GOVERNMENT OF
NEWFOUNDLAND AND LABRADOR
Department of Mines andEnergy

An Introduction to THE PETROLEUM INDUSTRY

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Table of Contents

Table of Contents

Table of Contents

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Alphonsus Fagan

Materials Used in Compiling This Manual

(1) The Oil and Gas Lease In Canada; Second Ed.: John B. Ballem; University of Toronto Press, 1985.

(2) Handbook on Basic Land Management: Lewis G. Mosburg, Jr. The Institute for Energy Development, Inc., 1978.

(3) Fundamentals of Petroleum; Second Edition: Petroleum Extension Service, The University of Texas at Austin, 1981.

(4) Our Industry Petroleum; The British Petroleum Company Ltd., Fifth Edition, 1977.

(5) Oil Business Fundamentals; Robert D. Langenkamp; 1982.

(6) The Story of Petroleum, Shell Oil Company.

(7) This Fascinating Oil Business, Max W. Ball; The Bobbs-Merrill Company, 1940.

(8) An A-Z of Offshore Oil and Gas, Second Ed., Harry Whitehead; Kogan Page Ltd., 1983.

(9) The Illustrated Petroleum Reference Dictionary, Second Edition; Robert D. Langenkamp, Pennwell Publishing Company, 1982.

(10) Petroleum Politics and Power; E.B. Brossand, Pennwell Publishing Company, 1983.

(11) Our Petroleum Challenge, The New Era; Second Edition, The Petroleum Resources Communication Foundation, 1980.

(12) Offshore Drilling Deeper and Deeper, Shell Canada Resources Ltd., 1982.

(13) Reference Points, Canadian Oil and Gas: The First One Hundred Years; Canadian Petroleum Association, 1984.

(14) Mining, Oil and Gas, Northern Miner Press Ltd., 1979.

(15) The Offshore Search For Oil and Gas, Fourth Edition; Exxon Background Series; September 1980.

(16) Facts About Oil, American Petroleum Institute, 1984.

(17) SEEDS Energy Literacy Series; SEEDS Foundation, Edmonton, Alberta.

(18) Introduction To The Petroleum Industry; Seminars On The Petroleum Industry: The Newfoundland and Labrador Petroleum Directorate In Conjunction with Van Meurs & Associates Ltd.

Introductory Remarks

It is not known exactly when humankind first used petroleum. It is known, however, that ancient peoples worshipped sacred fires that were fuelled by natural gas seeping to the surface through pores and cracks. It is also known that asphalt, a very viscous form of petroleum, was used to waterproof boats and heat homes as early as 6,000 BC. Asphalt was also used as an embalming agent for mummies and in the construction of the Egyptian pyramids around 3,000 BC. Petroleum's usefulness, so it seems, was recognized from the very beginnings of civilization.

Petroleum's importance to humankind took a giant leap in the late 1800's when it replaced coal as the primary fuel for the machines of the industrial revolution. In today's industrialized society, petroleum means power. It provides the mechanical power to run machines and industries and also the political power that comes from being able to shut down the machines and industries of those who depend on you for their oil supply.

Today, petroleum remains our primary source of energy, and today, the province of Newfoundland is preparing to become an important player in the Canadian oil industry. A number of large oil and natural gas fields were discovered offshore Newfoundland and Labrador during the 1970's and 1980's and more discoveries are expected to be made with further drilling.

We are now developing our offshore petroleum resources, and this has the potential to have significant economic and social impacts on our province. To reap the maximum benefits from petroleum developments, we need to understand this new industry. By educating ourselves as individuals, we can be in a better position to take advantage of the resultant employment and business opportunities. By educating ourselves as a population, we can help ensure our governments make good decisions in relation to this industry that will serve the long term interests of our people. This manual is intended to play a role in this education process. It attempts to give a basic understanding of the petroleum industry; where it started, why it is important, and how it works. It takes the student through the different phases of petroleum exploration, development and production and discusses some of the careers associated with the petroleum industry. The last two chapters are workshops which do not introduce any new material, but which require the students to draw upon knowledge gained in the first ten chapters and conduct some research of their own.

This manual has been designed around the belief that the most enjoyable and effective means of learning is by doing. Each chapter contains several pages of text followed by a few review questions and one or more exercises. In most cases, it is important that the student understand the text part of the chapter to appreciate the exercises. Each activity attempts to illustrate at least one important concept. In cases where the ideas to be explained did not easily lend themselves to illustration by simple activities, the activities are to be replaced by the viewing of pertinent films.

The development of Newfoundland offshore oil is coming at a time when we have become highly sensitized to environmental issues and yet remain very dependent on petroleum. As we proceed with offshore development, we must bear in mind the lessons that have been learned elsewhere and the special challenge our offshore area presents to the oil industry. We must ensure that our offshore petroleum resources are developed wisely and, in cooperation with the fishery so that we can reap maximum benefits from both industries. These noble goals can best be achieved with input from a well informed public and it is hoped that this manual will be useful for those who want to become informed about this increasing important sector of our economy.

Introduction to the Petroleum Industry

Introduction to the Petroleum Industry

What is oil? We hear about it almost every day in the news. People around the world are very concerned with the price of oil; countries who may be at war attempt to cut off the supply of oil to their enemies; countries like Canada and the United States are concerned with obtaining a secure supply of oil. Why does the whole world seem to be preoccupied with oil? How is oil different from other commodities which are traded in the world market such as wheat, fish, paper or steel, all of which are important in our daily lives? These are some of the questions we will address in this chapter.

Terminology

Oil, petroleum, natural gas, hydrocarbons and *crude* are terms we commonly hear. If we are going to study the oil industry, we must first become familiar with the "lingo". Appendix I provides a glossary, but it will be useful at this point to introduce you to the some of the key terms.

There are many kinds of oils. We have “oils” that are used for cooking and sun tanning. Some of these oils come from different types of plants (such as vegetable oil) and animals (cod liver oil). The oil we are concerned with here is derived from rocks within the earth. It is called *petroleum*, a name taken from the Latin words meaning "rock oil". Throughout this text when we speak of oil, we will always mean *petroleum*.

The term *hydrocarbons* refers to the chemical makeup of petroleum. A detailed discussion of petroleum chemistry is beyond the scope of this manual, but it will suffice to say that petroleum is a compound made up predominantly of atoms of *hydrogen* and *carbon*; thus the name hydrocarbons.

Hydrocarbons can combine in various ways to form many different compounds. They can form solids, such as the asphalt that is used to pave roads; liquids such as conventional liquid petroleum, and gases such as *natural gas* (not to be confused with gasoline). Natural gas is a mixture of hydrocarbons that are in a gaseous state at normal temperature and pressure (Figure 1.1).

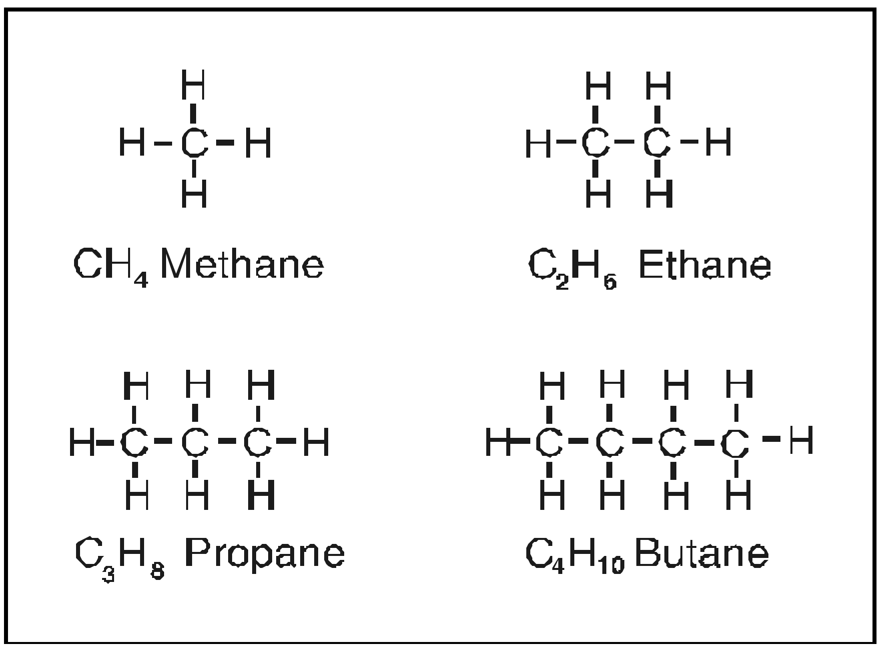


Figure 1.1 - Hydrocarbon Molecules

Methane is the simplest hydrocarbon molecule with only one carbon (C) atom. The first four members of this hydrocarbon series shown here, are gases under normal conditions. Natural gas contains mixtures of these molecules as well as certain impurities. Subsequent members of this hydrocarbon series represent increasingly heavier liquid and eventually waxy solids. Hydrocarbon molecules in this group are known to contain up to 78 carbon atoms (i.e., C_{78}). How many hydrogen atoms would be present in such a molecule? (ie, $C_{78}H_?$).

It consists mostly of methane, but also contains ethane, propane, butane and pentane, which are the simplest and lightest hydrocarbons. The different properties of hydrocarbon compounds are determined by differences in the number and arrangement of hydrogen and carbon atoms they contain. Carbon is much heavier than hydrogen and thus the weight of the hydrocarbon molecule is predominantly determined by the number of carbon atoms. Natural gas molecules will contain only a few carbon atoms per molecule while a heavy petroleum such as tar or asphalt may contain a great number of carbon atoms per molecule. Petroleum may also contain certain impurities such as nitrogen, sulphur and oxygen.

The term *crude oil* refers to oil in its "crude" or unrefined state; that is to say oil as it comes out of the ground. This crude oil must be transported to a refinery to be separated into constituents such as gasoline, aviation fuel, fuel oil, etc. before it can be used by the consumer (Figure 1.2).

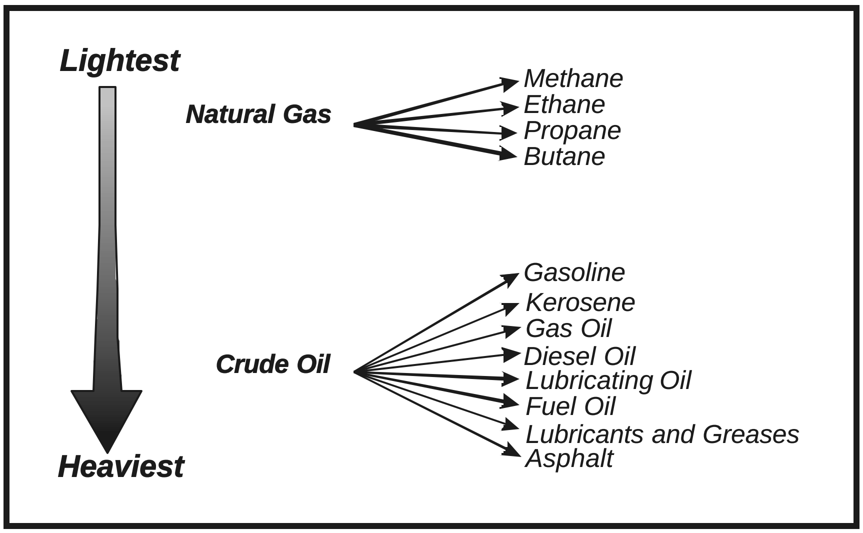


Figure 1.2 - Petroleum and some of its components

Crude oil, which may be a mixture of all of the above components, is separated into these and other petroleum products in the refinery.

• Why is Oil so Important in Today's World?

The answer to this question may already be obvious to you but let's try and see how big a role oil plays in your daily life.

When you got out of bed this morning, the electricity you used to cook breakfast may have been generated from an oil-burning generating station; or perhaps your family uses a natural gas-burning stove. You were able to enjoy breakfast in comfort and warmth because of the oil-burning furnace in your basement. Next you may have taken a gasoline or diesel powered car (or bus) to school. So, as you can see, before you even started your school day you already used a certain amount of petroleum. Many of us tend to take these conveniences for granted. Try and imagine how your life might change if we suddenly lost our supply of oil.

A Source of Energy

Oil's primary importance lies in the fact that it is a very versatile and powerful source of energy. There are many other energy sources that we routinely use, including firewood, coal, and hydroelectric and nuclear generating stations. All of these sources have their advantages and disadvantages. A clean and renewable source of energy, would certainly be the most desirable.

Oil is a non-renewable source of energy. What this means is that our natural sources of oil are finite; there will come a time when we have used them up. One of the exercises at the end of this chapter will ask you to calculate how long our present known supplies of oil will last at today's consumption rates.

The reason that oil has such importance is that it provides the fuel that runs the internal combustion engine. The internal combustion engine was invented by Karl Benz in 1885-86. Gotlieb Daimler improved on this invention and eight years later Rudolph Diesel created the engine that bears his name. These types of engines are still used today in all kinds of machinery including automobiles, ships, tractors, generators and tanks. Oil is also the raw material for the fuels that are used in jet engines and in some cases to fuel rocket engines to propel spacecraft into outer space.

It should now be obvious why oil plays such a dominant role in today's world. If oil supplies were to be cut off, cars, boats and planes would grind to a halt. We would have to find alternate means of heating many of our homes and generating sufficient electricity. Our personal security would also be threatened because our military forces and police forces would be largely immobilized.

Oil's principle importance derives from the fact that it fuels the machines of our industrialized society.

Other Uses for Oil

Although oil is primarily an energy source, it is also used as a raw material in manufacturing more than a thousand other products including; plastics, paints, fertilizers, detergents, cosmetics, insecticides, and even food supplements (Figure 1.3).

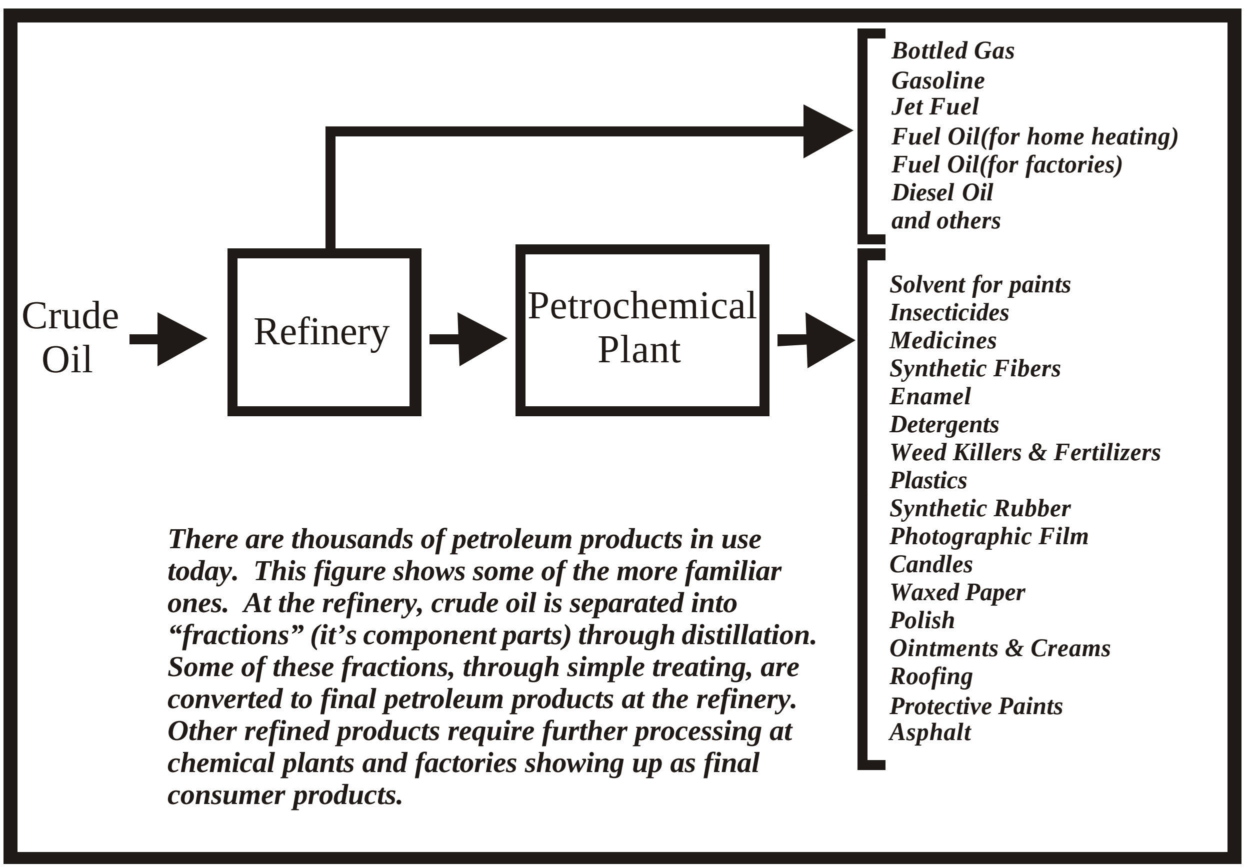


Figure 1.3 - Petroleum Products

- ## Will Society Always be Dependent on Oil?

As long as we depend on oil to fuel the engines of the world, it will continue to play a major role in our lives. But research is ongoing in many countries to find ways to harness new sources of energy.

Perhaps one day our cars will have electricity powered engines and run on batteries that must be recharged every few hundred kilometres. Or, perhaps the batteries will draw on the sun's energy and recharge even as we drive. Who knows what the future holds?

One thing that is certain, however, is that the air pollution resulting from the combustion of *fossil fuels* such as petroleum and coal is of increasing concern to the inhabitants of planet Earth. Thus, the search for a non-polluting replacement energy source is one of the most important challenges faced by humankind.

