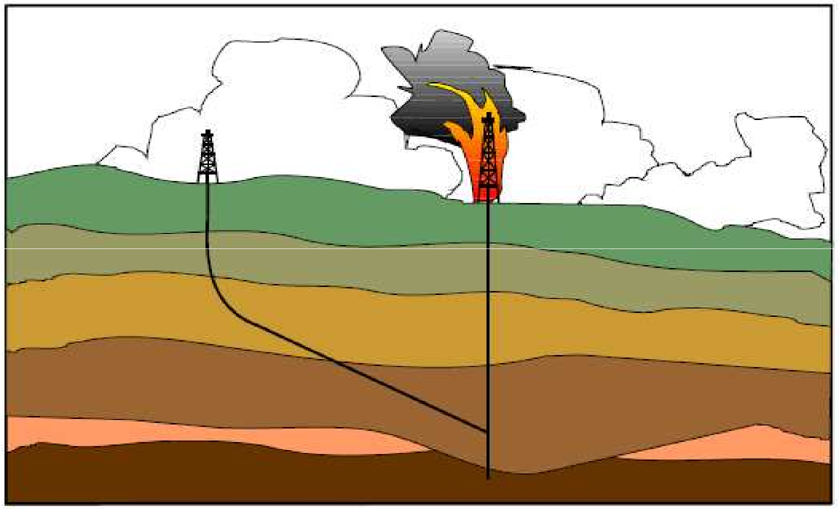
a) Multiple wells offshore or from artificial islands.
b) Shoreline drilling.
c) Fault control.
d) Inaccessible location.
e) Stratigraphic trap.
f) Relief well control.
g) Straightening hole and side tracking.
h) Salt dome drilling.
i) Salt dome drilling.
j) Salt dome drilling.

Application of directional drilling

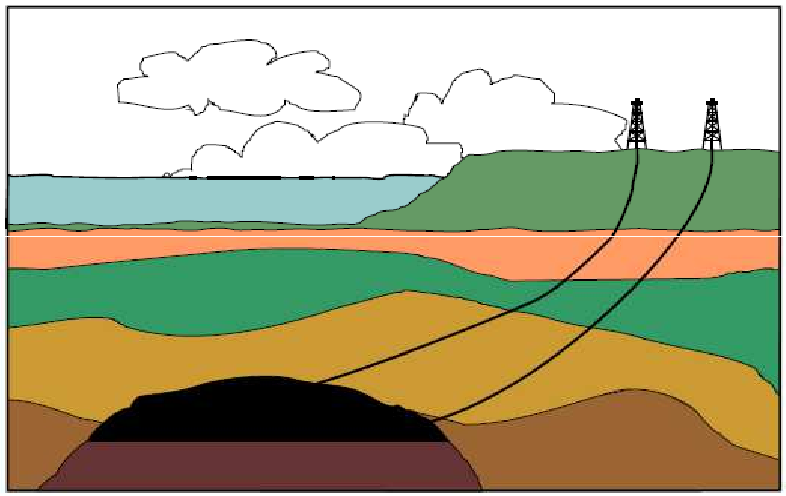
Multiple wells from offshore structures



Relief wells



Shoreline drilling

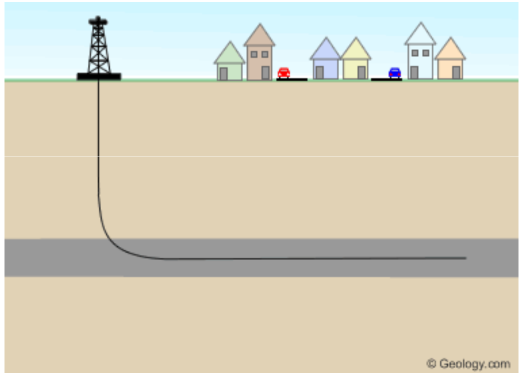


d) Inaccessible location.

Directional drilling under city:

- Directional drilling can be used to reach targets that cannot be drilled with a vertical well.
- For example, it may not be possible to get a drilling permit for a well located within a populated area or within a park.
- However, a well could be drilled just outside of the populated area or park and then steered directionally to hit the target.

Target can't be reached by vertical drilling

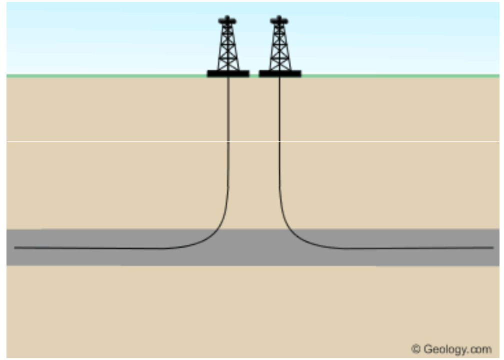


k) Drain a large area from one drill pad.

Minimize footprint:

- One drilling pad can be used to drill a number of wells. This reduces the footprint of drilling operations.
- In 2010 the University of Texas at Arlington drilled 22 wells on a single platform. These wells are draining the natural gas from about 1100 acres beneath the campus.
- The alternative would be to drill many wells, each requiring a drilling pad, pond, access road and gathering line.

Drain a large area from one drill pad

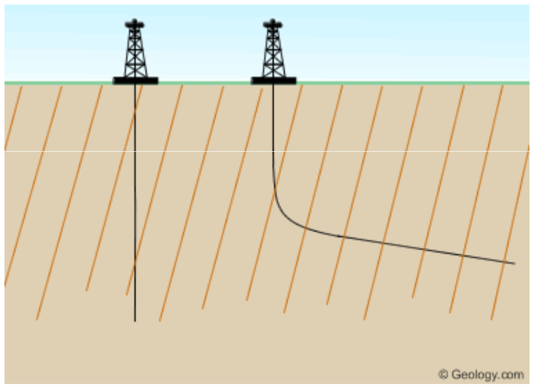


l) Improved production in a fractured reservoir.

Fractured reservoir:

- Some reservoirs have most of their pore spaces in the form of fractures.
- Successful wells must penetrate fractures to have a flow of natural gas into the well.
- If the well is drilled perpendicular to the plane of these fractures, then a maximum number of fractures will be penetrated.

Improved production in a fractured reservoir

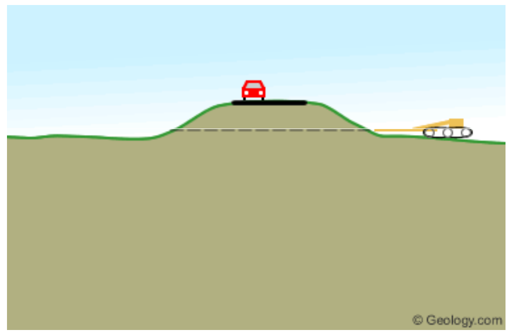


m) Installation of underground utilities.

Utility line:

- Utility service lines such as those delivering electricity, water, or natural gas are sometimes installed by directional drilling.
- This method is used when they must cross a road where excavation would disrupt traffic, cross a river where excavation is impossible, or transverse a community where surface installation by excavation would be extremely expensive and disrupting.

Installation of underground utilities



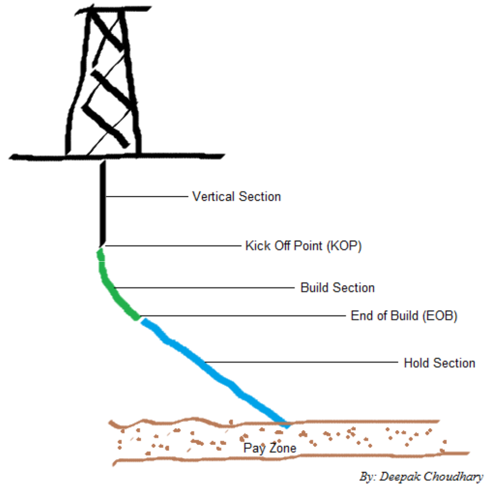
Common types of directionally drilled wells

There are many complex factors that go into the design of a directionally drilled well; however, most deviated wells fall into one of four types.

Type I wells

Simple ramp well, sometimes called an "L" shaped hole.

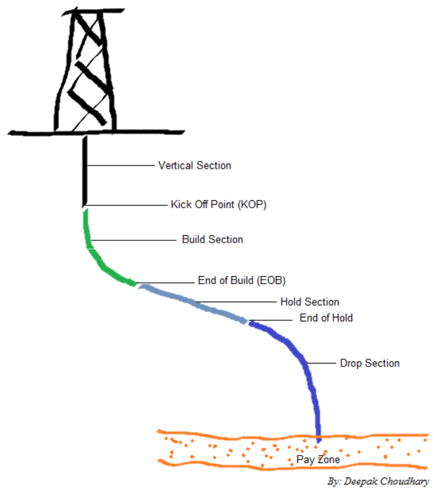
These wells are drilled vertically to a predetermined depth (**Kick Off Point**) and then deviated to a certain angle which is usually held constant to total depth (TD) of the well.



Type II wells

"S" shaped design.

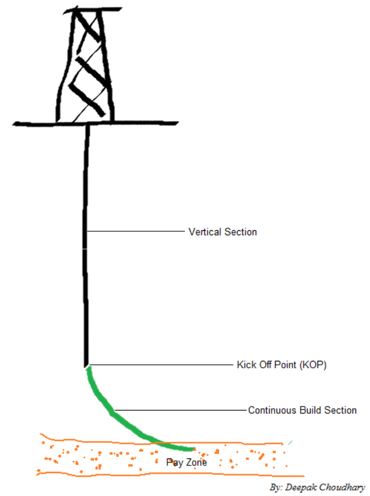
With an "S" shaped hole, the well begins as a vertical hole and then builds to a predetermined angle, maintains this angle to a designated depth and then the angle is lowered again, often going back to vertical.



Type III wells

Deep Kick off wells or J Profile wells (as they are J - shaped).

- Are made up of a vertical section, a deep kick off and a build up to target.
- They are similar to the Type I well except the kickoff point is at a deeper depth.
- The well is deflected at the kickoff point, and inclination is continually built through the target interval (BUILD).
- The inclinations are usually high and the horizontal departure low.



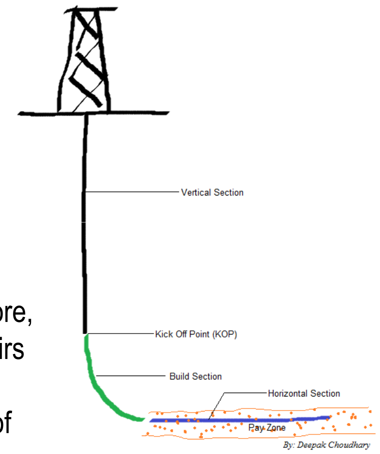
Type IV wells

Horizontal wells or Horizontal Directional Wells.

Are made up of anyone of the above profiles plus a horizontal section within the reservoir.

Horizontal drilling is:

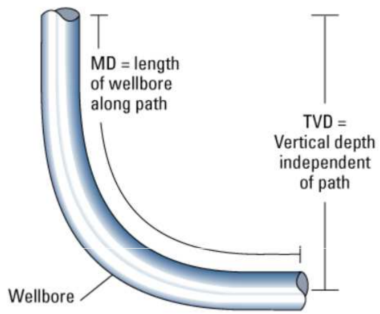
- used to increase productivity from low permeability reservoirs by increasing the amount of formation exposed to the wellbore,
- used to maximize production from reservoirs which are not being efficiently drained by vertical wells and to connect the portions of the reservoir that are productive.



Definitions

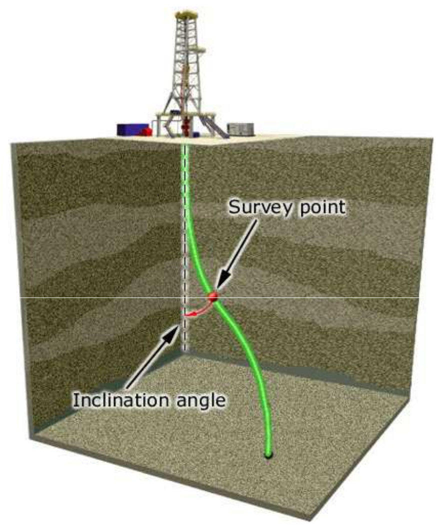
- **Depth**
  - True Vertical Depth
  - Measured Depth
- **Inclination (Drift)**
- **Azimuth (Direction)**
- **Kick Off Point (KOP)**

- **Depth**
  - True Vertical Depth (TVD).
  - Measured Depth (MD).