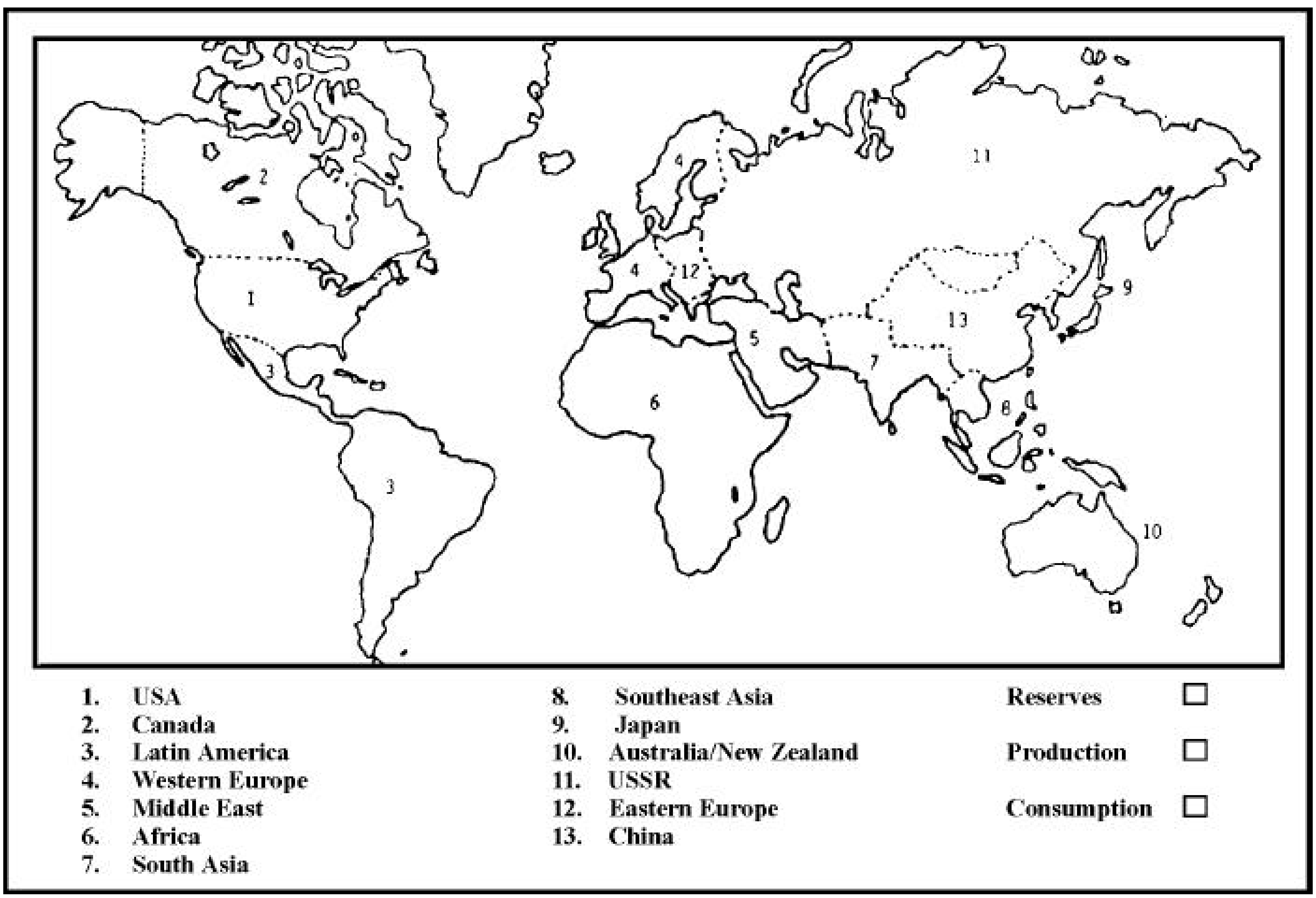


Figure 1.4 (See exercise 4)

Questions

(1) *What are some of the other sources of energy we use?*

(2) *Why have we not replaced oil with a non-polluting renewable energy source?*

(3) *Can you think of alternative sources of energy to fuel our cars?*

(4) *Why are petroleum and coal called fossil fuels?*

Exercises

(1) Examine some samples of conventional light oil and heavy oil.

(2) Use a blowtorch or Bunsen Burner to demonstrate the use of natural gas.

(3) Discuss the advantages and disadvantages of some of the different energy sources.

(4) Figure 1.4 is a map that divides the world into 13 major regions based on petroleum consumption, production and reserves. Petroleum consumption and production rates of each region are listed in millions of barrels per day (Table 1.1). The oil reserves are listed in billions of barrels and represent the total amount of crude oil that has been discovered and remains to be produced. All of these numbers are estimates that will change over time as known reserves are consumed, new oil fields are discovered, and production and consumption rates fluctuate.

In this exercise, you will graphically illustrate the oil production and consumption patterns in the world and the reserve distribution. Draw vertical bars on the map to represent the reserves, production and consumption rates (in each region). Color the bars for better illustration. A convenient scale will be 1 inch = 10 million barrels per day for production and consumption and 1 inch = 100 billion barrels for reserves. If a bar is too long, just tape an extension to the page.

Study the map with the colored bars and answer the following questions:

(1) Which regions are net exporters of oil? Importers?

(2) Which regions or countries are most vulnerable to a disruption in the supply of oil such as might occur as a result of war or political upheaval?

(3) Which region is in the best position to control the supply of oil available to the world and hence the price of oil in the long term future?

(4) Does this illustration suggest why it may be important for the industrialized countries to maintain good trade relations with the countries of the Middle East?

Table 1.1			
Country/Region	**Oil Reserves (Billions of Barrels)**	**Oil Production (Millions of Barrels per Day)**	**Oil Consumption (Millions of Barrels per Day)**
1. USA	26.5	8.1	16.0
2. Canada	6.8	1.6	1.5
3. Latin America	120.3	6.2	4.6
4. Western Europe	18.2	3.9	12.4
5. Middle East	564.8	14.0	2.2
6. Africa	55.2	5.0	1.7
7. South Asia	7.0	0.7	1.3
8. Southeast Asia	12.9	1.8	2.6
9. *Japan	-	-	4.5
10. Australia/New Zealand	1.8	0.6	0.7
11. USSR	58.5	12.4	9.1
12. Eastern Europe	N/A	1.0	2.6
13. China	23.6	2.7	2.1

* Japan’s reserves and production rates are too small to be considered. N/A—Not Available (Source: International Petroleum Encyclopedia, 1989)

Exercises (cont…)

(5) What would be a good strategy for a country like the U.S.A. to ensure a reliable supply of oil? Should it purchase all of its oil from one source?

(6) Break the class up into groups and have each group consult a world map and compile a list of the countries included under the areas designated in Figure 1.4 as:

(a) Latin America
(b) Western Europe
(c) Middle East
(d) Africa
(e) South Asia
(f) Southeast Asia
(g) Eastern Europe

(7) Using the data in Table 1.1 (i.e., oil reserves and oil consumption rates), estimate how long the world's present oil supplies will last at today's consumption rates.

$$\text{No. of Years Supply Left} = \frac{1}{365} \times \frac{\text{(Total barrels in reserve)}}{\text{(Total barrels consumed per day)}}$$

(8) What do you think will happen to the price of oil when the known oil reserves are almost used up? Will this help us find more oil? Will higher prices of oil make other energy sources more viable?

The History of Petroleum

The History of Petroleum

Various theories have been advanced over the years as to the origin of petroleum proposing an animal, vegetable, mineral and even meteoric origin. Today, however, most scientists believe that oil and gas originated in plant and animal matter that accumulated in fine grained sediments at the bottom of ancient seas many millions of years ago. This theory suggests that oil originated as the remains of countless organisms that either lived in the sea or were deposited there with mud and silt from prehistoric rivers and streams. The remains of these ancient plants and animals were transformed into oil and gas by bacterial action with heat and pressure resulting from deep burial beneath other sediments (Figure 2.1).

It seems, then, that the story of petroleum began hundreds of millions of years ago. But when did humans first learn to use petroleum?

Petroleum Used by Ancient Civilizations

No one knows exactly when humans first used petroleum. It is known, however, that ancient peoples worshipped sacred fires fuelled by natural gas seeping to the surface through pores and cracks.

The use of thick gummy asphalt to waterproof boats and heat homes was recorded as long ago as 6000 BC.

About 3000 BC the Egyptians used asphalt in the construction of the pyramids, to grease the axles of the Pharaoh's chariots, as an embalming agent for mummies and in medicinal preparations.

There are numerous references to asphalt or pitch (a form of petroleum) in the Bible, including that it served as mortar for the builders of the Tower of Babel, was used by Moses' mother to waterproof his cradle of bulrushes, and by Noah to caulk the Ark.

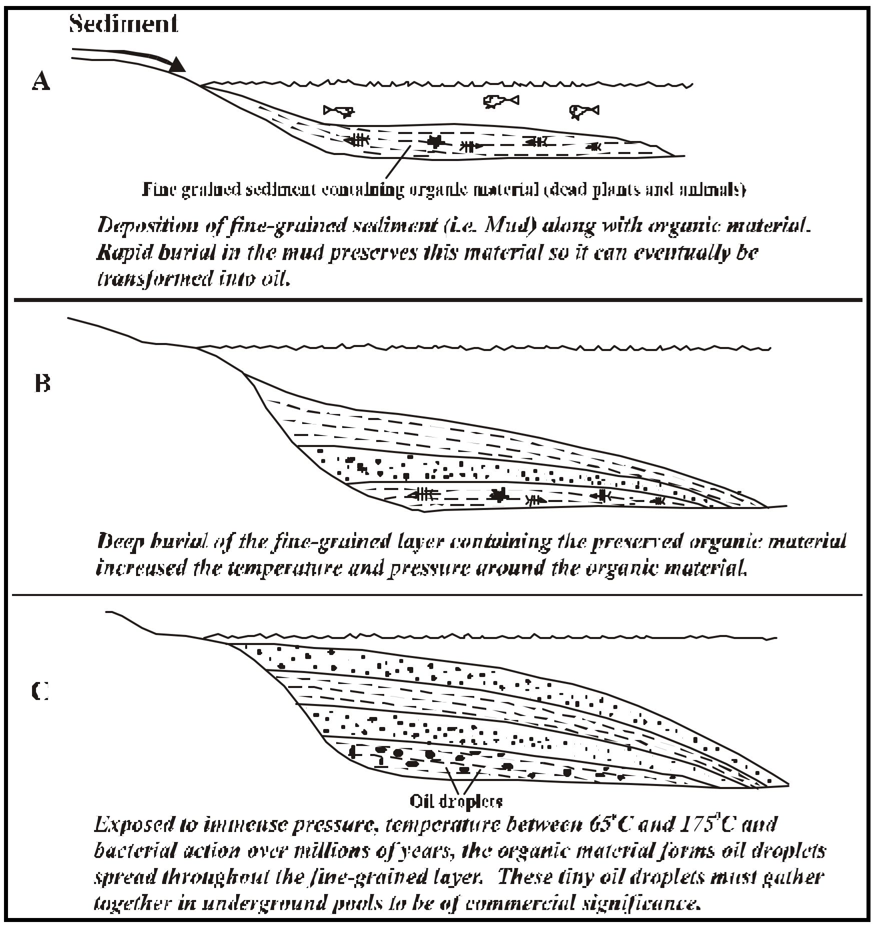


Figure 2.1 - Formation of Petroleum

In early North America, Indians skimmed oil from the surface of springs using it to waterproof canoes and in the making of war paints. They taught the colonists to use oil for healing and self-styled *"doctors"* bottled *"Seneca oil"* or *"rock oil"* and sold it as a cure-all.

When whale oil, the main source of lamp fuel in the early 1800's, became scarce, a new source was needed.

Inventors began to distill illuminating and lubricating oils from natural petroleum seeps and from coal.

Despite the varied and inventive uses being recognized, petroleum was still thought to be a substance of only minor importance. Some thought it was suitable only for use as a lubricant, patent medicine, asphalt and kerosene (for lamps) and nothing else. Others even argued that removal of petroleum from beneath the earth's surface would put out the fires of Hades. But changes were occurring in the world. Changes that would make the continued development and growth of the petroleum industry inevitable.

The First Oil Wells

For thousands of years, the only sources of petroleum had been *surface seeps* or *tar pits*. These sources were not very productive, so certain individuals decided to look for oil underground, by drilling.

In 1858, one such individual, a 39 year old carriage maker from Hamilton, Ontario, named James Miller Williams made the first major commercial oil discovery in North America at Oil Springs, Ontario. Drilling in "gum beds" in Lambton County, 25 km southeast of Sarnia, he struck oil at a depth of only 18 metres. Williams refined the oil he produced and sold the product as lamp oil. In the following year, Colonel Edwin L. Drake discovered oil in Titusville, Pennsylvania by drilling to 21 metres (Figure 2.2). This discovery signalled the birth of the modern petroleum industry in the United States*.

Figure 2.2

Drake's well at Titusville, Pennsylvania, marked the start of the U.S. oil industry in 1859. (Courtesy of Shell Oil Company).

The Oil Boom Begins

As a result of the oil discoveries of the 1850's, numerous refineries were built to turn crude oil into kerosene for lamps and into lubricating oils for the machines of the industrial revolution. Oil began to replace coal as the fuel for steam engines.

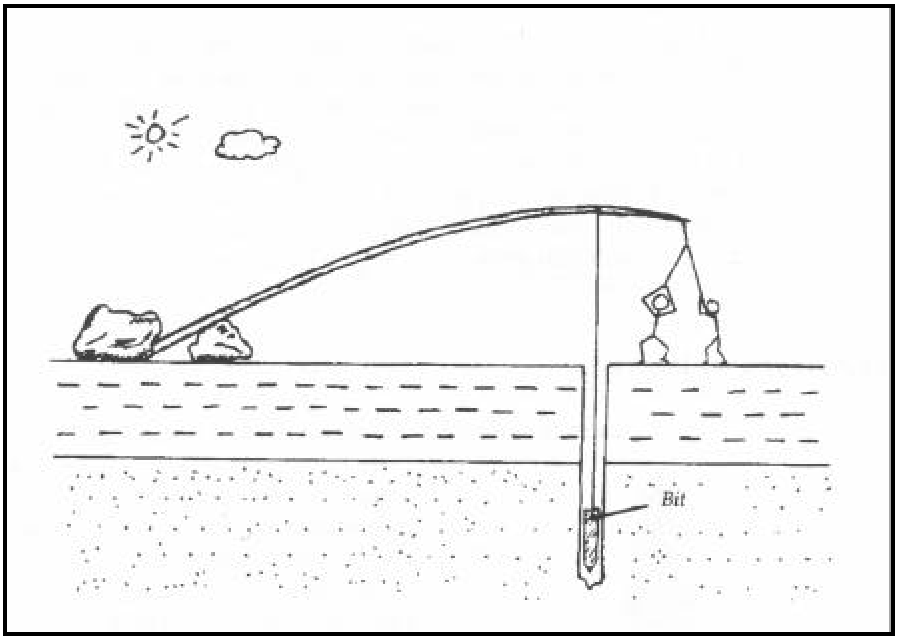
The invention of the gasoline engine (1885) and diesel engine (1892) allowed inventors of horseless carriages to adopt a new power source to replace steam and electricity. Gasoline which had previously been considered a useless by-product of the distillation of crude oil would now take on a new importance as advancements in technology made possible the mass production of the automobile in early years of the twentieth century.

In 1903, at Kitty Hawk, North Carolina, the Wright brothers utilized petroleum to realize what could only be imagined by previous generations - flight. Since that first flight at Kitty Hawk, North Carolina, petroleum has fuelled every type of aircraft from Lindberg's "Spirit of St. Louis" to today's jumbo jets.

***** The Chinese are recognized to be the first civilization to drill for oil. As early as 300 BC they pounded holes in the ground with heavy, bronze bits suspended from spring poles (Figure 2.3)

Figure 2.3 - Spring Pole Drilling

Drilling technique of ancient Chinese. The spring pole eliminated some of the manual labor in raising and dropping a heavy bronze bit. Early drillers in the "modern" oil industry used a variation of this technique called "cable tool drilling" which utilized a steam or internal combustion engine to raise and lower a wooden or metal beam from which the bit was suspended.



The Present

Today, we are well into the space age, but petroleum is still the dominant source of energy used by humankind. This is especially true in the transportation industry.

This versatile fuel that is so easily transported and poured into the fuel tanks of our cars and planes has also been largely responsible for the rapid technological advances we have experienced in the past 100 years.

It was less than 500 years ago, in 1519, that Ferdinand Magellan set out with five ships on one of the greatest expeditions in human history; to circumnavigate the world. This voyage cost the lives of most of Magellans' men, including his own, and took three years to complete. Today, it would not be considered a great accomplishment to go around the world, using modern air travel, on a three week vacation. Indeed the world has become a much smaller place, largely due to petroleum - that smelly, oily substance that had its beginnings in ancient seas millions of years before men and women walked the earth.

Questions:

(1) *How is petroleum formed?*

(2) *Why do you think whale oil became scarce?*

(3) *What invention in the late 1800's lead to petroleum becoming a substance of great importance?*

(4) *Find out the difference between a gasoline powered and a diesel powered engine.*

Exercises:

(1) Split the class up into teams and debate some of the positive and negative effects of the industrial revolution on people and the environment.

(2) *(To be performed by Teacher in Front of the Class).* In this exercise you will compare three sources of light; the candle, the kerosene lamp, and the electric light bulb.

Oil provides the raw material to produce candles as well as kerosene. Candles have been widely used as a light source and kerosene is the fuel that burns in kerosene lamps. Kerosene lamps were the most common sources of light before electricity. Indeed, many of your parents or grandparents studied their schoolbooks by the old kerosene lamp. These lamps are still in common use today, especially during power failures.

Materials:

- kerosene lamp (with fuel)
- candle
- matches
- electric lamp

(Caution: Only kerosene fuel should be used in a kerosene lamp. Do not use camp fuel).

Procedure:

Draw the curtains and darken the classroom. Light the candle. Observe the quality of the light. Is it bright or dull? Try and read something. Extinguish the candle.

Light the kerosene lamp. Observe the quality of the light. Try and read in this light. Extinguish the lamp.

Turn on the electric lamp. Compare the quality of the light with that of the candle and the kerosene lamp. Try and read in this light.

Questions:

(1) *Which gave the best quality of light?*

(2) *Which was the cleanest source of light?*

(3) *What is the process by which the wax in the candle burns? Does it burn the same way as a match burns or is something slightly different happening?*

(4) *What is the process by which the fuel in the kerosene lamp burns? What causes the kerosene to rise up through the wick?*

Questions (cont…):

(5) *Of what chemical element is the black soot that is deposited on the lamp glass composed? (**Hint:** It is not hydrogen).*

(6) *What makes the light bulb glow? Is it also burning a fuel?*

(7) *Is the electricity that lights the bulb generated by the burning of petroleum or by a hydroelectric plant?*

(8) *When did electricity first come to your area?*

(Adapted from SEEDS Energy Literacy Series)

Porous and Permeable Rocks

Porous and Permeable Rocks

We have already established that petroleum is found by drilling holes into the ground. Our curiosity must now lead us to wonder what is going on down underground that allows us to drill a hole and suddenly have this "black gold" come flowing conveniently to the surface for our use. Are we drilling into underground rivers or lakes of oil? Caverns filled with natural gas? We will begin to answer these questions in this chapter. When we reach an understanding of where the oil comes from, it will become apparent why oil is found in some areas and not in others. This information can then be used in the search for new places to drill for petroleum.

Three Types of Rocks

Before we proceed to discuss where oil is found in the subsurface, we must become familiar with some new terminology; namely, the three types of rocks; igneous, sedimentary and metamorphic.

Igneous rocks are rocks that have solidified from a molten or liquid state. These rocks can be formed deep in the earth or at the surface from the cooling of volcanic lava. Igneous rocks do not normally contain hydrocarbons.

Sedimentary rocks are formed by the laying down of sediment in seas, rivers or lakes. The particles of sediment that accumulate are eventually cemented together to form sedimentary rock by the percolation of mineral rich waters through the spaces between the particles. It is these sedimentary rocks in which hydrocarbons are normally found. This type of rock will be discussed in more detail in Part "B" of this Session.

Metamorphic rock is formed by the metamorphosis of existing rock, be it igneous or sedimentary, by extreme heat and pressure. These factors cause recrystallization of the minerals in the rock. Metamorphic rocks do not normally contain hydrocarbons.

Porosity

Petroleum is not found in underground rivers or caverns, but in pore spaces between the grains of *porous* sedimentary rocks (Figure 3.1). But what does the word *porous* mean? This is most easily explained by illustration.

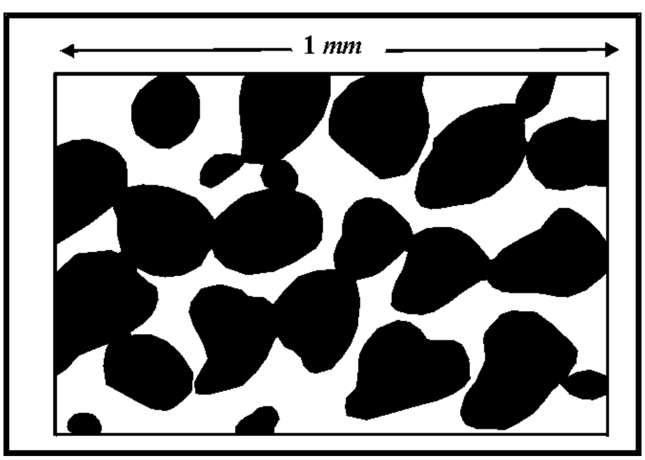


Figure 3.1 - Porosity

A piece of porous sedimentary rock. The pore spaces are the white areas between the dark grains. It is within such pore spaces that fluids such as oil, natural gas, or water can be found in the subsurface.