Measured depth. The measured depth is the length of the path of the wellbore. In the case of a vertical well, measured depth is the same as true vertical depth. This illustration demonstrates, however, that a deviated wellbore has a longer measured depth than true vertical depth.

- **Inclination (Drift)**
  - The angle (in degrees) between the local vertical and the tangent to the well bore axis at a particular point.
  - By oilfield convention, 0^{o} is vertical and 90^{o} is horizontal.

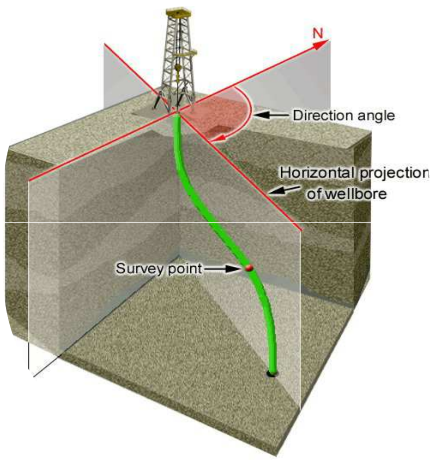


○ Azimuth (Direction)

- Azimuth is the angle between North Reference and a horizontal projection of the current Survey position.

The azimuth of a hole indicates the direction in which it is pointing on a 360° radius. If it is pointing:

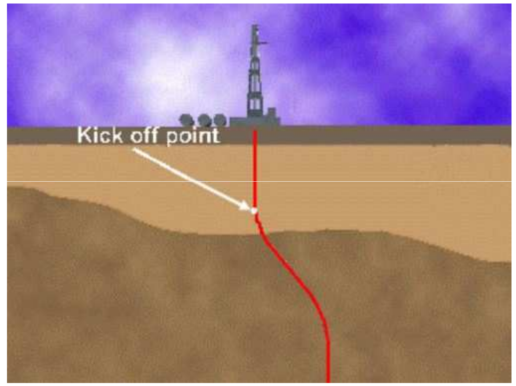
- North it will have an azimuth of 0°
- South the azimuth would be 180°
- East would be 90°
- West would be 270°.



○ Kick Off Point (KOP)

The kickoff point is the location at a given depth below the surface where the wellbore is deviated in a given direction.

Kick Off Point = Depth of initial deviation from vertical measured as measured depth (MD), true vertical depth (TVD), or subsea true vertical depth (SSTVD).



Homework:

Describe what you see.

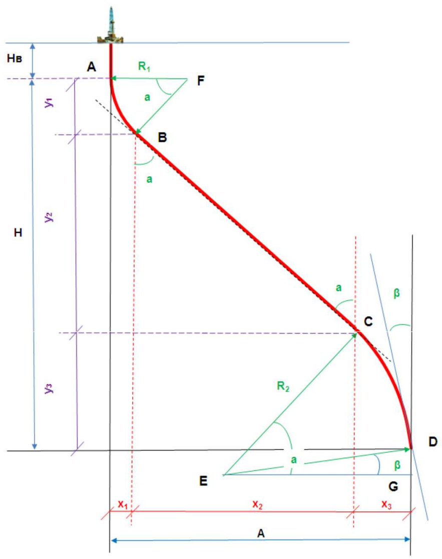


Figure 2. Design scheme of the S-shaped profile in controlled directional wells.

Subsurface thicknesses

There are a few terms to describe exactly what thicknesses are being measured in the subsurface.

- MLT, ***measured log thickness:*** The calculated thickness of an interval measured in a well log.
- In flat-lying strata, this is equal to the ***true stratigraphic thickness*** (TST), but in dipping strata the MLT is larger than the TST (unless the well is deviated and perpendicular to the unit).
- ***True vertical thickness*** *(TVT)* is *the* vertical thickness of an interval and the ***true vertical depth thickness*** *(TVDT)* is the vertical thickness between the borehole entry and where it exited the interval.
- In a vertical well the MLT, TST, TVT, and TVDT are all equal, but they are not equal if the wellbore is deviated or if the strata are dipping.

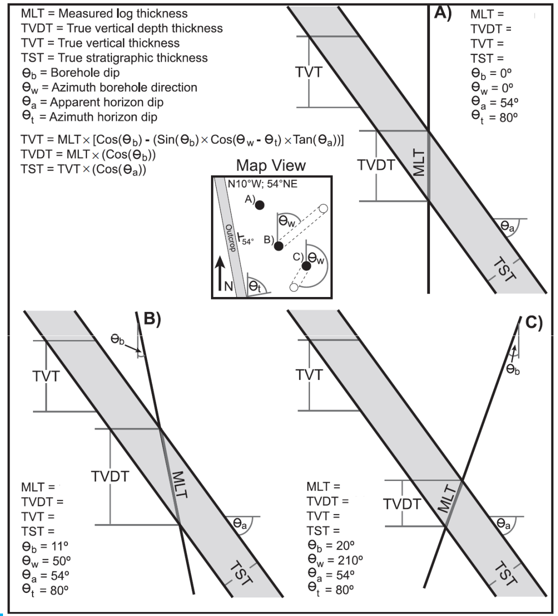
- In the latter cases, *Setchell's equation (1.1) can be used to calculate the TVT regardless of the borehole* direction or deviation, and dip of the strata.

The basic variables needed are:

- the MLT,
- the dip angle and azimuth direction of the borehole,
- and the dip angle and direction of the unit.

The TST can be calculated from the TVT using equation (1.2) and the TVDT, if needed, can be calculated using equation (1.3).

An illustration of three wells, one vertical (A) and two deviated (B and C), that penetrate a dipping unit with a constant thickness. See the map view in the middle for well locations. Each well has the same TST, but different MLTs, TVDTs, and TVTs.



$$TVT = MLT \times [\cos(\theta_b) - (\sin(\theta_b) \times \cos(\theta_w - \theta_t) \times \tan(\theta_a))] \quad (1.1)$$

where:

MLT = measured log thickness (calculated from log picks)

TVDT = true vertical depth thickness

TVT = true vertical thickness

TST = true stratigraphic thickness

θ_b = borehole dip (measured from vertical)*

θ_w = azimuth borehole direction (measured from north)*

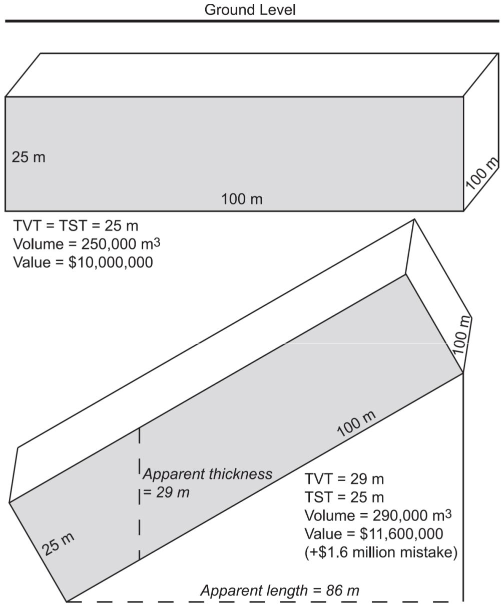
θ_a = apparent horizon dip (measured from horizontal)*

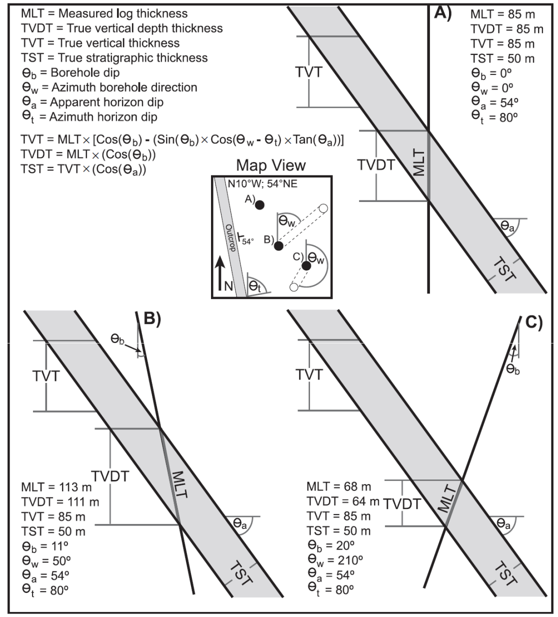
θ_t = azimuth horizon dip (measured from north)*

$$TST = TVT \times \cos(\theta_a) \quad (1.2)$$

$$TVDT = MLT \times \cos(\theta_b) \quad (1.3)$$

An example of how misusing thickness values in volume estimates can be problematic. In this example, the TVT was incorrectly used with the length of the beam instead of using the TST. The TVT value can only be correctly used with the apparent length to yield an accurate volume estimate. In practice, this calculation method is typically easier to solve because it does not involve calculating the true length and width of the target.





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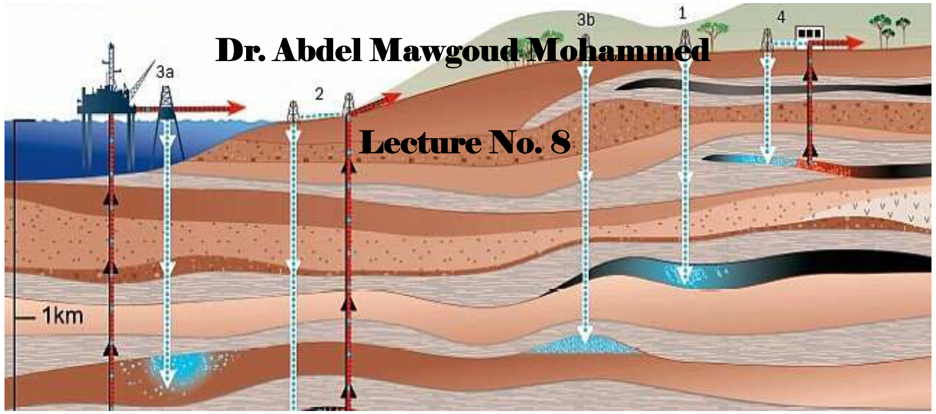


Dr. Abdel Mawgoud Mohammed

Lecture No. 8

Subsurface Mapping

1. Contour Maps

- A. Structure Contour maps
- B. Isopach maps
- C. Isochore maps
- D. Ratio maps

Contouring and Contouring Techniques

The following list shows examples of contourable data and the associated contour map.

Data	Type of Map
Elevation	Structure, Fault, Salt
Stratigraphic Thickness	Interval Isopach
Percentage of sand	Percent Sand
True Vertical Thickness	Net Pay Isochore
Pressure	Isobar
Temperature	Isotherm
Lithology	Isolith

Contouring and Contouring Techniques

The construction of a contour map from raw data involves two general steps: interpolation and interpretation.

○ **Interpolation**

The choice of the contour interval depends on:

- the amount of relief present on the surface
- the map scale
- the spacing of the data points and
- the accuracy of their location and elevation.

The procedures to contour a map can be taken as follows:

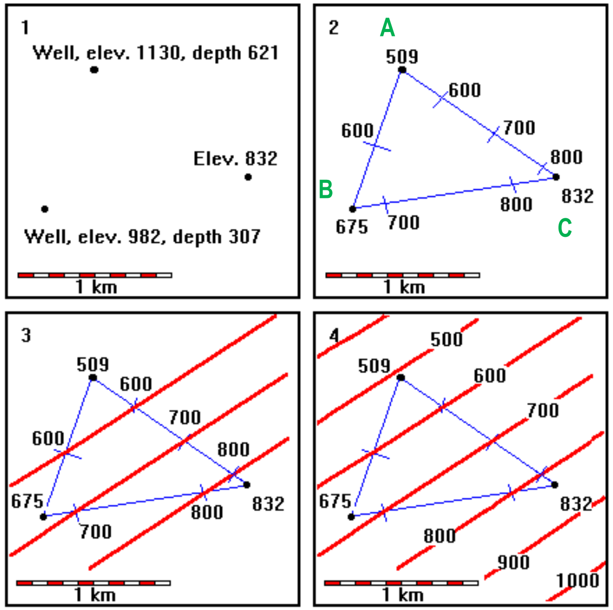
○ A given set of points can be contoured into a nearly infinite number of shapes, depending on the methodology followed.