A sponge is a good example of a household object that is porous or in other words possesses *porosity*. If we take a dry sponge and dip it in water, the sponge will soak up the water. The water that is soaked up is absorbed into pore spaces within the sponge. The sponge has porosity. If we now squeeze the sponge, we will close up some of these pore spaces and water will be forced out of the sponge.

In the same way as the sponge, certain types of sedimentary rocks can also be porous and contain oil and gas within pore spaces . It may not be obvious that a solid piece of rock can act like a sponge, but if we were to take a piece of porous sandstone (a type of sedimentary rock) and weigh it before and after we allowed it to sit in a pail of water, we would find that it weighed more after. This is because it would have soaked up some of the water, just as a sponge would. We cannot squeeze the water out with our hands because we are not strong enough, but you can imagine that if the rock could be squeezed by some giant hands without being crushed, some of the water would come out.

Porous rocks that contain oil and gas buried thousands of metres below the earth's surface are being squeezed in this fashion by the weight of the overlying rock and the water contained in that rock. That is why the oil flows out of the rock and up to the surface when the rock is penetrated by a well.

Permeability

For oil or gas to be able to flow freely through a rock, that rock must possess *permeability* as well as porosity. The permeability of a rock is a measure of the ease with which fluids can flow through a rock. This depends on how well the pore spaces within that rock are interconnected (Figure 3.2). If none of the pore spaces were connected to other pore spaces, then no oil could flow through the rock. The only oil that would come into the well would be from the pores that were actually in contact with the well bore. This would obviously not make for a very profitable oil well. On the other hand if the rock has good permeability oil can flow to the well from pores that are thousands of metres from the well bore.

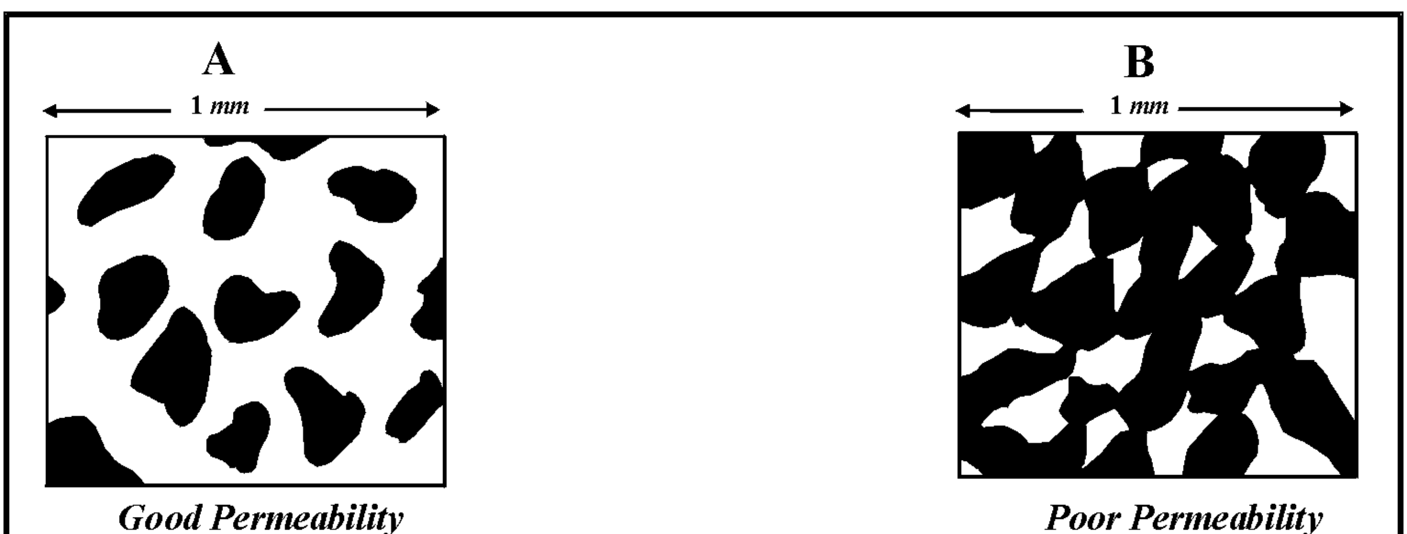


Figure 3.2 - Permeability

In sketch A above, the pore spaces are well connected allowing fluids to flow quite easily. This rock has good permeability. In sketch B, the pore spaces are largely isolated from one another giving this rock poor permeability. Sketch A may be somewhat confusing as it appears that the grains are being held in free suspension with nothing to support them. Remember, however, that this is just a simplified two dimensional sketch. The grains make contact with other grains somewhere out of the plane of the sketch.

Questions

(1) *In what kind of rocks is petroleum found?*

(2) *What does porosity mean? Permeability?*

(3) *Which type of rock is likely to be more permeable, a sandstone which is formed from sandy sediment or a shale which is formed from muddy sediment?*

Exercises

(1) Examine some samples of igneous, metamorphic and sedimentary rocks.

(2) "Porosity and Permeability".

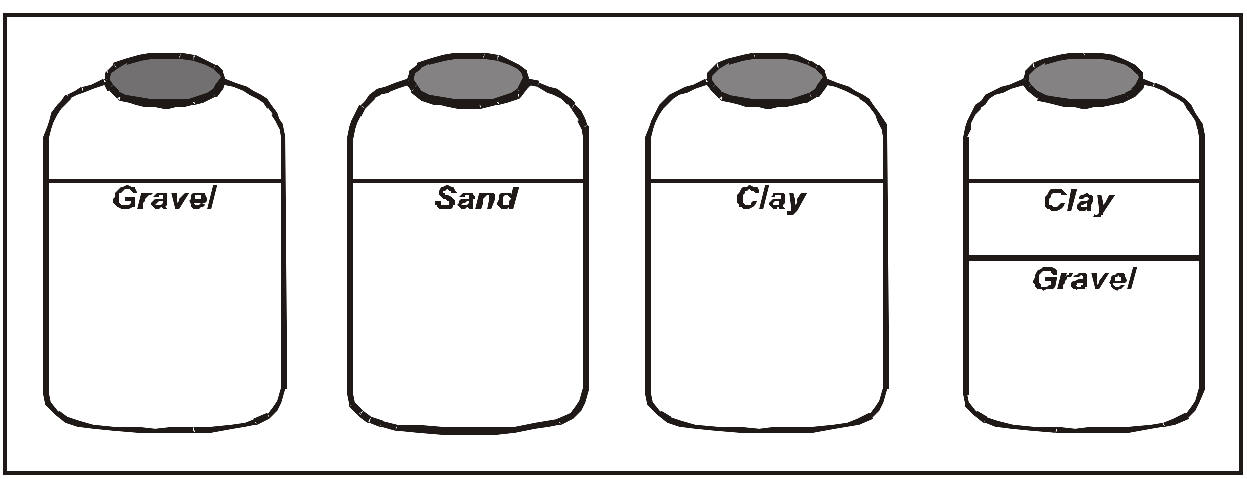
Purpose:

To examine the porosity and permeability of various sediments.

Materials:

- four large glass jars (at least 750 ml)
- measuring cup
- wire mesh window screen
- water
- about 2 kg of dry gravel
- about 2 kg of sand
- about 2 kg of clay or potting soil

Fill each of the glass jars as shown in the illustration following; one with clay, one with sand, one with gravel and one with two thirds gravel on the bottom and one third clay on top. Pack each one firmly.



Using the measuring cup add water to each until no more will soak in and it just covers the surface. Record the volume added in each case.

Using the wire mesh to hold the sediments in place, pour the water out of each jar into the measuring cup and record the amount that comes back, and take note of how quickly the water pours out.

Questions

(1) *Spaces between particles are called pore spaces and their percentages of the total volume of sediment is called the porosity of the material. Which jar took the most water and which the least? Which type of sediment had the greatest porosity? Why?*

(2) *Permeability is a measure of the ease with which a fluid can flow through a material. It is related to how well the individual pore spaces are interconnected. Which jar did the water flow out of the fastest? The slowest? Which sediment has the greatest permeability? The least? Are they the same ones that had the greatest and least porosity?*

(3) *What happened when water was added to the jar with the clay overlying the gravel? Is the clay an impermeable seal?*

(4) *Name the sedimentary rock formed from sand; from clay.*

(Adapted from SEEDS Energy Literacy Series)

How Sedimentary Rocks are Formed

Erosion and Transport

All rocks including igneous, metamorphic and sedimentary that are exposed to the elements of wind, rain, heat and cold eventually give way to wear and tear and are eroded. Some are simply broken up into small pieces by frost and running water while others are dissolved slowly as weak acids in ground water react with the minerals contained within the rocks. In either case, the debris or sediment, as it is called, is gradually carried downhill by the forces of gravity and running water.

As the sediment is washed further and further "downstream", it is broken into smaller and smaller pieces. Eventually, these rock fragments are deposited in sediment traps such as ponds or lakes. Sediment traps on land, however, are relatively short-lived. A pond, for example, in which sediment is continuously being deposited and not being removed will eventually become filled with sediment. So, inevitably, most sediment moves on until it is finally deposited into a large body of water such as a very large lake or the ocean itself. A large depressed area in which a lot of sediment has been or is being deposited is called a *sedimentary basin*. Figure 3.3 shows where the main sedimentary basins are located in Canada.

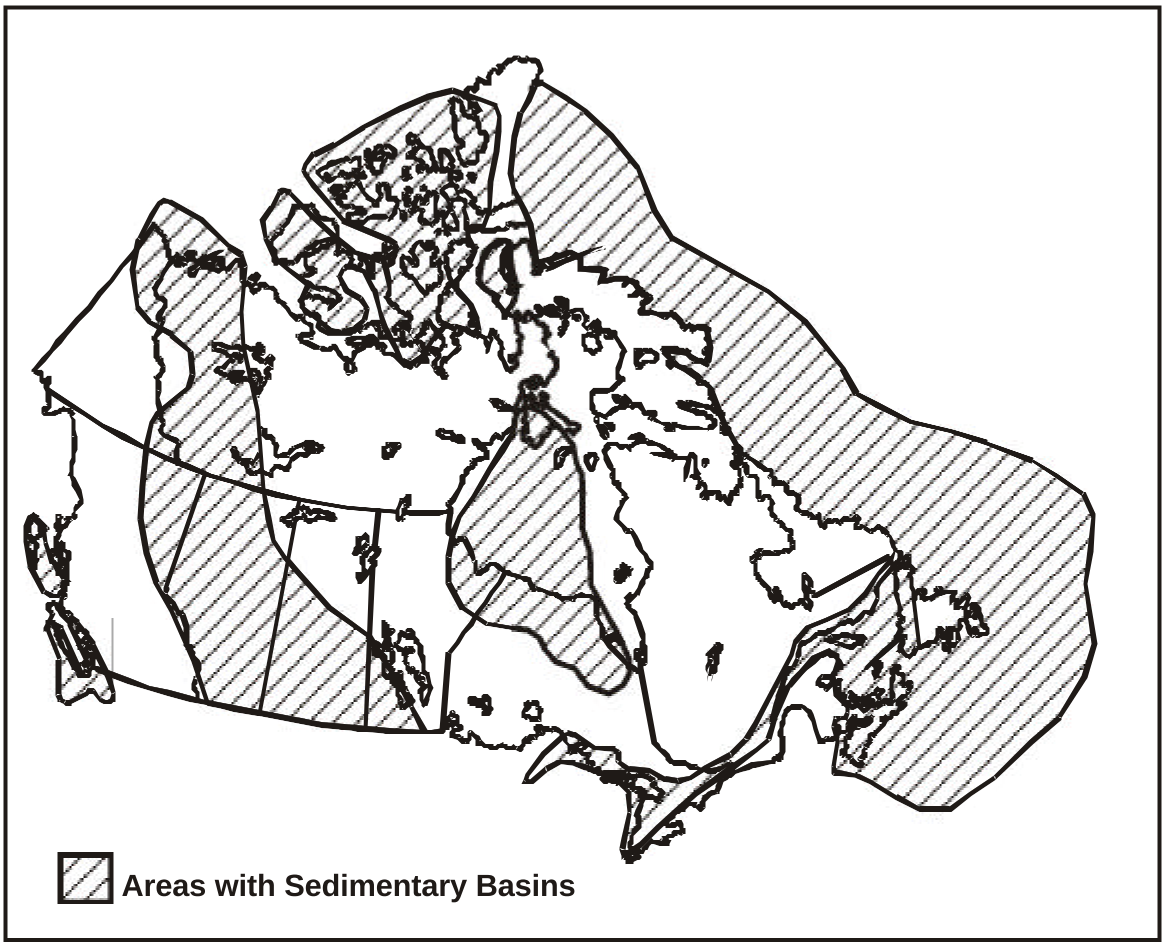


Figure 3.3 - Sedimentary Basins of Canada

(After the Canadian Petroleum Resource Foundation)

During transport, the sedimentary particles become sorted by size and density. This means that the larger and heavier fragments will settle faster than the lighter ones. The very smallest particles (fine sand and mud particles) can be carried hundreds of kilometres out to sea before settling to the bottom in the quiet deeper waters. The larger pieces (sand, gravel and boulders) will be deposited closer to the shore such as along beaches (Figure 3.4). Sedimentary rocks that are formed primarily from fragments of other rocks are called *clastics* and include sandstones (from sand-sized particles), conglomerates (from gravel-sized pieces) and shales (from clay particles). But in addition to the rock fragments being transported into the sea, the flowing waters also contain dissolved minerals such as calcium and salt. These minerals will eventually come out of solution and form *precipitates* (solids) when the conditions are right. Sedimentary rocks formed primarily from this precipitation process include limestone, gypsum and salt.

Sedimentation

As sediment is continuously dumped into the ocean, it gradually sinks to the bottom and starts to form layers. Coarser, heavier material (gravel) is deposited close to the shore and finer grained sediment (fine sand and clay particles) is deposited further out, in the deeper water (Figure 3.4) Over millions of years, these layers become thicker and thicker. Sea levels rise and fall because of worldwide changes such as the start and end of ice ages or as a result of the raising or lowering of the land in the area by powerful forces from within the earth (the same forces that cause earthquakes). This means that an area that was, at one time in deep water, can at other times lie in shallower water, and vice versa. Varying the water depth and environmental conditions of an area results in different types of sedimentary layers being deposited in the area at different times. The result is that in any given area there can be many different layers, containing different kinds of sedimentary rock. This fact, as we will come to appreciate later, is very important to a person who wishes to explore for petroleum.

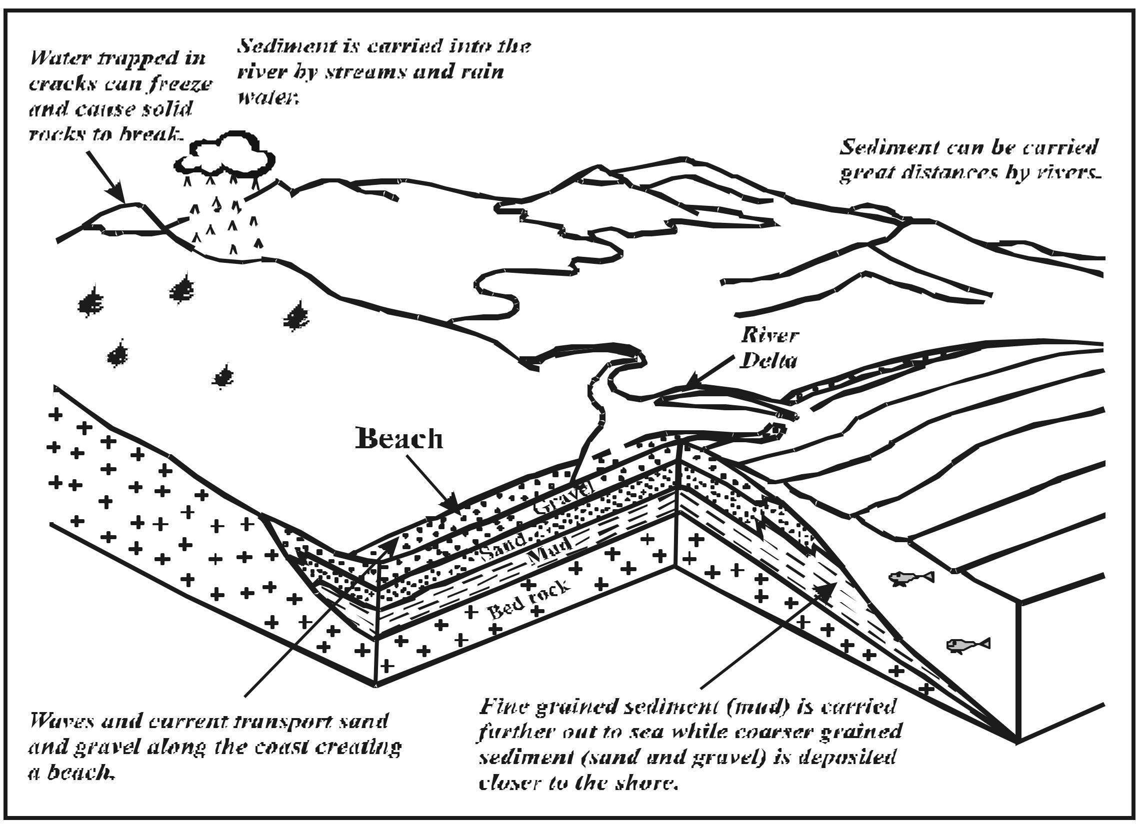


Figure 3.4 - Sedimentation

Subsidence

As millions of tons of sediment are deposited onto the seabed in an area, the weight of the sediment can cause the underlying ground to *subside* or buckle downward (Figure 3.5). This *subsidence* allows the area to stay under water even as thick layers of sediment are deposited over millions of years. Subsidence of the seabed allows thousands of metres of sediment to be deposited in an area even though the water depth may never exceed a few hundred metres.

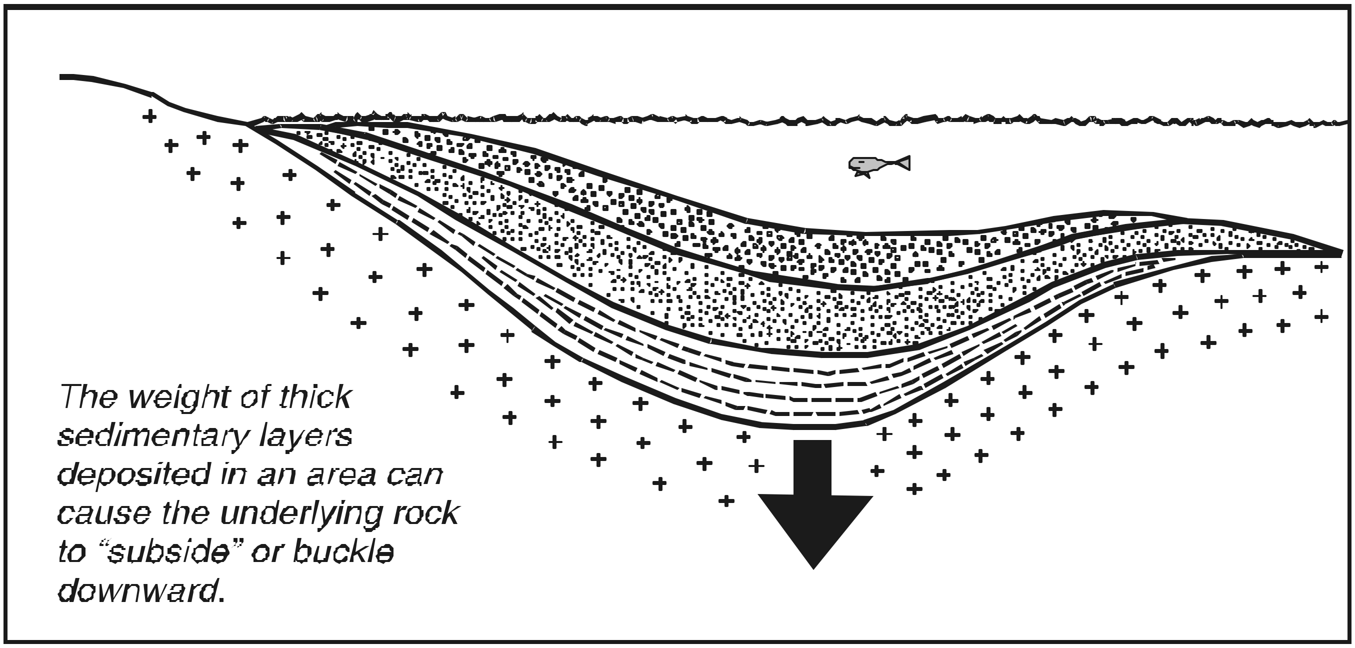


Figure 3.5 - Subsidence

Cementation

We now know how sediment is created, transported and deposited. But how is this material transformed into the solid rocks that we call sedimentary rocks?

As sediment becomes more deeply buried, it is squeezed by the weight of the overlying material. This pushes the sedimentary particles very close together, forcing out much of the water. The temperature of the material also increases with the depth of burial and this combination of increased heat and pressure accompanied by chemical action of certain dissolved minerals in the ground water cements the sediment into solid rock.

Why Is It We Find Sedimentary Rock On Dry Land? Shouldn't It Always Form Underwater?

The answer to this puzzling question lies in the fact that, as previously mentioned, sea levels have risen and fallen throughout the geologic ages. This combines with the fact that forces within the earth cause the land to rise up at certain times and subside at other times. Indeed, sedimentary rocks containing marine fossils that were formed in ancient oceans, eons ago, can now be found at the peaks of the highest mountains.

So it seems that areas that are dry land today may have once been part of the seabed. It is known, for example, that the province of Alberta, which we know to be rich in oil and gas resources, was underwater throughout much of its history.

Questions:

(1) *What causes erosion?*

(2) *What are clastics; precipitates?*

(3) *What can cause sea levels to rise and fall over the ages?*

(4) *Where is most sediment deposited?*

(5) *How is sediment that is eroded from rocks thousands of miles from the coast carried to the sea?*

(6) *What is subsidence?*

(7) *Why is it that we can find fossils of ancient creatures that lived in the sea at the peaks of mountains?*

Exercises:

(1) Field Trip to a River Mouth

Figure 3.4 shows the formation of a delta by sediment being carried to the coast by a river. Deltas are common throughout the world, especially when the river is very long and carries a lot of fine sediment. Longer rivers will tend to carry a greater proportion of fine sediments because they tend to have large drainage areas and the rock fragments will tend to be broken down into smaller pieces by the many collisions with the river bed and with other rock fragments that take place over a long distance. A river that carries a lot of fine sediment may become overloaded and choke up at the mouth, creating a delta. The size of the sedimentary fragments is also very much influenced by the type of rock that is being eroded. If the rocks being eroded are soft and easy to break (sandstone or shale for example), the sediment created will be fine. If the rocks are very hard (like granite), the fragments will not break down into small pieces as easily.

In Newfoundland, most of our rocks are very hard and our rivers are not very long compared to other areas of the world. As a result, we don't often get the fine sandy beaches that are common in some other areas. Most of our beaches are largely made up of coarse gravel. We also don't often get the type of delta shown in Figure 3.4 but are more likely to find a barrier beach (or spit) as shown in Figure 3.6.

The barrier beach is created when coarse sand and gravel being dumped into the ocean by the river is driven back by the waves so that it piles up as shown.

In this exercise, you are to visit a beach where a river meets the ocean and observe the process of sedimentation first hand. It will be best to go at low tide.

Exercises (cont…):

When you arrive have a good look around. Look for different types of sediment (mud, fine sand, gravel, etc.). Note where each kind of sediment is found. Have a look at any cliffs or rocks outcrops nearby. Can you match any of the beach rocks with the types of rock in the cliff? Can you guess where some of the sediment may have been eroded from?

Draw a simple sketch of the area showing where each type of sediment is found. Why was the sediment deposited where it is?

Collect samples of different kinds of rocks that can be found at the beach. From what you have learned so far, try and determine which ones are fragments of sedimentary or igneous rocks.

(2) Precipitation of Salt

We mentioned in this chapter that sedimentary rocks can be formed by the precipitation of minerals (such as salt) out of water. In other words, minerals that have been dissolved in water as it moved downstream toward the ocean can later become "undissolved" or precipitated out of the water to form solids again. This exercise illustrates how this can happen with salt. Warm 500 ml of water to boiling then carefully add salt until no more will dissolve. When no more salt will dissolve the water is said to be "salt saturated". Pour off the solution into a container leaving behind any excess salt. Place a frying pan on a hot plate, pour in some salt solution and heat it until it evaporates. Continue to pour small amounts of salt solution into the frying pan until it is all used up. Observe what happens. (It may be preferable to have the instructor demonstrate this experiment to the class).

Questions:

(1) *What process occurs in the frying pan? The same process is occurring along the shores of the Dead Sea.*

(2) *Why are the oceans filled with salt water instead of fresh water?*

(3) *Under what environmental conditions would you expect to find thick layers of salt deposited as part of the sedimentary sequence?*

(Adapted from SEEDS Energy Literacy Series)

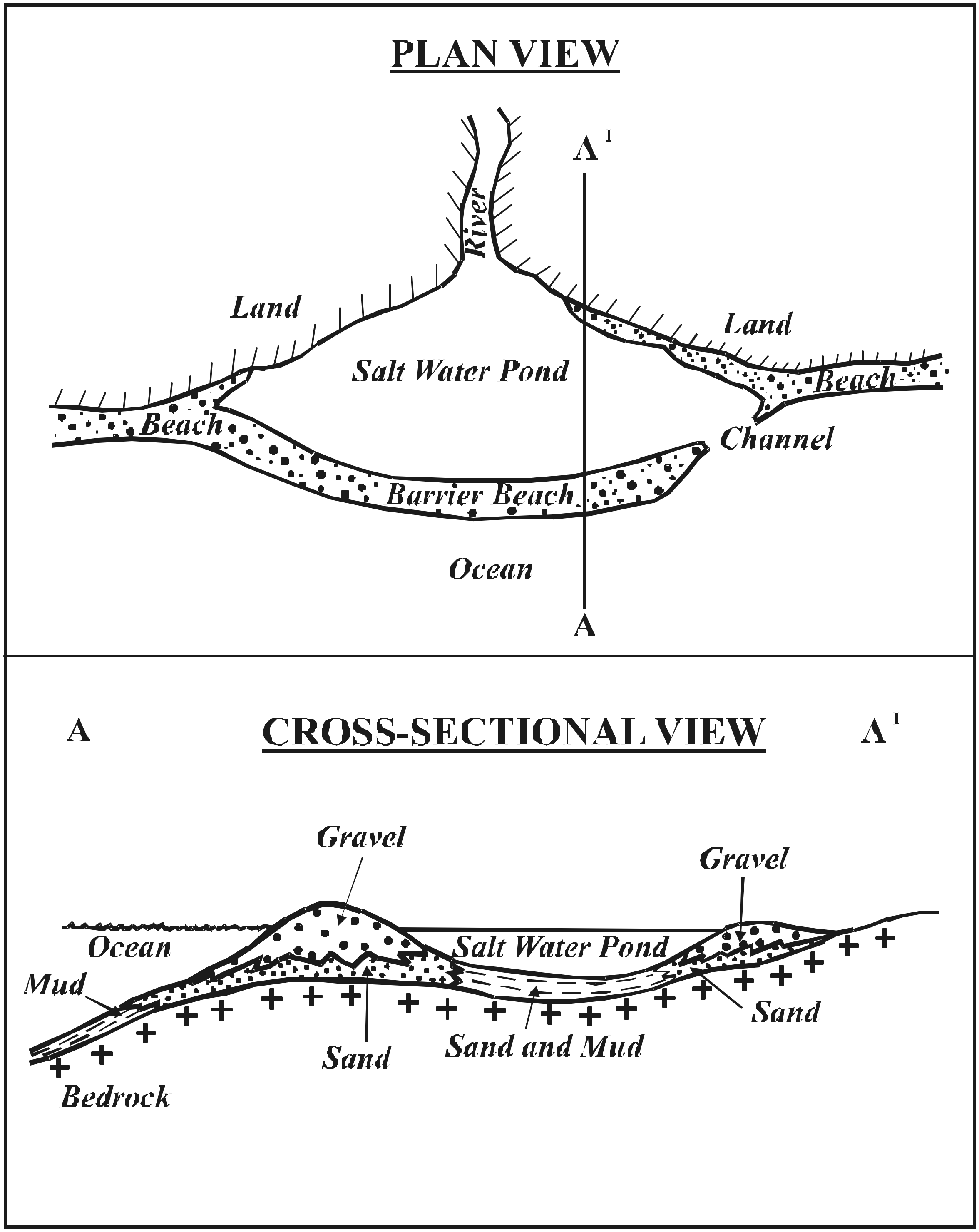


Figure 3.6 - Barrier Beach

Hydrocarbon Traps

Chapter 3 explained how oil and gas are found in porous sedimentary rocks within sedimentary basins. But does this mean that if you drill a well anywhere at all in a sedimentary basin you will strike oil or gas? The answer to this question is, of course, no. There are only certain places within sedimentary basins where hydrocarbons will tend to accumulate or become "trapped". This chapter explains why.

Reservoirs

If you wanted to find a large supply of water, where would you look? You would, of course, go out and look for a lake or a pond. But, have you ever thought of why ponds and lakes are located where they are? To understand why water collects where it does, we must consider the forces that are acting upon it.

The force of gravity makes water run downhill. Therefore, water collects in low bowl-shaped depressions in the land. These bowl-shaped depressions provide traps in which water collects and become lakes and ponds. Fortunately for us, there are many such natural water traps or *reservoirs* that conveniently store large amounts of water for our use.

In a similar fashion, when we look for oil, we must look for places that oil is likely to accumulate in large quantities. To understand where oil will collect, we must consider the forces that are acting on droplets of oil buried deep within the earth.

Oil Floats

Anyone who has ever seen oil spilled in a water puddle will notice that it creates colourful patterns in the sunlight. This is because the oil, which is less dense than water, forms a separate layer which actually floats on the surface of the water. The different light refracting properties of the two layers create a prism effect, and hence, the colour patterns.

Droplets of oil in rocks buried deep underground will also float above the water that is also present within these rocks. Chapter 3 explained how the sedimentary rocks containing these oil droplets formed under water. Hence, these rocks must still contain some water. So, instead of running downhill as surface water does under the force of gravity, oil droplets in the subsurface tend to move upward, under the force of buoyancy, so as to float above the water that shares the same pore spaces. Driven by buoyancy, these oil droplets migrate upwards toward the surface through pores and cracks within the layers of rock. If these drops of oil encounter an impermeable surface through which they cannot flow, they will continue to flow upward along the underside of this impermeable sealing rock and collect in traps as shown in Figure 4.1. If no traps are encountered, the oil droplets will migrate all the way to the surface creating an oil seep. Oil seeps(1) are quite common in areas of petroleum potential and were used by the earliest oil prospectors to identify drilling locations.

Oil reservoirs in the subsurface in many ways resemble inverted ponds or lakes. Unlike ponds and lakes, however, accumulations of hydrocarbons are contained inside the pore spaces of solid rock.

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(1) Oil seeps are common throughout the western portion of the island of Newfoundland especially in the Port au Port and Parsons Pond areas.

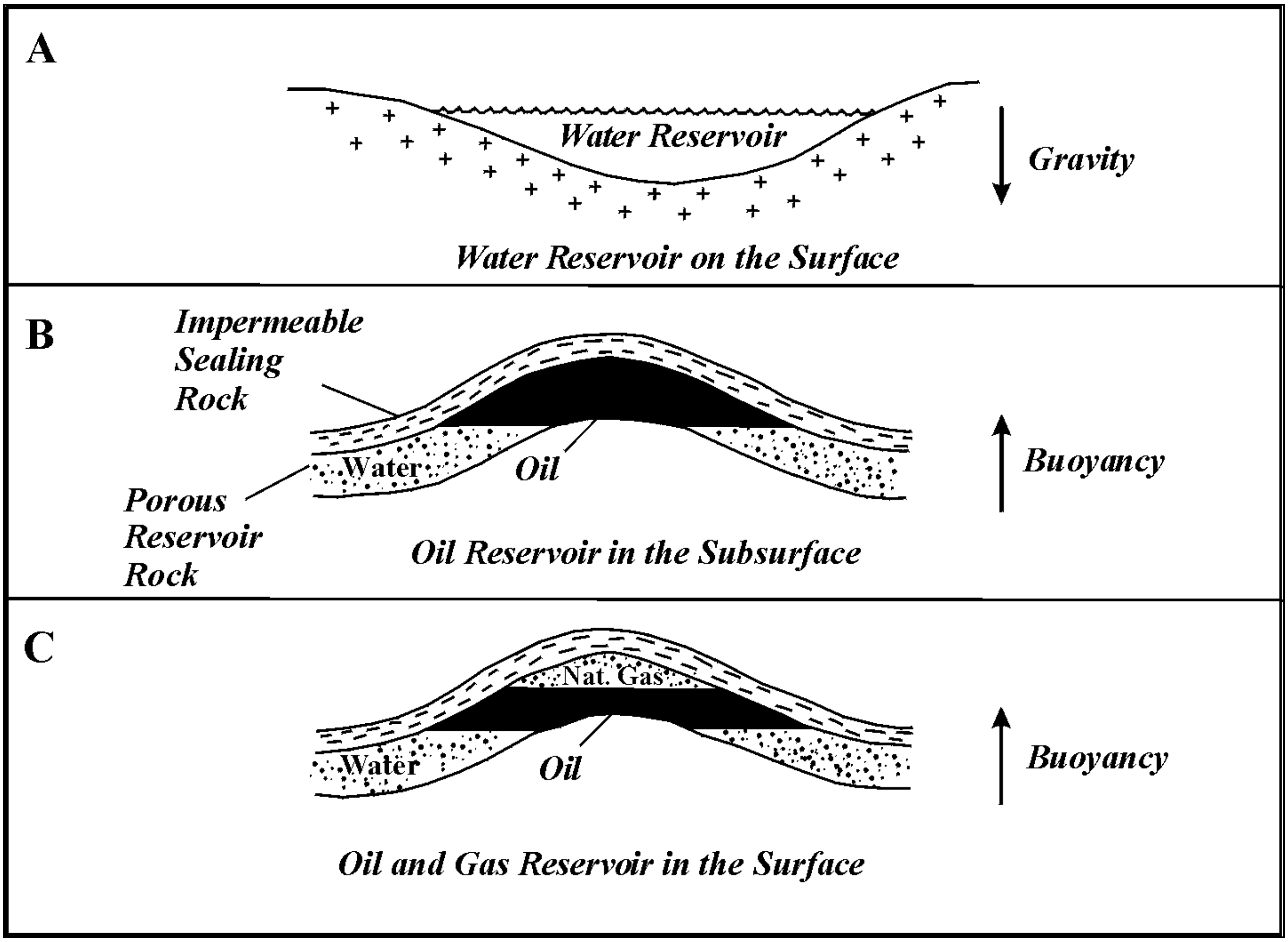


Figure 4.1

Reservoirs occur in places where fluids tend to collect.

Natural Gas Reservoirs

Natural gas, being less dense than either oil or water, tends to float above water and oil in the subsurface. Sometimes, the natural gas is dissolved in the oil, but it very often forms a separate layer of its own which floats above the oil layer. In such a case, we get a layer of natural gas floating upon a layer of oil which is in turn underlain by a layer of water (Figure 4.1C).

Geologic Structures Become Hydrocarbon Traps

In Chapter 3, we talked about how sedimentary rocks are formed from sediment settling on the floors of oceans and lakes. Common sense suggests that these sedimentary layers will tend to be laid down more or less horizontally over large areas. We also know, however, that we need traps to provide areas in which oil and gas can collect. This means that the layers of rock must somehow become buckled and bent to provide the geologic structures that may become traps. Fortunately for oil prospectors, forces within the earth itself create these geologic structures. These powerful forces that tend to stretch, squeeze, bend and break the rock layers are the same forces that cause earthquakes. The geologic structures that are created (ie., bends and breaks or faults in the rock layers) can become hydrocarbon traps where certain conditions are present:

(1) There must be hydrocarbon source rock in the area. Source rock is the fine grained rock in which the organic material originally present has been converted into hydrocarbons.

(2) There must be a porous and permeable rock layer to provide a *reservoir* in which the hydrocarbons can accumulate.

(3) There must be an impermeable *sealing rock* overlying the reservoir rock to trap the hydrocarbons.

Figure 4.2 shows some examples of geologic structures that commonly form hydrocarbon traps. Note that there are both *structural traps* and *stratigraphic traps*. Stratigraphic traps are traps that are formed by changes in the characteristics of the rock formation such as a loss of permeability or porosity or a break in continuity of a layer. Structural traps on the other hand are caused by the bending or breaking of the sedimentary layer. The most common and simplest type of structural trap is the *anticline* which is a structure formed when the layers of rock have been buckled upward.

In oil exploration, it is the job of the geologist and geophysicist to find these geologic structures which are potential hydrocarbon traps and thereby recommend drilling locations. We speak of "potential" hydrocarbon traps because not all structures contain hydrocarbons. Many structures contain no reservoir rock, and so no oil or gas can accumulate. Many contain excellent reservoir rocks, but are full of water. In other structures, the lack of a good sealing layer prevents oil and gas from accumulating. In other areas, the lack of a good source rock could be the problem. **The only way to know for sure if oil or gas is present in a structure is to drill a well.**

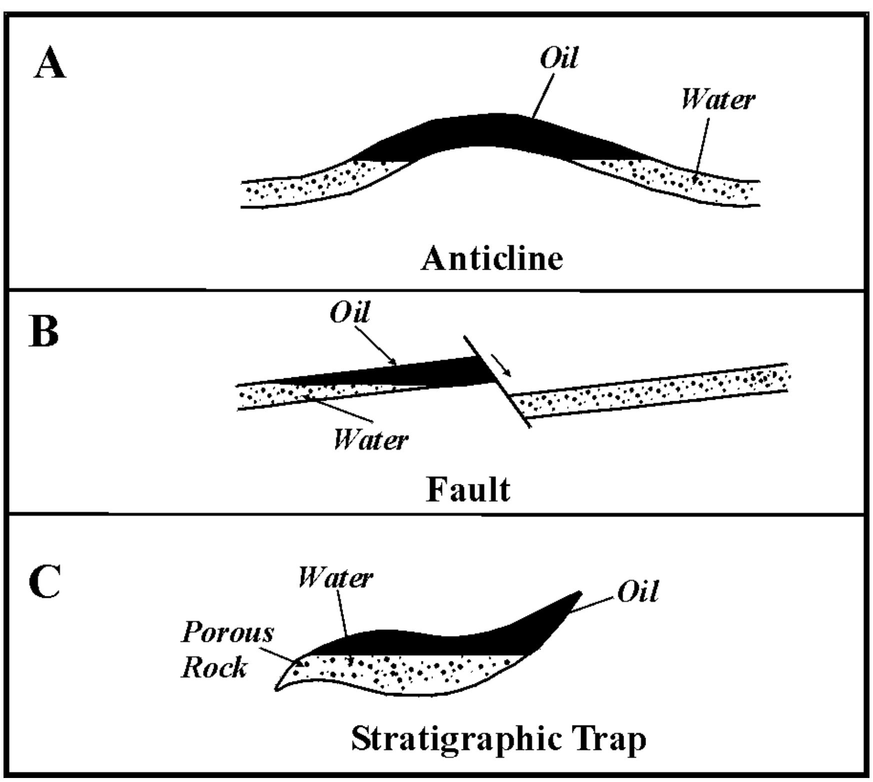


Figure 4.2 - Hydrocarbon Traps

A and B are both examples of structural traps. C is an example of a stratigraphic trap formed when a porous rock layer is encased in non-porous impermeable rock. Revisit Figure 3.4 and see if you can see how a stratigraphic trap might be formed along a coastline.