○ There is no absolute best technique for contouring and the overall appearance of the map is not necessarily an indication of its quality (Davis 1986).

○ Connect three adjacent elevation points with straight lines (for example, points A, B, and C on the Figure.

○ By assuming that these three points define a planar portion of the surface, the location of the intermediate points can be found easily (Figure).

Three Point Problem



Contouring Rules

○ A contour line separates points that are higher from points that are lower

○ Contour lines cannot cross

○ Contour lines cannot merge

○ Contour lines must close on themselves within the map area or extend to the edge of the map

○ Contour interval must remain constant for the entire map

○ Contour lines are repeated to indicate reversals in the slope direction

○ Faults cause breaks in a continuous map surface.

○ Interpretation

A map can be contoured so that all of the technical requirements are fully satisfied.

C illustrates the method by which the map, B, was constructed

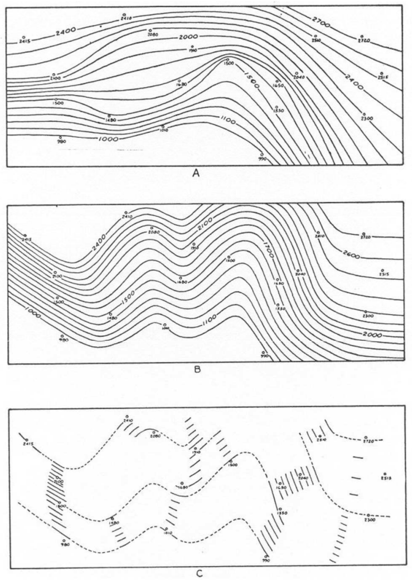


Figure 4 Comparison of careless (A) and orderly (B) methods of contouring.

A. Structure Contour maps

- ○ A structure contour is a lines or curves of equal altitude drawn on a specific horizon.
- ○ Structure contours for planar inclined beds are made up of a series of evenly spaced and parallel strike lines.
- ○ Structure contours have properties similar to those of topographic contours (partially analogous to topographic contours).
- ○ Both sets of contours are used to represent the shape of a particular surface.
- ○ The visualization of the features portrayed by both types of contours follows the same rules.

- ○ Structure contours are employed to illustrate the shape of geological surface. Such surfaces may include: bedding planes, fold shapes, fault planes, salt domes.
- ○ A structure contour are straight lines only when the geological surface resembles a flat plane, like an inclined planar bed or a planar fault.
- ○ The spacing of the contour lines in such structure-contour maps reflects the gradient of the slope. The closer the contours, the steeper the inclination of the structural surface. Widely spaced contours imply gentle slopes.
- ○ The difference in elevation between adjacent contours is constant on any given map.

Strike and dip determination

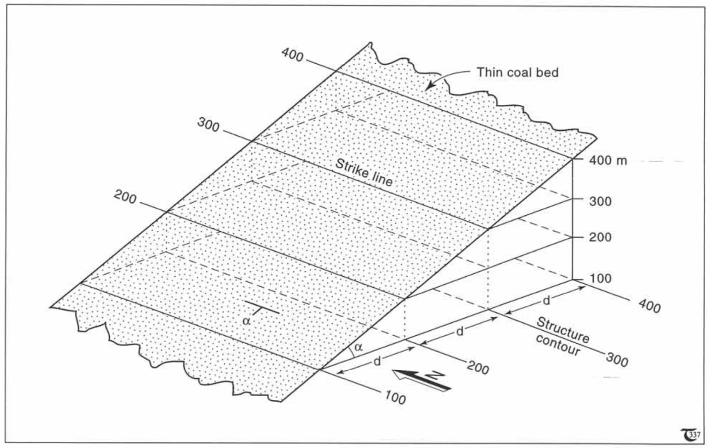


Figure 5-4: *Structure contours on homoclinal beds are parallel to the strike lines and mark regularly spaced elevations. Orthographic projection of the contours gives a structure-contour map of the coal bed.*

The maximum depth of the basin is four kilometers (12,000 feet)

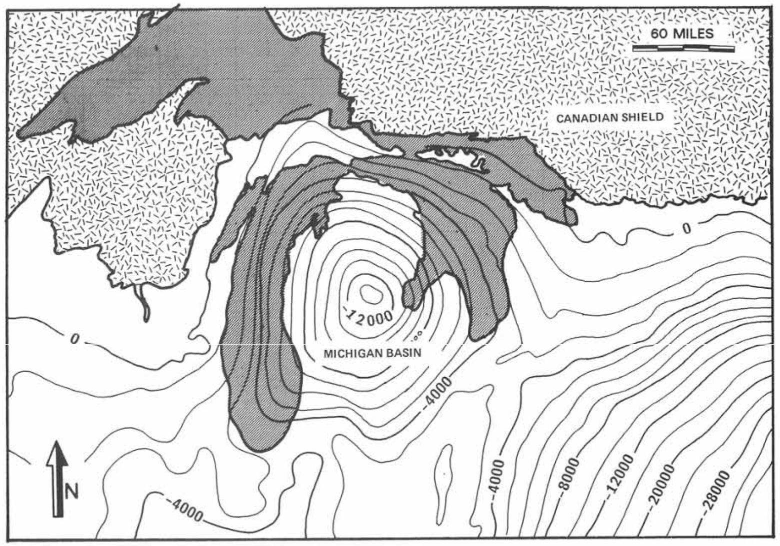
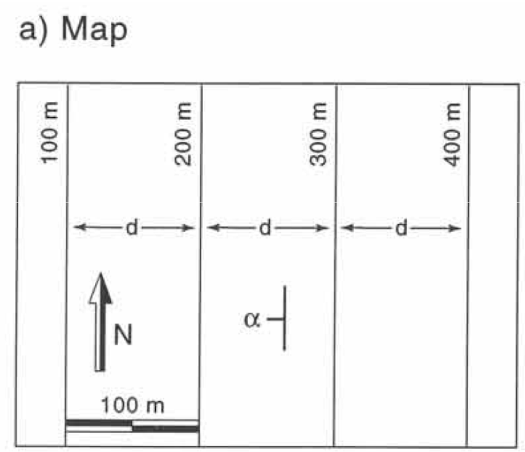


Figure 5-2: Structure-contour map of the top of the Precambrian basement in the Michigan Basin. Units are in feet.