Questions:

(1) *From where else do we get fresh water other than lakes, ponds and rivers?*

(2) *Why does water accumulate in lakes and ponds?*

(3) *What causes oil to move upward in the subsurface?*

(4) *What prevents all of the oil in the subsurface from leaking out at the surface?*

(5) *What two properties are needed for a rock to be a reservoir rock?*

(6) *What are the two classifications of hydrocarbon traps?*

Exercise:

(1) Oil Floats

Purpose:

To demonstrate that oil floats on water and forms an emulsion with the water when agitated.

Materials:

- glass jar with cover
- water
- motor oil
- coarse sand or gravel

Half fill the jar with fresh (or salt) water. Slowly pour motor oil into the jar and observe what happens. Continue to pour oil until it forms a layer approximately one centimetre thick. Observe how the oil floats in a separate layer. Now, put the cover on the jar and shake well for a few seconds. Allow the jar to stand for a few seconds and observe what happens.

Questions:

(1) *Why does oil float in water?*

(2) *What happens when the oil and water were mixed together by shaking the jar?*

(3) *What would happen to an oil slick in the ocean that was being tossed about by the waves? Would it form a completely separate layer from the oil or form an oil/water emulsion?*

(4) *Fill an empty glass jar with coarse sand. Now add water until it's half full. Fill the rest of the jar with motor oil. Can you now picture how oil and water can co-exist in solid rock in the subsurface?*

(2) Build a Model Oil Well

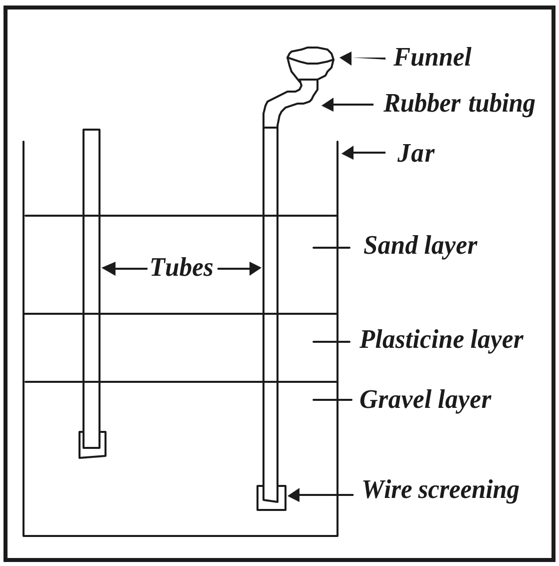
Purpose:

To demonstrate how a fluid such as oil or water can flow out of an underground reservoir and up to the surface.

Materials:

- large glass jar
- dry sand and gravel
- plasticine (or silly putty)
- length of rubber tubing (attached to a funnel)
- two glass tubes (drinking straws will do in a pinch)
- water
- wire screening taped to the lower end of each tube would be useful, but it is not necessarily required.

Procedure:



Place the tubes in the jar as shown in the diagram. Pack gravel into the bottom half of the jar around the tubes. Firmly pack a layer of plasticine on top of the gravel and seal tightly around both the tubes and the edge of the jar. Fill up the rest of the jar with sand.

Attach a rubber tubing to one of the tubes as shown in the diagram and pour water slowly into the funnel. Raise the funnel higher above the can to apply more pressure. Observe what happens. Blow some air down the funnel (use your lungs) and observe what happens. Blow harder. What happens.?

Questions:

(1) *Make a sketch of the model and trace the path of the water.*

(2) *What happened when you blew air into the gravel? Does this suggest a way of increasing the amount of oil that can be recovered from an underground reservoir?*

(Adapted from SEEDS Energy Literacy Series)

Petroleum Exploration I - Contour Mapping

We have now become familiar with the basic concepts of how petroleum is formed in underground sedimentary rocks and how it migrates into underground traps. We will now proceed to learn some of the basic methods of *petroleum exploration*. In other words, we will study the techniques by which geologists and geophysicists search for geologic structures that may be good places to drill for oil and gas.

Contour Maps

Contour maps are one of the most effective means of displaying information about the geologic structure (ie., the degree of buckling and faulting of the layers) of an area. A contour is a line on which every point is at the same level above or below a chosen reference surface. In most maps the reference surface is sea level. If a contour line represents an elevation on the surface of the ground, it is a *topographic* contour. A map showing topographic contours for an area would be called a *topographic map*.

If such a contour represented an elevation of a rock stratum (layer), then it is called a *structure* contour. A map showing structure contours for a certain rock layer throughout an area would be called a *structure contour map* (Figure 5.1). Such maps are used to illustrate the size, shape and location of geologic structures.

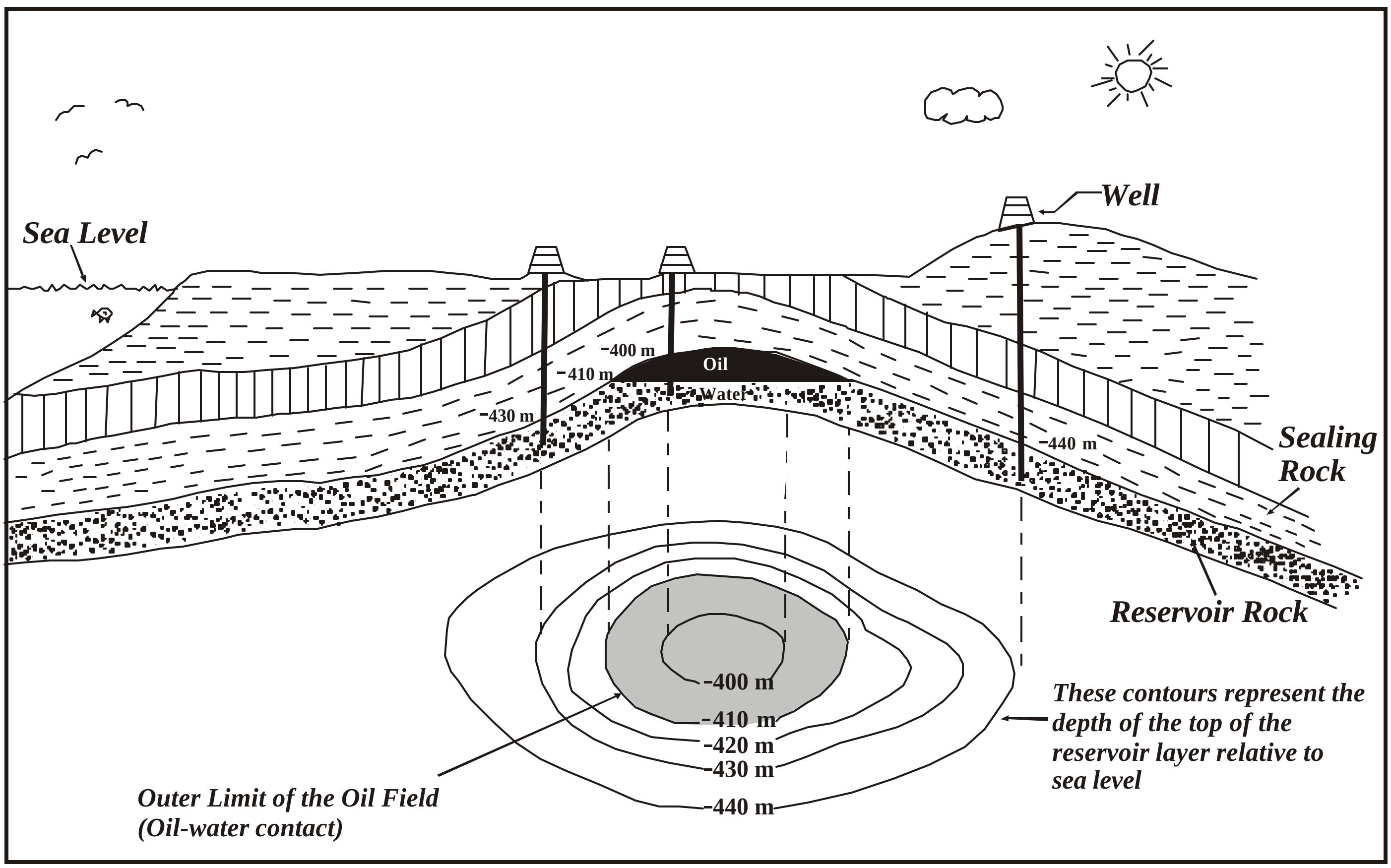


Figure 5.1 - Subsurface Structure Contour Map

Contour Maps (cont…)

For example, suppose you are a geologist working in a given area and you know that approximately 500 metres below the surface there is a porous and permeable sandstone layer overlain by a thick impermeable shale. And suppose that somewhere in the area the sandstone was arched up in the shape of a dome or anticline. Aha - you say, this is a perfect candidate for a hydrocarbon trap. But now you must somehow construct a structure contour map to determine the size and exact location of the anticline. You will need to know this so that you can acquire petroleum rights for all of the land overlying the structure before you drill it and also to determine the best drilling location.

But how can you determine the elevations of a sandstone layer that is buried under 500 metres of rock? This is something we will address in Chapter 6. For now, we will imagine that you can shovel off the 500 metres of rock and walk around on top of the sandstone layer. Suppose you (with your surveyor) found that the top of the dome was at an elevation of – 400 metres (the minus sign indicates that an "elevation" below sea level). Then, if you walked 10 metres down the dome to an elevation of – 410 metres and started painting a line on the surface of the sandstone at that elevation, you'd find you would paint a line clear around the dome and end up back where you had started painting. The line you had painted would be the – 410 metre contour on the sandstone layer. Drop down another 10 metres and paint the – 420 metre contour. You will have a longer walk and use more paint this time. Nevertheless, keep dropping down and painting a line at each ten-metre elevation until the whole structure has been contoured. You will know that you have completed contouring the structure when the line you are painting no longer "closes" or in other words no longer comes back to the point at which you started painting it.

Now that you have contoured the whole structure with your paint brush, hire a plane, fly over the area and take a photograph. The picture you get will be a contour map of the structure.

Questions

(1) *What is a contour?*

(2) *Why do geologists and geophysicists make contour maps?*

(3) *What's the difference between a topographic map and a structure contour map?*

Exercises

(1) Geologists can rarely get elevations for every point on the surface of a formation that they wish to map. Instead, through various ingenious methods to be discussed later, they determine elevations for as many points as possible, plot these values on a map (as in Figure 5.2) and then construct a contour map. In this exercise, you are to construct a contour map on the "_________" sandstone using the data supplied in Figure 5.2. You can name the sandstone. Usually a rock layer or "rock formation" is named for the locality in which it was first recognized and described. (You may use your own name or surname if you wish).

Exercises (cont…)

(2) Superimpose Figure 5.3 on Figure 5.2 and determine who owns the most prospective land. Which farmer would you be most eager to talk to about the possibility of obtaining petroleum rights? Where would you drill?

(3) Study a topographic map of an area that is very familiar to you (your own community perhaps). What is the major difference between this map and the type of map you have just contoured?

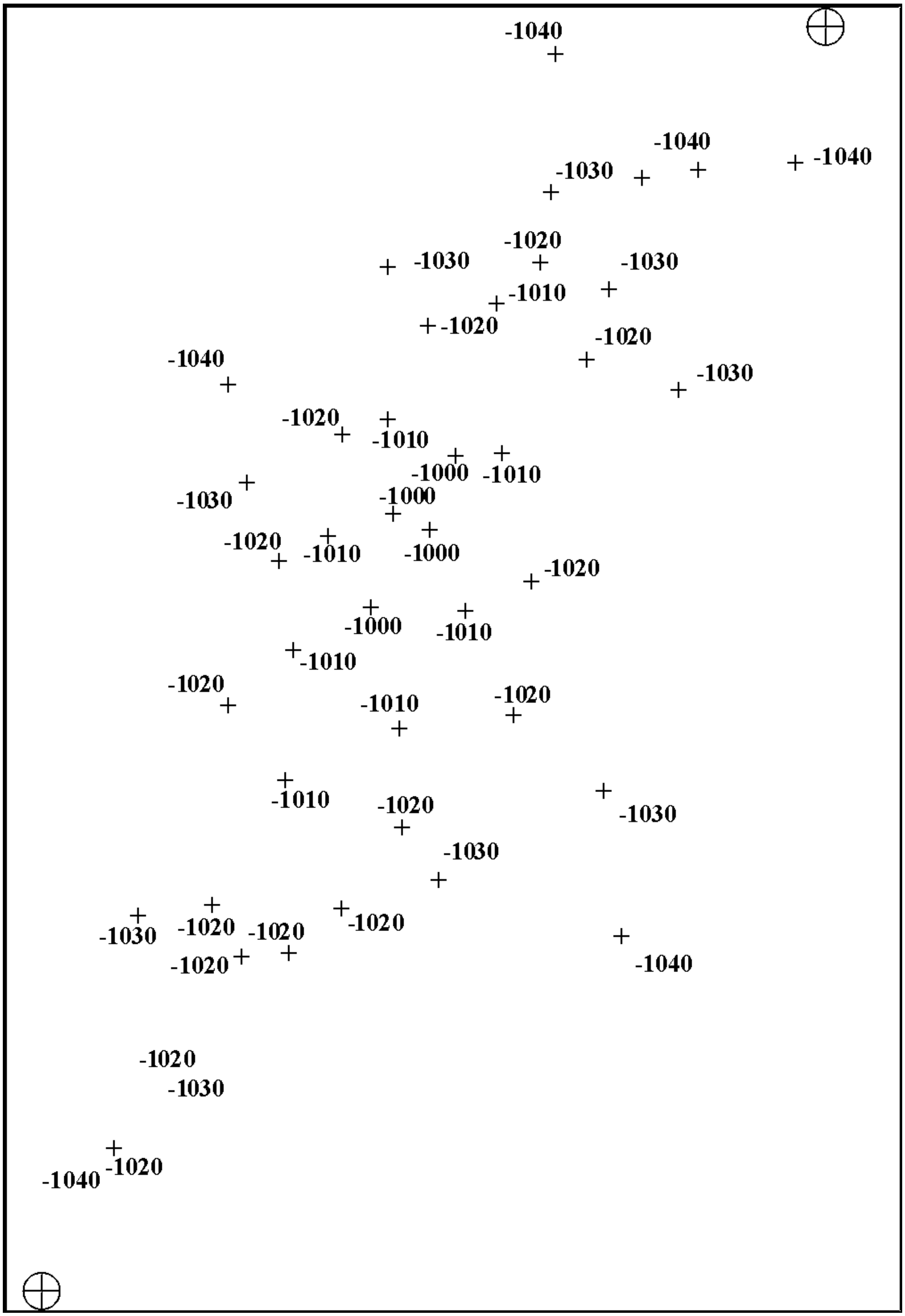

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Figure 5.2

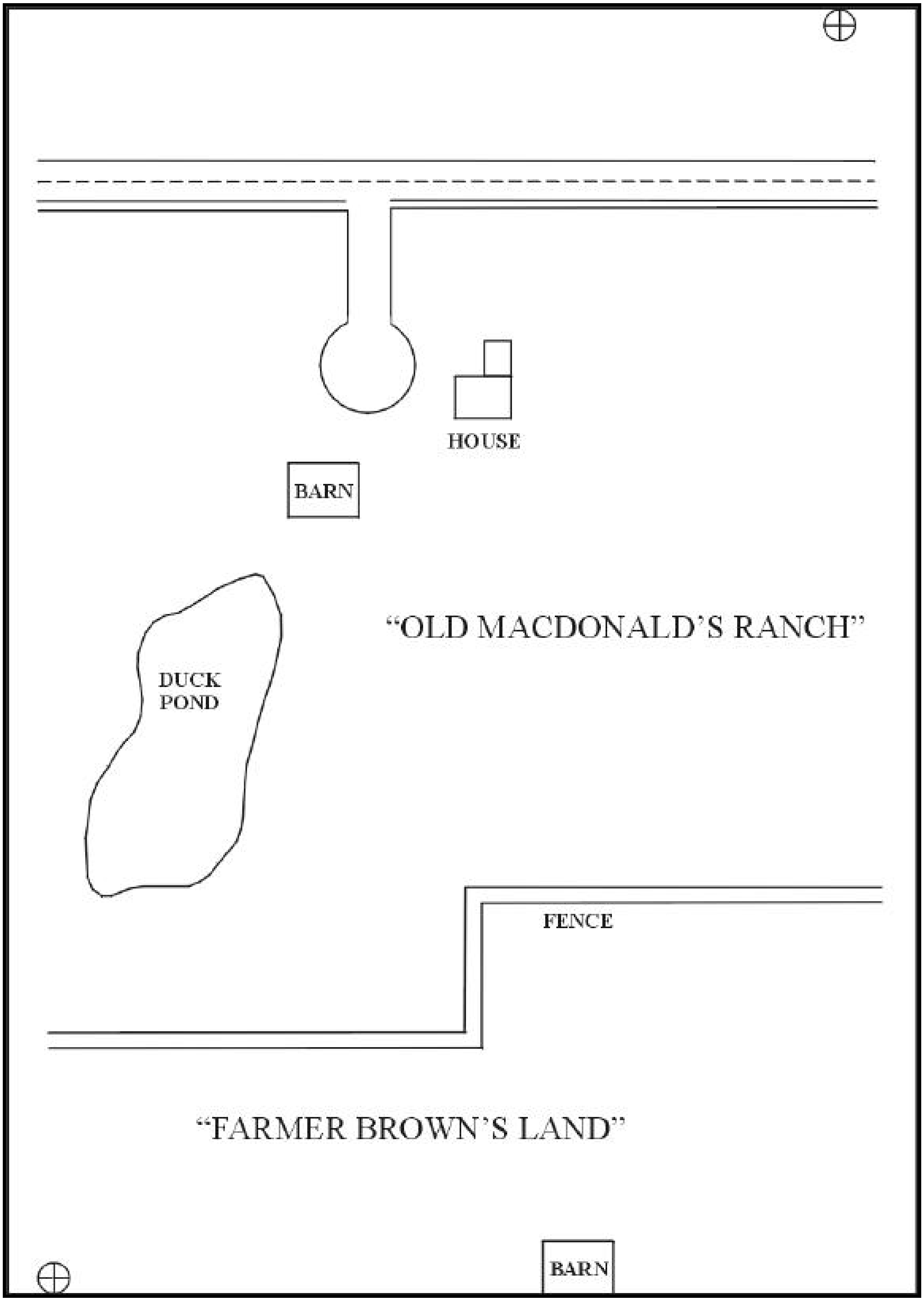
HOUSE
BARN
"OLD MACDONALD'S RANCH"
DUCK POND
FENCE
"FARMER BROWN'S LAND"
BARN

Figure 5.3

Petroleum Exploration II
Surface Mapping, Gravity and Magnetic Surveys

In the last chapter, we were given a map to contour that provided us with all of the necessary data points. To determine the geologic structure, all we had to do was draw the contours. But contouring is the easy part. The tough and expensive part is in acquiring the data that allows us to contour such a map. In this chapter, we will study some of the methods by which oil prospectors obtain such data.

Surface Mapping

In some areas, the presence of subsurface geologic structures, especially anticlines, is evident at the surface. In such a case, geologists can search for anticlines by studying topographic maps and air photographs, and by going into the field and studying the rock layers that are exposed (i.e. outcrops) at the surface. Anticlines are not, however, always represented as ridges or hills on the surface. An anticline is an upfold of rocks, true, but the land surface is a product of erosion and may not reflect the underlying structure. Sometimes the crest of an anticline is represented by a topographic low (Figure 6.1) such as a river valley.

To determine the subsurface structure from the surface geology, the field geologist must study every possible outcrop in the area and determine the angle and direction at which the formations or layers are dipping. He or she must sometimes dig holes through the surface sediments, climb down into water wells or dive into rivers and lakes to acquire the precious data points that are needed to construct a contour map.

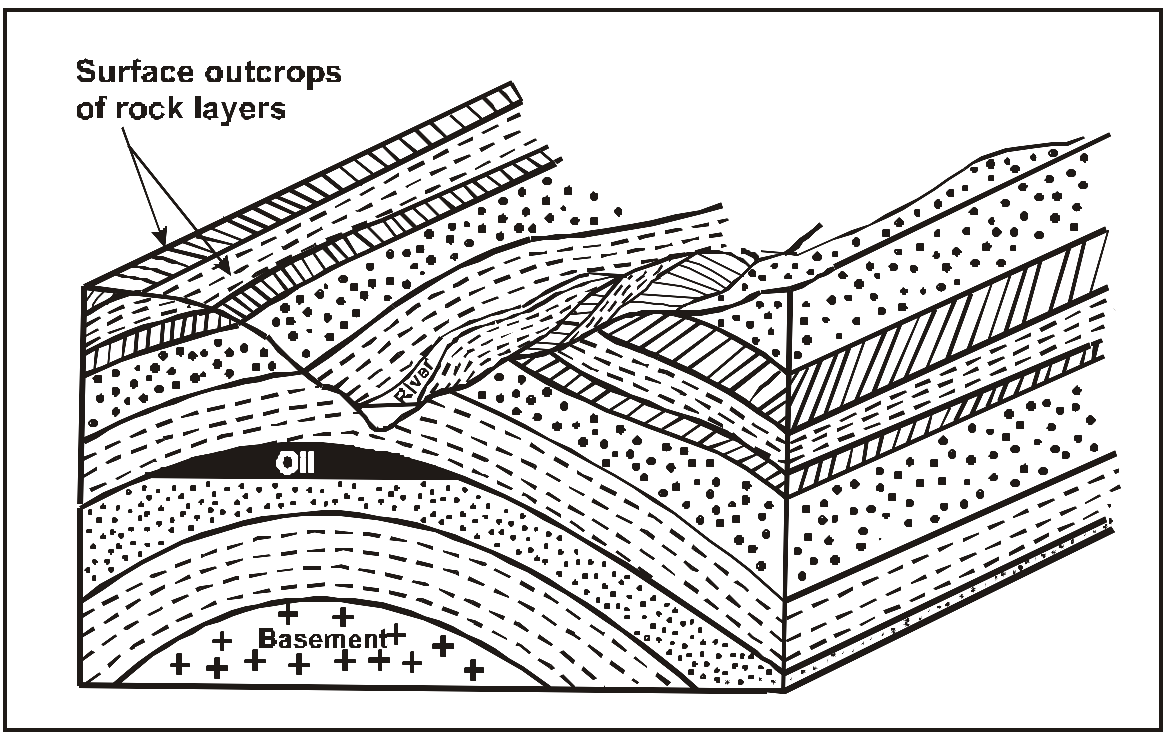

Figure 6.1 - Eroded Anticline

Sometimes geologists can estimate the subsurface structure by studying the rock layers that "outcrop" on the surface. The subsurface does not always match the surface topography. In this example, a topographic low (river valley) overlies a subsurface high (an anticline).

Geophysics

In most areas, the subsurface structure cannot be determined from studying the surface alone. In such areas, the formations may have been eroded and then covered by thick layers that do not parallel the underlying beds (Figure 6.2); or the area may be covered by swamps or jungle or may even be under the ocean as is the case on the Grand Banks of Newfoundland. Fortunately, the geologist has a friend to help out in these situations. That friend is the *geophysicist*.

The geophysicist uses physical phenomenon such as magnetic attraction, the pull of gravity, the speed of sound waves through different types of rocks, and the behaviour of electric currents to determine the subsurface structure. Here we will discuss two of the more important exploration methods used by geophysicists; namely, gravity mapping and magnetic mapping. But first we must introduce a new term; *basement rocks.*

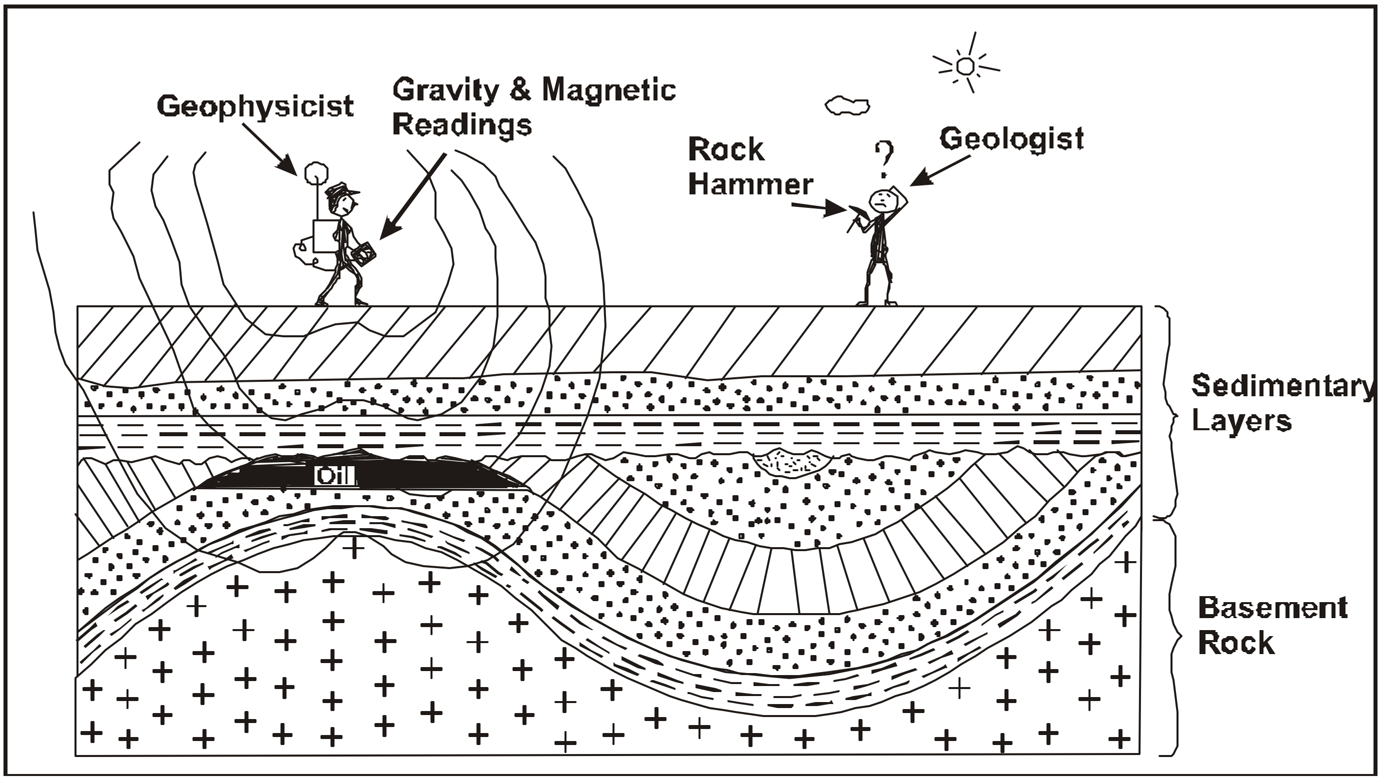

Figure 6.2

In many areas there are no clues to the subsurface structure visible at the surface. Geophysical methods must be utilized to estimate subsurface structure in such areas. Here the geophysicist is recording gravity and magnetic measurements to determine the topography of the basement rocks. Hydrocarbon traps are often formed over basement highs as shown here.

Basement Rocks

A sedimentary basin is normally underlain by igneous and/or metamorphic *basement rocks* (Figure 6.2). These basement rocks have two important properties that distinguish them from sedimentary rocks in the eyes of a geophysicist. (1) They are more magnetic than sedimentary rocks; and (2) They are more dense than sedimentary rocks. These two differences provide the basis for two very useful geophysical techniques; magnetic surveying and gravity surveying.

Magnetic Surveys

The magnetic properties of basement rocks create distortions and anomalies in the earth's magnetic field. The magnitude of these anomalies as measured at the surface, is proportional to the depth of burial of the basement rocks (Figure 6.3). In other words, when the basement rocks are close to the surface, the magnetic distortions (measured on an instrument called a magnetometer) are stronger. When the basement rocks are buried deeper, the magnetic distortions seen at the surface will be weaker. The geophysicist, by taking magnetic measurements throughout an area, can estimate the geologic structure of the basement rocks, as well as the thickness of the sedimentary cover rocks.

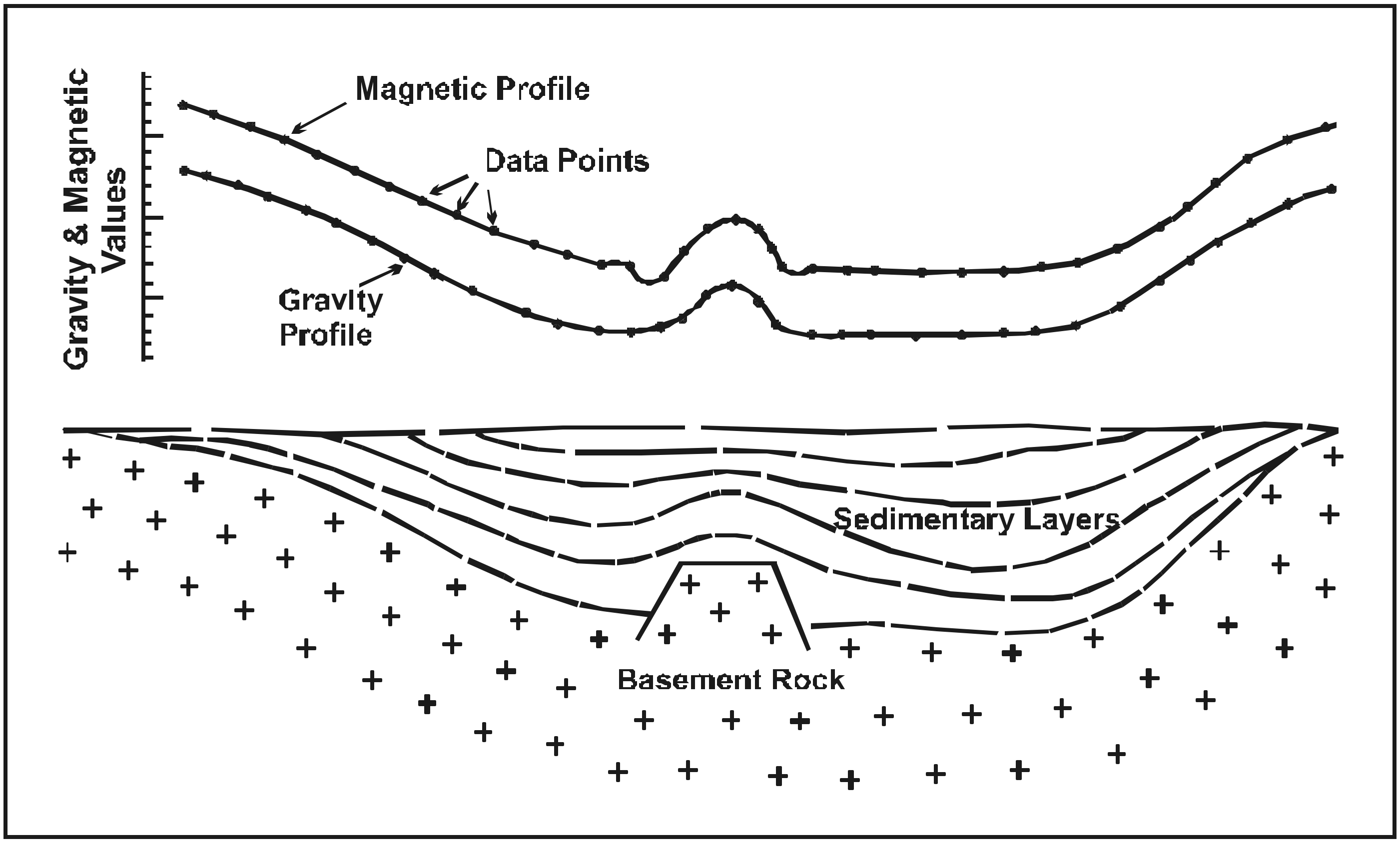

Figure 6.3 - Gravity and Magnetic Profiles

This simplified schematic shows how gravity and magnetic measurements taken at the surface can pinpoint the location of a subsurface anticline.

Gravity Surveys

Since basement rocks have a higher density than sedimentary rocks, they have a stronger gravitational attraction. The tiny differences in the earths gravitational field that are measured in gravity surveying are too small to be noticeable to humans. In other words, you would not feel heavier if you were standing in an area where the basement rocks were close to the surface. These gravitational differences can only be detected using a very sensitive instrument called a gravity meter.

The principles employed in gravity surveying are very similar to those of magnetic surveying. That is, when basement rocks are close to the surface, the gravitational distortions will be greater; when the basement rocks are deeply buried, the gravitational distortions will be less pronounced (Figure 6.3). Once again

Gravity Surveys (cont…)

the geophysicist, using the gravity meter, takes hundreds (or even thousands) of measurements throughout an area. The values are plotted on a map at the appropriate locations and then, after making a number of mathematical corrections, the geophysicist is able to make a map that will show the structure of the basement rocks which may be thousands of metres below the surface.

Questions:

(1) *Is it possible to sometimes find a good place to drill for oil just from surface mapping?*

(2) *In what kinds of areas is surface mapping not very effective?*

(3) *What do we mean by basement rocks?*

(4) *What characteristics of basement rocks are important to geophysicists?*

(5) *What is the instrument used in magnetic mapping?; gravity mapping?*

Exercise:

(1) Gravity Mapping

Table 6.1 contains a list of gravity values acquired during a gravity survey. Figure 6.4 shows the location of the "gravity stations"; ie., the exact locations where gravity measurements were taken. The gravity values listed do not represent the absolute gravitational pull at each station, but are rather a measurement of the gravitational distortion created by the basement rocks. The unit of gravity measurement is the "milligal". One milligal equals one millionth of a "g". One g is the gravitational force we normally experience at the surface of the earth.

Using the data provided in Table 6.1, plot the gravity values at the appropriate stations on the map (Figure 6.4). When all of the values have been plotted, contour the map using a 10 milligal contour interval (ie., use values of 10, 20, 30, etc., for contour lines). Note that contour lines need not always go through the stations. If, for example, a certain station had a value of 5 milligals and the next station had a value of 15 milligals then we would know that the 10 milligal contour should go halfway between these stations.

Table 6.1					
Data for Gravity Mapping Exercise					
Station #	Gravitational Value (milligals)	Station #	Gravitational Value (milligals)	Station #	Gravitiational Value (milligals)
11	80	33	73	56	21
12	74	34	60	57	12
13	67	35	28	61	7
14	60	36	21	62	60
15	30	37	10	63	28
16	25	41	78	64	23
17	20	42	68	65	15
21	82	43	60	66	7
22	76	44	28	67	6
23	72	45	18	71	60
24	60	46	10	72	27
25	27	47	7	73	19
26	20	51	77	74	12
27	12	52	70	75	8
31	82	53	60	76	7
32	77	54	28	77	6

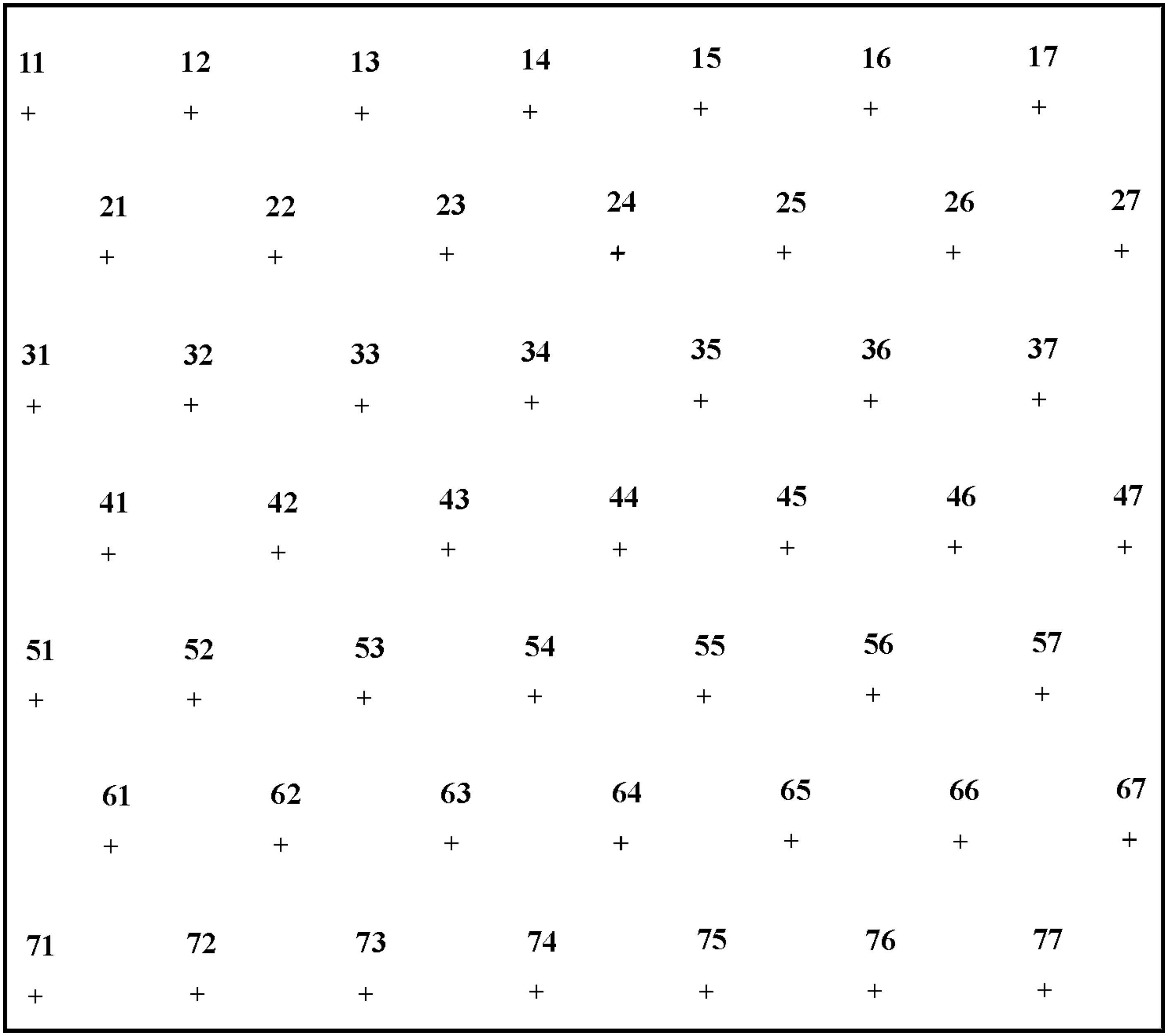

Figure 6.4 - Location of Gravity Stations

Petroleum Exploration III - Seismic Exploration

Reconnaissance and Detailed Surveys

Geophysical surveys can generally be classified into two categories: *reconnaissance* surveys, which are run to define broad areas of interest that contain the thick sedimentary layers that have the potential to contain hydrocarbon traps; and *detailed* surveys which are conducted to locate individual geologic structures which can then be drilled.