It is simple to infer the strike and dip of the original bed from its structure contours.

- The strike orientation of the bed immediately follows from the trend of the contours, which is parallel to the strike.
- The dip of the bed, **α**, can be inferred from the horizontal spacing between the projected contour line, **d**, and the contour interval, **x**, using:

$$\alpha = \tan^{-1}(x/d)$$



Contouring faulted surfaces

The contouring of faulted surfaces adds complications in the contouring of both structural horizons and fault surfaces. A completed structure contour map of one or more horizons is usually the main objective in any mapping project. In order to construct a completed structure map, however, the faults themselves must be contoured and the fault maps integrated with the structure maps. This integration is required to support a reasonable geologic interpretation and to prepare accurate maps. In terms of map accuracy, this integration does the following (Fig. 8-10):

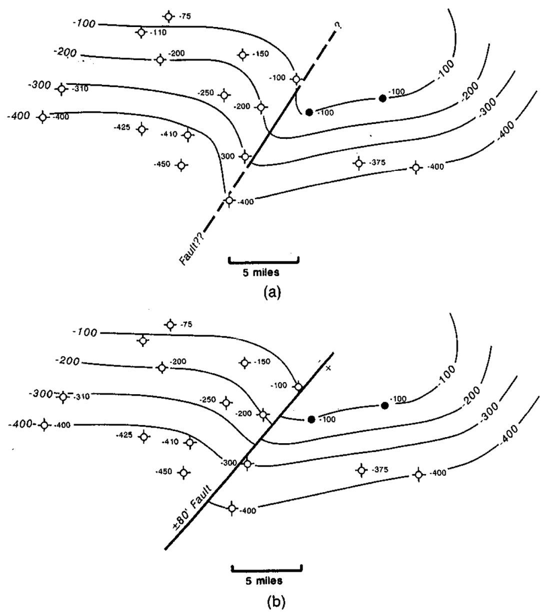
1. delineates the position of the upthrown and downthrown traces of the fault;
2. depicts the vertical separation of the fault for any particular mapped horizon;
3. defines the limits of fault bounded reservoirs; and
4. provides for the proper contouring of the mapped horizon across the fault.

Contouring faulted surfaces

14. In areas of either limited subsurface control or vertical faults, it is important to contour the limited data to reflect as simple a geologic interpretation as possible, rather than just to connect points of equal elevation. Therefore, any *radical change that occurs in the strike of the contours* may suggest faulting even though no fault has been recognized by well control. Figure 8-6a depicts such a situation. In these cases, all available data need to be reviewed, including production and pressure data to help resolve the geologic problem. In the example shown in Fig. 8-6, notice a significant change in contour strike in the area marked as a possible fault, although no fault is recognized in the wells. An interpretation that fits all the geologic and hydrocarbon data includes a vertical fault not intersected by the wells (Fig. 8-6b).

An abrupt increase in the rate of dip perpendicular to strike is a good indication of faulting. An increase in the rate of dip accompanied by an abrupt change in strike is very strong evidence of faulting (Bishop 1960). Increased dip might, alternatively, result from folding, but in most cases the increase is more abrupt where faulting is responsible.

Figure 8-6



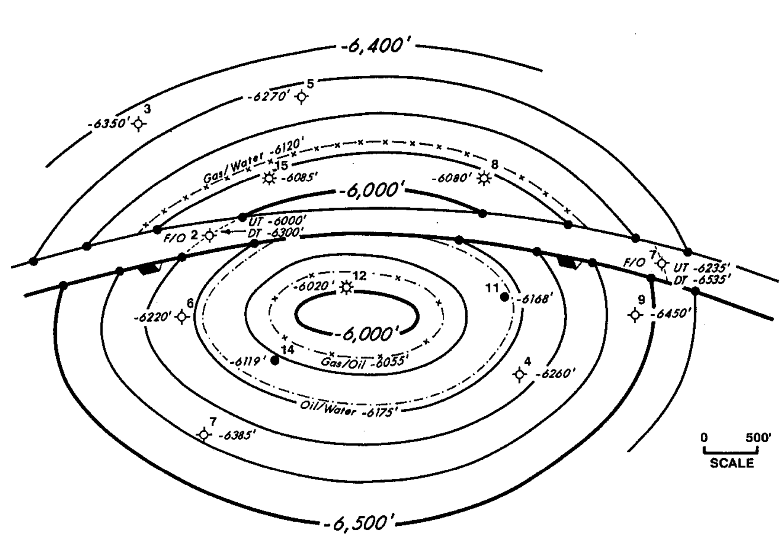


Figure 8-10 Integrated fault and structure map for the 6000-ft Sand. The darkened circles delineate the intersection of each structure contour with the fault contour of the same elevation.

Structure maps I: making a structure map

Geologists working with subsurface data commonly need to make structure maps, which are maps using contours to show the configuration of stratigraphic surfaces. One begins this effort by compiling tops (relative to sea level) from logs of boreholes (see the *PG&SG* page on "Picking tops") and plotting them on a map. In Map A at right, our pick from "Picking tops" is shown in red as a reminder of whence we have come.

The geologist's task is to contour these data in a manner compatible with the rheological behavior of sedimentary strata, which are slightly, but only slightly, ductile in the subsurface. Most geologists are taught to make contour maps by contouring data from topographic surfaces, which are continuous surfaces that are commonly incised by streams. The result is a map like Map B, which has kinked contours suggesting sharp bends that are unlikely to form in layers of sedimentary rock. Thus the topographic model is a less-than-useful model for contouring of structure maps, and one that suburface geologists commonly must unlearn.