The gravity and magnetic surveys discussed in Part "A" of this chapter would generally be classified as reconnaissance type surveys. Magnetic surveys are often done from an airplane flying a grid pattern over a large area. These "aeromagnetic" surveys define the areas where sedimentary rock is thick enough to warrant further, more detailed work.

Gravity and magnetic surveys are also frequently done from ships to find sedimentary basins in offshore areas. Once again, these surveys would be followed up by a more detailed type of survey before well locations could be chosen. The most common geophysical technique for obtaining the detailed geologic structural information needed to pick well locations is, however, the *seismic survey*.

The Seismic Survey

The most accurate and widely used means of finding good drilling locations is the seismic survey. Seismic surveying involves sending sound waves down into the ground and recording the echoes that bounce back off the various sedimentary layers.

The sound or shock waves are generated by; setting off small explosive charges just below the surface; hitting the ground with a heavy weight; or shaking the ground using large vibrator trucks. The echoes returning from the subsurface are detected by sensitive instruments called geophones which are strung out along the ground in a straight line. The geophones are connected by electrical cable to a recording system. The recording system precisely records, to the nearest one thousandth of a second on magnetic tape, the time it takes for the echoes to return to the surface. By knowing the amount of time it takes for a sound wave to reach a certain layer and then bounce back to the surface, as well as the speed of sound through the rock layers in between, the geophysicist is able to determine the depth to that layer at that location. By determining the depth at a large number of points along the seismic line, the geophysicist is able to create a profile of the underground layers along the line.

A good analogy to the seismic method is the sonar system used on ships to determine water depth and sometimes to locate schools of fish. The sonar system works by sending a small sound wave downward from the ship, which bounces off the seabed. The time it takes for the echo to return indicates the water depth. The principal involved is exactly the same as seismic, except that the sonar waves do not penetrate deeply into the seabed to give information about underlying layers. The more powerful seismic waves, on the other hand, can penetrate deeply into the subsurface and bring back information on rock layers tens of kilometres below the surface.

Figure 6.5 shows the basic setup used in seismic surveying. Note that many geophones are laid out in a straight line so that the depths for many subsurface points can be determined all at once. Also, notice that all of the energy in a seismic wave does not bounce back from the first layer encountered. Some energy

The Seismic Survey (cont…)

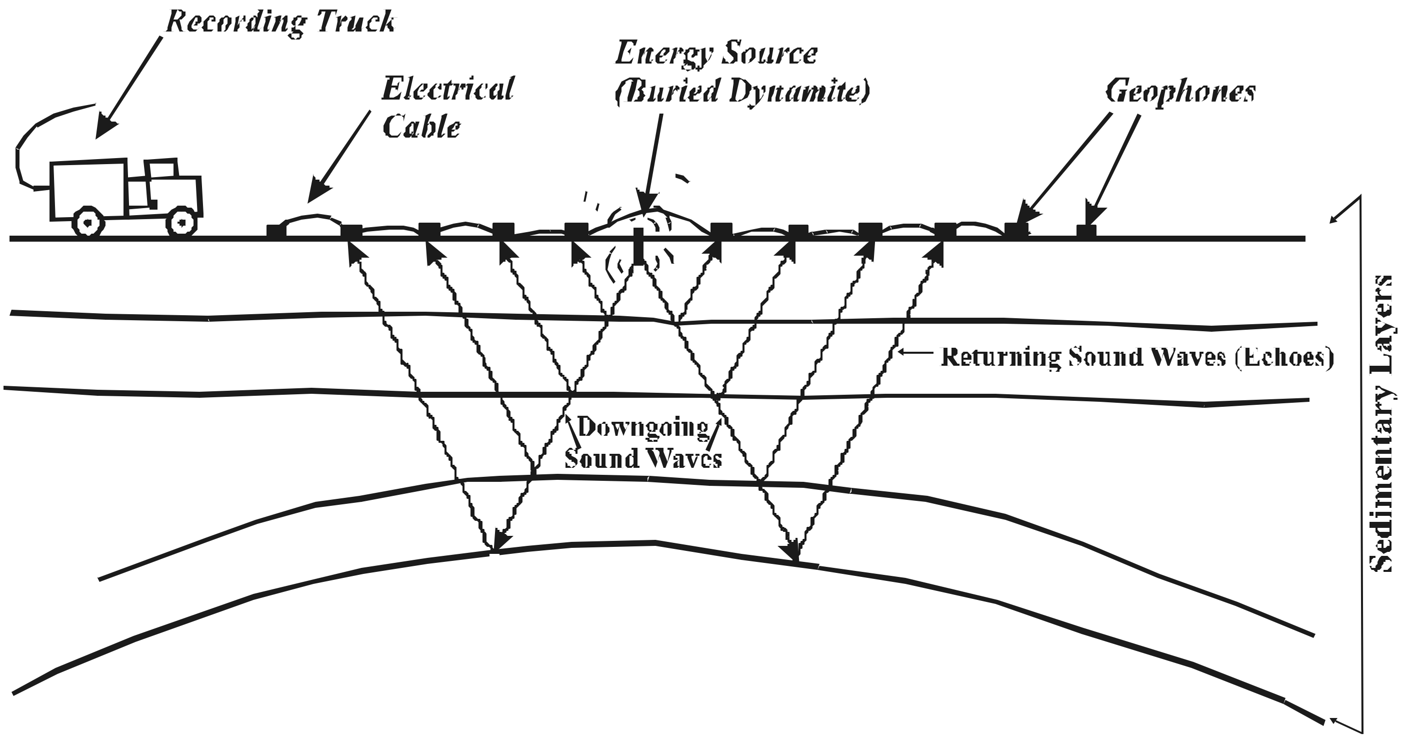

Figure 6.5 - Seismic Exploration

bounces back, but some of the energy continues its downward journey to bounce off other, deeper layers. Some rock layers will reflect very little energy back to the surface while others, such as limestone, reflect a lot of energy. It is these strongly reflecting layers that are most useful to the *geophysicist* in mapping the subsurface structure.

Figure 6.6 is an example of a *seismic section*. The seismic section is the most common method of displaying and interpreting the massive amounts of data that are acquired during a seismic survey. The horizontal scale in this display represents a straight line along the surface of the ground. The vertical scale represents the time it took for the echoes to return from different sedimentary layers. From this display, one can readily see the subsurface geologic structure along this line.

Hibernia

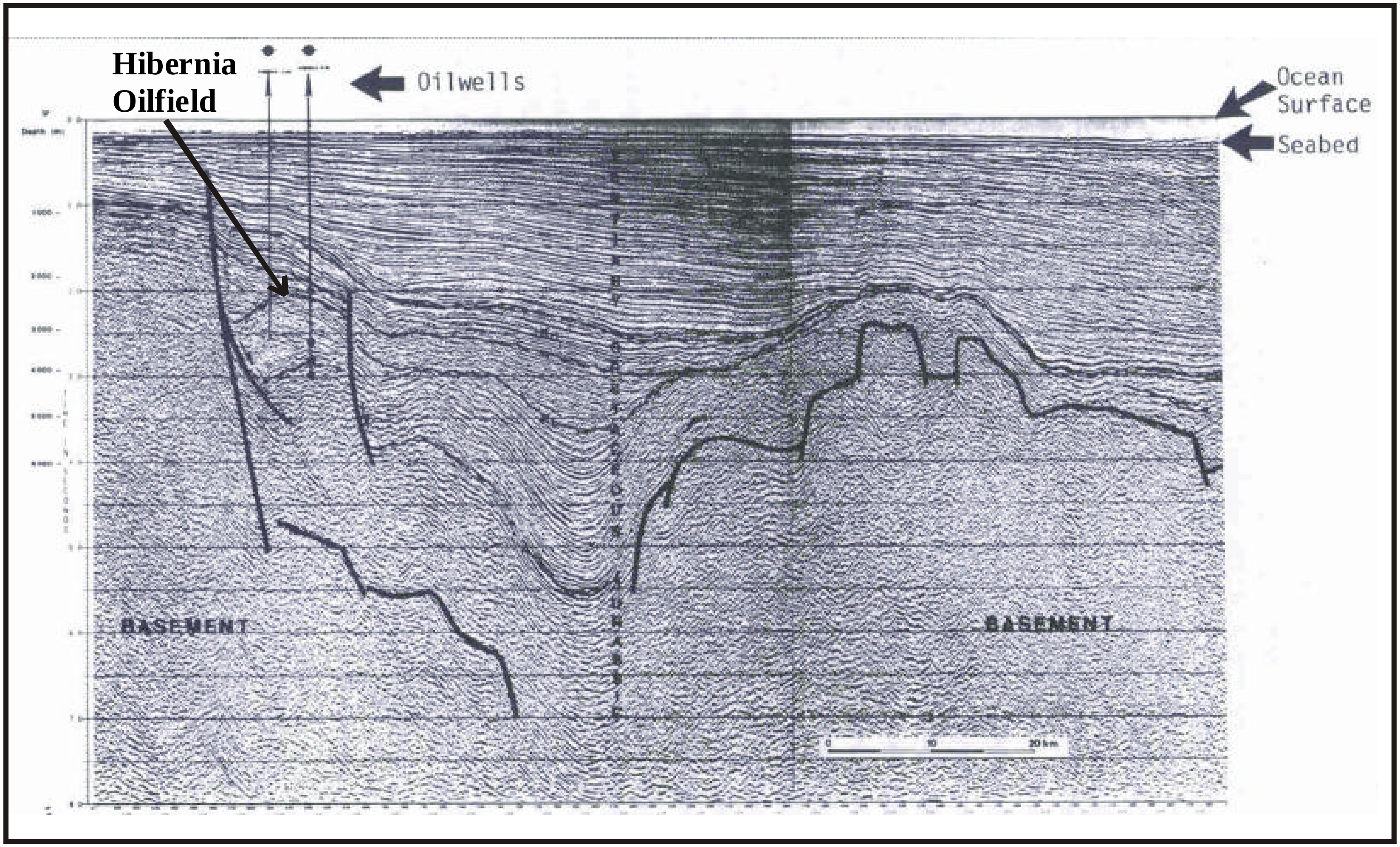

Figure 6.6

Seismic section across the Hibernia Field within the Jeanne d'Arc Sedimentary Basin offshore Newfoundland. The lines on the section show how the geophysicist has interpreted the section. The darkened circles on the well on the right identify the different zones in which oil was discovered. Note that the Hibernia field is a structural trap; an anticline bounded by two faults.

(Seismic line courtesy of Geophysical Services Incorporated).

Offshore Seismic

Figure 6.7 shows how a seismic crew operates in the offshore. In this case, the aquatic equivalent of the geophone, the *hydrophone* is used to detect echoes returning from the underground layers. The hydrophones, which are essentially underwater microphones, are attached to a buoyant cable and towed behind the ship. The shock waves are generated by a high pressure air gun towed near the back of the ship. Although the equipment used in recording offshore seismic is somewhat different than that used onshore, the principles involved are exactly the same.

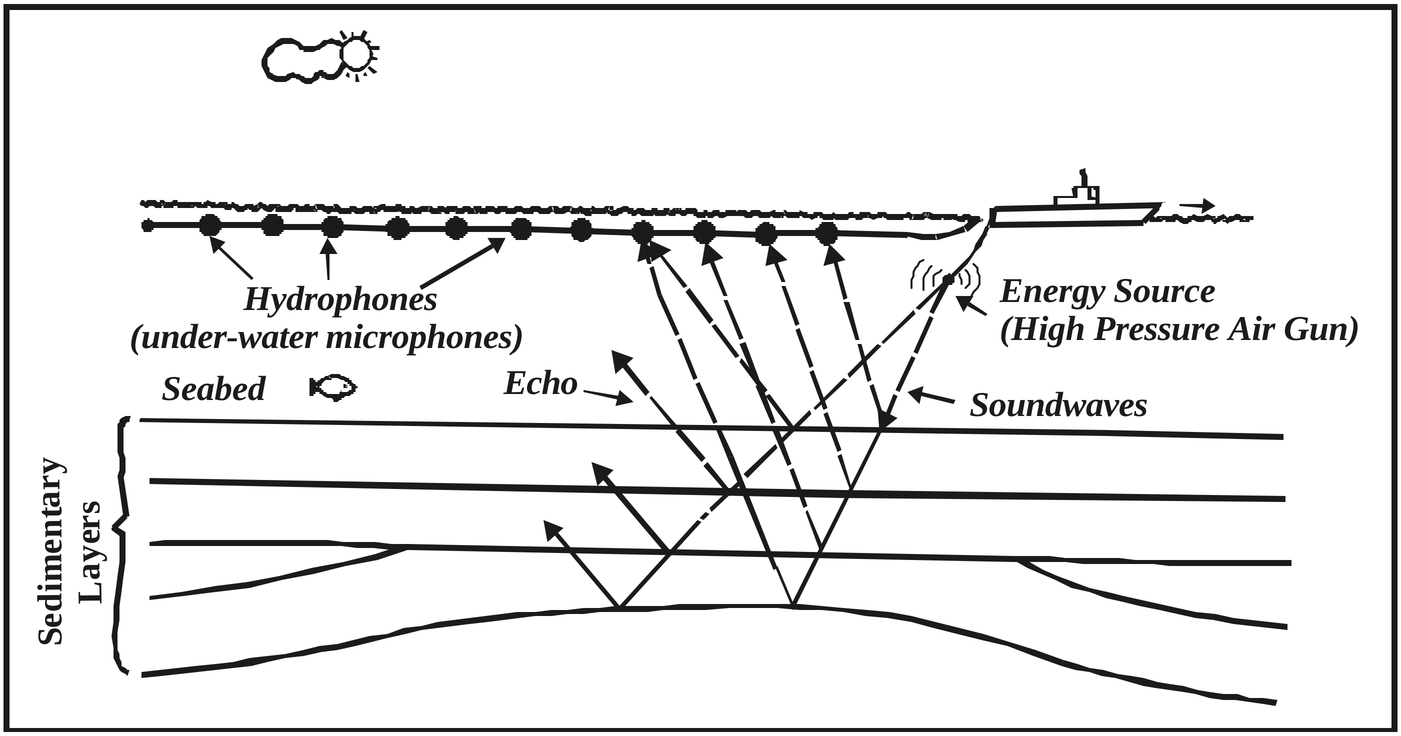

Figure 6.7 - Offshore Seismic Exploration

Questions:

(1) *What's the difference between a reconnaissance and detailed survey?*

(2) *How are seismic energy pulses generated on land?; in the ocean?*

(3) *On what principle is seismic exploration based?*

(4) *How is a bat's navigation system and a whales sonar system similar to the seismic technique?*

(5) *What's a geophone?; a hydrophone?*

Exercises:

(1) Examine the sample seismic section in figure 6.6. Can you see why the Hibernia field is located where it is? Can you find any other good drilling locations?

(2) Go to an area where a good clear echo can be generated. A starters pistol can be used as an "energy source". Using a stopwatch (accurate to 1/100 of a second), measure the time it takes for the echo to return. Now calculate the distance to the echoing object using the following.

distance = 1/2 x (time for echo to return) x (speed of sound in air)

speed of sound in air at sea level = 330 metres per second

(3) Vary the distance from the echoing object and repeat exercise 2.

Petroleum Exploration III - Acquiring Petroleum Rights

Acquiring Petroleum Rights

Up to this point in our study of petroleum exploration, we have met two important characters; the geologist and geophysicist. These are the people who are diligently mapping the countryside using all of the techniques at their disposal to find new geologic structures to drill. But before any drilling can take place, petroleum rights must be acquired for the land areas under which these structures are located. This is the job of the *landman.**

Surface Rights vs Petroleum Rights

When a petroleum landman talks about acquiring land, he or she is really talking about acquiring the petroleum rights below the surface of that land. The landman does not usually wish to acquire the surface rights as well, but does want to obtain the right to perform work on the land in order to explore for petroleum.

For example, a landman may approach a rancher who owns both surface and petroleum rights on the ranch. The landman will negotiate a deal whereby the oil company can drill and produce any oil or gas found on that property. The rancher, however, still owns the surface rights and continues ranching on the property. This is a beneficial arrangement to both parties, because if oil is discovered, a certain percentage will belong to the rancher who will get a share of the profits. The oil company, on the other hand, saves the cost of having to buy expensive surface rights.

Resource Ownership

In Canada, surface rights and petroleum rights are usually owned separately, by individuals, by corporations, by the federal government or by a provincial government. If surface or petroleum rights are owned by a government, they are said to belong to the Crown and are called *Crown lands*. If surface or petroleum rights belong to an individual or company, they are called *freehold lands*. In most areas in Canada, the Crown owns the petroleum as well as other types of mineral rights even though the surface rights may belong to individual citizens. Surface rights may change hands repeatedly on these lands, but the petroleum and mineral rights remain the property of the Crown.

Freehold petroleum rights (freehold lands) originated in the early years of settlement in this country. During those times, when homesteaders were granted lands by the government, the grant included the rights to petroleum or any other mineral that might be present on or beneath the land. Eventually, the government changed this policy so that petroleum and mineral rights were excepted from those grants. Freehold lands that exist today usually belong to the descendants of these original freeholders. Individuals who owned these freehold lands and were fortunate enough to have oil discovered on their property often became rich.

Freehold land is much more common in the United States than in Canada. The State of Texas which has been the most important oil producing state in the U.S. has witnessed the creation of many millionaires who were lucky enough to have oil discovered under their property.

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* The term “landman” is a “term of trade” that applies to both male and female members of the profession.

The Lease

In today's oil industry, there are a variety of agreement types that allow for the exploration and the production of oil. The most important type of agreement and the most widely used is the *lease* (Figures 7.1 and 7.2).

In most cases, when a company acquires a lease, it does not purchase the surface rights. The surface rights remain with the surface owner who is usually compensated in some way for the inconvenience of having petroleum operations carried out on the property.

A number of variables are associated with individual leases, including: the *term*, *rentals*, *royalties* and *bonus payment*. The bonus payment is a one time lump sum payed up front when the lease is signed. The *drilling delay rental*, or *rental*, is a fee paid to the lessor when the lessee is delayed in commencing drilling a well. It may vary from a few cents per hectare to several dollars per hectare, depending on the level of activity in the area. The *royalty* is the percentage of the oil and gas produced that is the property of the lessor (the person, company or government that is granting the lease). This is usually handled as a regular cash payment to the lessor, but is sometimes a quantity of the petroleum itself. Historically, the royalty has been 1/8th (12.5%), but it varies widely today.

Figure 7.1

The lease is a widely used type of agreement between the owner of the petroleum rights and the oil company that allows the oil company to explore for petroleum on the lessors land and produce any petroleum discovered.

(Courtesy of Petroleum Extension Services (PETEX), The University of Texas at Austin).

Every exploration lease has a *term* or time limit attached. The term represents the amount of time in which the company has to find petroleum on the property. If no oil or gas has been found by the end of the term, the lease expires and petroleum rights revert to the original owner. The terms of leases vary, depending mainly on the level of activity in the area. In easily accessible areas of high activity, the term may be as short as 2 years. In remote areas of little activity, the term may be as long as 10 years or greater.