If one contours the data in Map A so as to avoid kinks (a good thing) and to maintain a continuous surface (not necessarily a good thing in subsurface mapping), one may arrive at a map like Map C. This map has curving rather than kinked contours, but presents a surface unlikely to form in the folding of a layer of sedimentary rock: slopes change abruptly from gentle to steep (see the areas shaded red), folds are tight, and fold axes bend sharply and/or diverge.

The closely spaced contours in the red areas of Map C would require tight folding of a layer of sedimentary rock. A not-very-ductile and instead relatively brittle layer of sedimentary rock would instead be likely to break to give a fault (and thus a discontinuous surface). An experienced subsurface geologist would look at the three problematic red areas in Map C, which form a line, and say "Let's try putting a fault there".

Map D is a more reasonable geological interpretation of the elevation data in Map A. The stratigraphic surface is folded gently and faulted, both of which are reasonable assumptions about the behavior of layers of sedimentary rock (whereas as Map C would require sharp folding not consonant with our understanding of how layers of sedimentary rock behave as they are deformed). Map D thus presents the most *geologically* parsimonious interpretation of the data.

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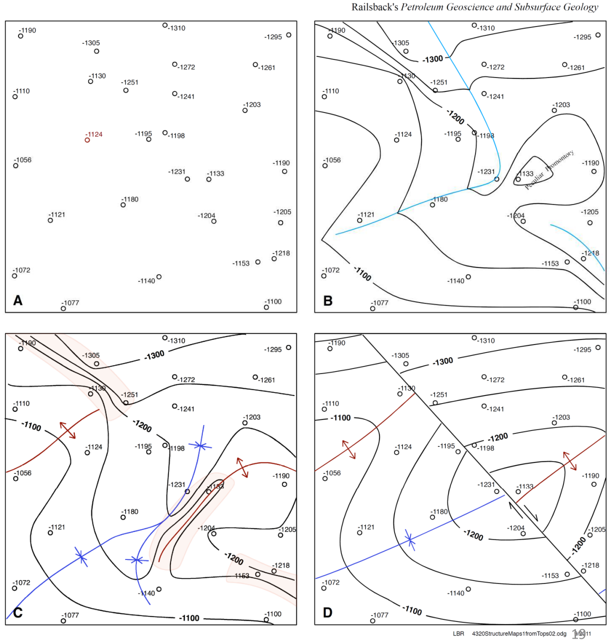


Normal Faults

Normal Faults. A **Fault trace** is defined as a line that represents the intersection of a fault surface and a structural horizon. Two fault traces are normally required to delineate a fault on a structure map. One line represents the upthrown trace and the heavier line represents the downthrown trace of the fault. One convention designed to indicate the direction of dip of the fault is to place a "*tent*" symbol on the downthrown fault trace. The structure map in Fig. 8-11 shows a fault displacing a contoured surface, using the conventional symbols described.

- Two lines are required to delineate a fault on a structural map.
- One line represents the upthrown trace and the other one represents the downthrown trace of the fault.

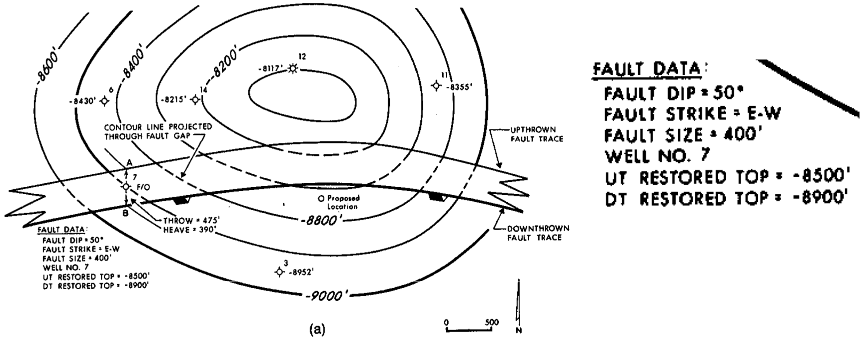


Figure 8-11 (a) Faulted structure map on the 8000-ft Sand. The structure is cut by a 400-ft fault. The correct method for contouring vertical separation (missing section) is illustrated by the dashed contour lines.

Throw is the difference in the vertical depth between where the fault intersects the formation in the upthrown block and where it intersects the formation in the downthrown block, *measured perpendicular to fault strike*. The fault shown in Fig. 8-11b strikes east-west; therefore, the throw can be determined by measuring across the fault in a north-south direction (see arrows in fault gap through Well No. 7). Using the points **A** and **B** on the map (Fig. 8-11a), the upthrown depth at point A is −8460 ft and the downthrown depth at point B is −8940 ft. The throw of the fault at this location is the difference between these two depths, or 475 ft.

Heave, which is the horizontal distance across the fault gap from the upthrown to downthrown traces, measured perpendicular to the fault strike, is 390 ft. We can see for this particular example that the throw is about 80 ft greater than the vertical separation.

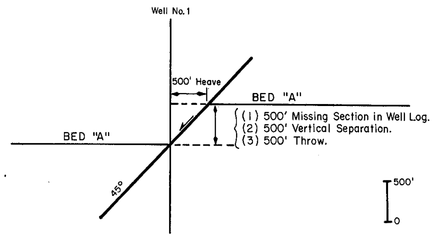
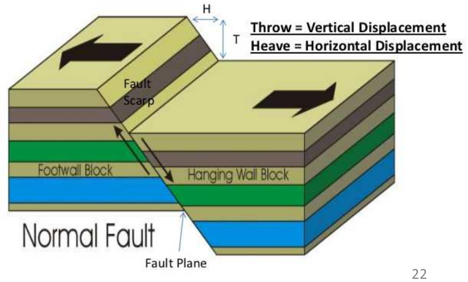


Figure 7-8 The values for throw and vertical separation are the same when the disrupted beds are horizontal. (Published by permission of Tearpock.)



Reverse Faults

Reverse Faults. The technique presented for contouring across a normal fault is also applicable for contouring across a reverse fault. Reverse faults and overthrusts, however, produce a fault overlap rather than a fault gap. Figure 8-19 shows the technique for contouring across a reverse fault. The 4500-ft Sand, which dips generally to the west-northwest, is displaced by a west-southwest dipping reverse fault. The fault size or vertical separation determined from well log correlation is 450 ft.

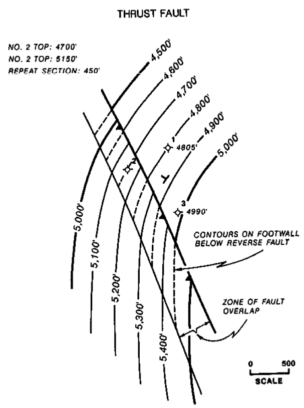


Figure 8-19 The correct method for contouring repeated section (vertical separation) across a reverse fault is illustrated by the solid and dashed contours in the fault overlap.

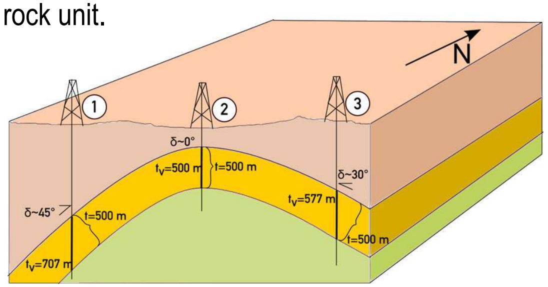
A. Isopach maps / B. Isochore maps } Thickness maps

- Thickness maps are another type of standard map used to explore for natural resources and to interpret stratigraphic relationships.
- Thickness maps are a graphical representation of variations in stratigraphic thickness.
- They represent thickness variations and thickness trends of a given unit.
- There are many different types of thickness (TST, TVT, MLT, TVDT, and net pay), and when each type of thickness is mapped, the maps have different names.

A. Isopach maps
B. Isochore maps
} Thickness maps

- An **isopach map** is a map of the **True Stratigraphic Thickness (TST)** of a rock unit. These maps are useful to differentiate between structural and stratigraphic traps, identify depositional changes, and determine possible locations to drill for hydrocarbons and oil.
- An **isochore map** is a map of the **True Vertical Thickness (TVT) or (drilling thickness)** of a rock unit.

t = TST
tv = TVT



To make an isopach or isochore map:

- It is necessary to measure the TVT or TST between two marker units or beds.
- The resulting thicknesses are plotted on a well location map and the data are contoured normally.
- Linear thickening trends are commonly the result of thrust faulting or depositional features, such as a marine channel or bar sand.
- An isolated thickening trend may represent a *karst feature, an isolated pinnacle reef, a reef complex, a salt dome, or an* erroneous data point.
- A prominent, oriented thickening may indicate a sediment source direction; sediments should thicken toward the source region.
- Using other types of maps will help constrain these interpretations.

Isopach and isochore maps are generally used:

a. for predetermining drilling depths to specific horizons in wells.

b. to locate buried structures in regions where formations habitually become thinner over structural crests.

c. In estimating the elevation of a datum bed below the total depth of a well that penetrated a higher known stratigraphic horizon.

d. To calculate the volume of oil in a formation.

Types of Isopach maps

There are several types of isopach maps important to the evaluation of petroleum potential. These include:

1. Interval
2. Net sand
3. Net pay isopach maps

1. An **interval isopach** map delineates the true stratigraphic thickness of a specific unit.
2. A **net sand isopach** map is an isochore map which represents the total aggregate vertical thickness of porous reservoir rock present in a specific stratigrphic interval.

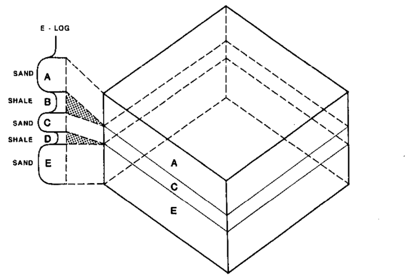
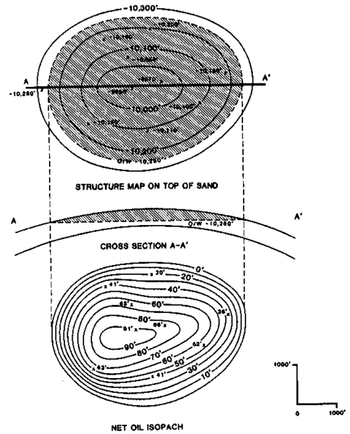


Figure 10-2 Net sand consists of porous reservoir quality rock. All shale and non-reservoir quality rock are removed. (From Tearpock and Harris 1987. Published by permission of Tenneco Oil Company.)

3. A **net pay isopach** map is a special isochore map that delineates the thickness of reservoir quality sand which contain hydrocarbons (gas, oil, or both) or water.

Figure 10-4 Structure map, cross section, and net oil isopach map for a bottom water reservoir. Net oil isopach map is a special isopach map showing the thickness of reservoir quality rock containing hydrocarbons. (From Tearpock and Harris 1987. Published by permission of Tenneco Oil Company.)



- **Net pay maps** are an important type of thickness map in the exploration of hydrocarbons or water reserves.
- Reservoirs or aquifers are heterogeneous, and as a result, the entire reservoir interval is not generally productive.
- Porosity and permeability vary laterally and vertically throughout any reservoir. It is necessary to get an estimate of how much of a given interval or reservoir is potentially a pay zone.
- A minimum porosity is usually defined as a **cutoff**, and will depend on economics, the field, and the exploration company. Four percent is a common cutoff because less than 4% usually means the reservoir has limited permeability and is thus incapable of effectively draining the limited amount of hydrocarbons it may contain.
- Any section within a potential reservoir interval having porosity higher than the cutoff is considered a net pay (fig. 6–3).
- The amount of net pay in a given interval is then summed and contoured as any standard map.

Fig. 6–3. A well log showing the net pay within a limestone and sandstone reservoir using a 4% cutoff neutron porosity. Notice the sandstone porosity had to be adjusted because the neutron log was run on a limestone matrix. Choosing an appropriate conversion chart will depend on which porosity logs are run, drilling fluid density, and an individual's preference.