But what if petroleum is discovered during the term of the lease? In this case, the lease does not expire. The company will be allowed to produce the petroleum for as long as possible, until no more can be economically recovered. In other words, the company will maintain the petroleum rights for "the life of the field". The life of an oil or gas field will depend on many things, including the size of the field and the rate of production. It may last only a couple of years or may last for decades. For example, the life of the Hibernia field on the Grand Banks is expected to be from 20 to 25 years at an average production rate of 110,000 barrels of oil per day.

Obtaining a Lease

The landman's job of acquiring leases will vary according to whether the petroleum rights are freehold or crown (Figure 7.3). If they are freehold, he or she will have to search the title of the property, discuss the company's anticipated operations with the owners, negotiate the terms and conditions of the lease, and ensure the proper recording of the agreement.

Obtaining a Lease (cont…)

In the case of crown lands the landman does not deal with individual citizens but with government agencies. Most crown leases are not acquired by negotiation, as is the case for freehold leases, but must be acquired through a competitive bidding process. Usually what happens is that an oil company indicates to the government that it is interested in acquiring lands in a given area. The government then makes an announcement that these lands are available for leasing and will be awarded to the highest bidder. Interested companies will then submit their bids in sealed envelopes to the government agency at a set time and place. The envelopes are then opened, the highest bidder is determined and the lease is awarded.

Lease

On the _________ day of Our Lord 19__, I ______ (lessor) grant petroleum rights on land outlined in the attached map (A map plus legal description of land would normally be attached) to _____ (lessee).

This lease shall come into effect on _____, 19__ and shall have a term of __ years.

The bonus payment for the lease is $ _____.

If the _____ (lessee) has not commenced drilling a well by the end of the first year of this lease the lessee shall be required to pay a drilling delay rental of $ _____ per hectare per year to the lessor until a well is commenced drilling on the lease.

If _____ (lessee) should discover petroleum on the lease then the term of the lease shall be extended until all petroleum that can be commercially recovered from the lease has been produced.

The lessee shall be required to pay to the lessor on a monthly basis a royalty equal in value to ___ % of all of the petroleum produced from the lease. The lessee reserves the right to take the royalty payment in kind (i.e., as a quantity of petroleum instead of cash).

Signatures

Lessor __________________ **Witness _________________**

Lessor __________________ **Witness _________________**

Figure 7.2 - Typical Lease Provisions

Obtaining a Lease (cont…)

Crown Land	Freehold Land
1. Companies inform the appropriate government agency of the lands they would like to see made available. 2. Government agency publishes a map showing which lands are available for biding. 3. Companies submit bids for the different parcels of land in sealed envelopes at a set time and place. 4. Envelopes are opened and the winning bids are announced. 5. Government issues leases to companies who submitted the winning bids for different parcels of land, for a set period of time.	1. Company landman approaches the owner of the land of interest to try and negotiate a lease. 2. If the landman is successful, the owner agrees to sign a lease and give the company petroleum rights for a set period of time. 3. Landman must register the lease with the appropriate government agency.

Figure 7.3 - How Petroleum Rights Are Usually Acquired

Questions:

(1) *What is the job of the landman?*

(2) *What's the difference between surface rights and petroleum rights?*

(3) *What do we mean by Crown lands?; freehold lands?*

(4) *Is most of the land in Canada Crown or Freehold?*

(5) *What are the usual components of a lease?*

(6) *What happens to the term of a lease when a lessee makes a petroleum discovery?*

Exercises:

(1) Split the class up into groups of three. One of the three will be a farmer who owns some freehold land, the other two will be landmen from competing companies who wish to negotiate a lease on the farmer's land. The farmer wants to get the best deal possible in terms of a bonus payment, royalty rate, rentals and length of term. The farmer also wants to ensure not being inconvenienced too much by the petroleum operations on the property. After all, a drilling rig with all the associated equipment and traffic can get in the way during the harvest.

The landmen, too, wish to negotiate the best possible deal for their companies. They do not wish to give too much away because every other farmer would want the same deal. However, they also want to be fair, because an unhappy lessor is no asset to their company, especially if they wanted to negotiate leases with other farmers in the area at a later date.

The farmer will talk to each of the landmen individually (twice) and then choose which company will get the lease. Use Figure 7.2 to seal the deal. Each group will report the details of the winning deals to the class and discuss.

(2) An oil scout is a person employed by an oil company to "keep an eye on" what the competition is doing. Oil scouts are not really "spies" as they are not to do anything illegal, but there is much that can be uncovered quite legally by an experienced oil scout with a good set of eyes and ears.

For example, the rig hand that likes to head to the local tavern at night and brag about all of the oil "he" is finding is someone the oil scout would probably like to have a few drinks with. Of course, the oil scout would never admit to who he or she really is, as that would put everyone on their guard. They'd probably pose as a salesman of some sort that's just passing through. But there is nothing illegal about that, is there?

Assume you are an oil scout in the employ of the Desperate Oil and Gas Company. Your company hasn't had much luck (except bad luck) in discovering any oil or gas in the last couple of years. You've heard rumours of a couple of discoveries in the Stephenville area, and your boss wants you to find out what's going on. Armed only with your wits, a desire to remain employed and what you've learned thus far in this manual, what would you do and what are the types of things and people you would look for?

(3) In Chapter 11, groups of students will be required to present an oil and gas news mural consisting of pictures, headlines from newspaper and magazine articles, hand drawings, etc. The mural should be constructed by pasting these items to a poster size piece of cardboard or construction paper. So skip ahead now, read Chapter 11, and have the students get started on compiling the needed materials.

Drilling

Now that we have found a promising geological structure and acquired the petroleum rights, it is time to go ahead and drill. Regardless of all the sophisticated geological and geophysical mapping that has been done, the only way to find out if there is any oil or gas present under your land is to drill a well (Figure 8.1).

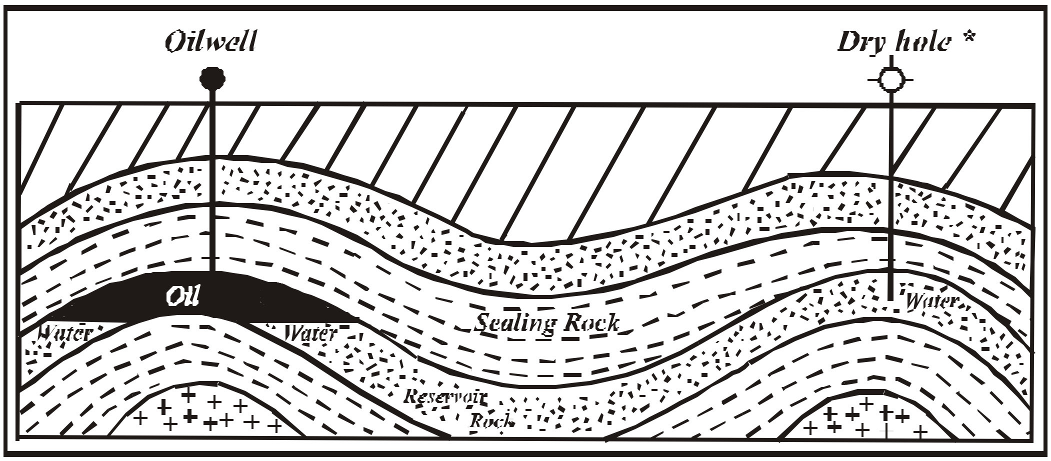

Figure 8.1 - Luck Does Play a Role!

Anticlines and other potential hydrocarbon traps can be located using seismic and other techniques, but the only way to find out if petroleum is present is to drill a well. Here we have two identical geologic structures side by side and only one of them contains oil. Only about one in ten wildcat wells is a discovery.

A Wildcat Well

The well that we are about to drill is called a *wildcat well*. This means that we will be drilling into a geologic structure in which no oil or gas has yet been discovered. We will be attempting to discover a new oilfield. If a discovery is made on this geologic structure, we will need to drill more wells (delineation wells) to determine the size of our oilfield. Drilling wells is an expensive and risky business. The costs can run into millions of dollars and the chance of success for wildcats is only about one in ten.

Drilling the Well

Drilling a well involves a whole new cast of characters. The drilling engineer, the driller, the tool pusher, the roustabouts, the roughnecks, the logging crew and many others. We will not get into detail regarding

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* Any well that does not find petroleum in commercial quantities is called a *dry hole*; even if the well does, as in this case, find water.

Drilling The Well (cont…)

the responsibilities of each of these individuals, as this reaches beyond the scope of this manual, but we will provide a general description of the drilling process and its challenges.

The overall objective of drilling is to bore a hole (the well bore) into the ground until you penetrate a target rock formation, that has been identified by the geologists and geophysicists as having the potential to contain commercial hydrocarbons. We know from Chapter 3 that the formations through which we will be drilling may be porous and permeable, and may contain fluids (oil, water or natural gas) at very high pressures. If we were to drill into such a formation without taking the appropriate precautions, the fluids would spew violently out of the hole and we'd have what's called a *blowout*. Blowouts can be extremely dangerous as well as damaging to the environment. In the early days of the oil industry, before drilling technology had evolved significantly, when a well struck oil it often blew out. These blowouts frequently caught fire, destroyed the rig, and sometimes cost rig workers their lives.

Figure 8.2 is a picture of a major oil blowout at the Spindletop field near Beaumont, Texas in 1901. This field went on to become one of the greatest oil producers in U.S. history.

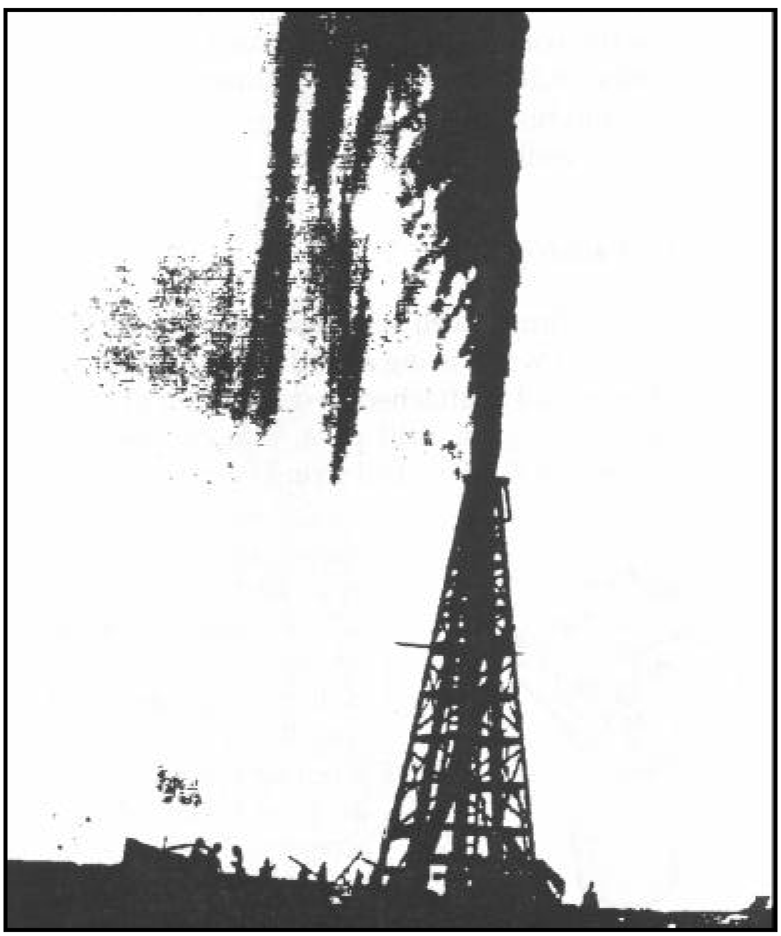

Figure 8.2 -Blowout

The Spindletop Blowout in Texas spewed 50,000 barrels per day for 9 days in 1901 before the well could be controlled. Oil drillers were ill prepared to deal with the pressure in this reservoir as no blowout of this magnitude had ever before been witnessed.

(With permission of the University of Texas at Austin and the Spindletop/ Gladys City Museum).

Drilling the Well (cont…)

In today's drilling industry, blowouts are very rare. The entire technology of today's drilling industry is focused on the ideal of drilling safely and economically into the pressurized underground formations, without allowing any uncontrolled flow of fluids out of the well. The well is allowed to flow through a series of valves only under controlled conditions.

But how do we accomplish this? What are the basic techniques of oil well drilling?

Drilling Technology

Drilling a well is, in many ways, similar to drilling a hole into a piece of wood using a rotating drill bit. The bit, in this case is much larger and is attached to the bottom of a hollow steel pipe called a drill string (or drill pipe) that can be thousands of metres long (Figure 8.4). The drill string is rotated by an engine at the surface.

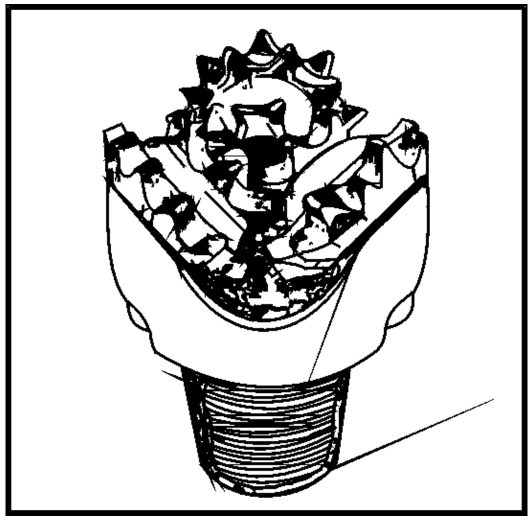

Figure 8.3 -Drill Bit

The rock drill bit is not the screw-shaped type, but is a roller-type bit made up of three cone-shaped, toothed cutters (Figure 8.3). As this bit rotates, under several tons of downward pressure, it crushes the rock. The drill string is composed of a number of 9 metre lengths of high strength steel pipe that are screwed together end to end. As the well is deepened, the drill string is lengthened by screwing additional lengths of pipe to the top. But now a couple of questions should come to mind.

(1) How do we get these pieces of crushed rock (rock cuttings) up out of that hole, which may be thousands of metres deep? (2) How do we keep the high pressured liquids and gases, that may be present in the rock formations, from blowing out? Both of these concerns are addressed by the *drilling mud*.

Drilling mud, which is a mixture of clay, high density solids (weighting material), water and chemical additives is pumped down through the inside of the hollow drill string (Figure 8.5). Because the drill bit, and hence the borehole, is larger in diameter than the drill string, a hollow space (the annulus) exists between the drill string and the walls of the borehole. The mud that is being pumped down squeezes through holes in the drill bit and circulates back to the surface through the annulus, carrying the rock cuttings along with it. Back on the surface, the rock cuttings are mechanically removed from the drilling mud in the "shale shaker" and can be examined by the wellsite geologist. The same mud can then be recirculated through the drill string and the process continues while drilling is in progress.

Figure 8-3, from An A-Z of Offshore Oil & Gas by Harry Witehead.

Drilling Technology (cont…)

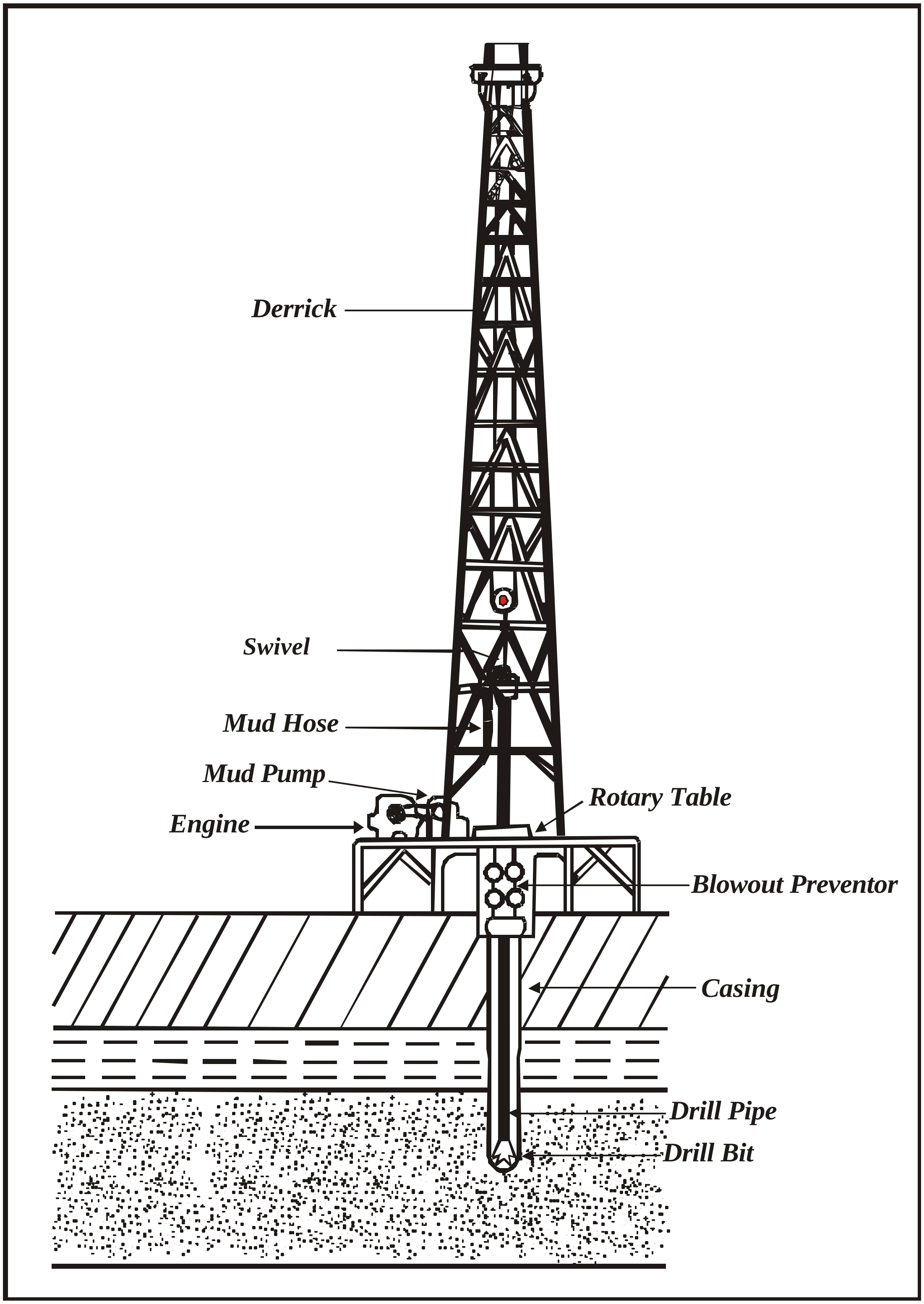

Figure 8.4 -Drilling Rig

Drilling Technology (cont…)

Drilling mud is also the key to preventing blowouts. If the drill bit penetrated a porous and permeable formation containing oil and gas under high pressure, the oil and gas would naturally tend to rush out of the formation and up the borehole. But in order to do this, it would have to overcome the downward pressure exerted by the thousands of kilograms of slowly circulating mud. What usually happens in such a case is that only small traces of oil or gas will flow out of the formation and circulate back to the surface with the mud. This result is actually useful to the wellsite geologist as oil returning with the mud is a good indication that there are hydrocarbons down below.

Drilling mud also helps to cool and lubricate the drill bit and provides a protective and stabilizing coating on the walls of the borehole, which helps to seal off porous formations and keep the wellbore from caving in.

Casing the Well

Although the drilling mud does help prevent the wellbore from caving in and does help to seal off porous formations that have been drilled, a more permanent and reliable method to accomplish this is to *case* the well. Casing the well involves lining the borehole with steel pipe (Figure 8.4) and cementing it in place.

To case a well, the drill string and bit are removed from the hole. The drill string, of course, cannot be removed in one piece. Every third joint in the drill string will be unscrewed and the *stands* of pipe will be stacked against the derrick. When all of the drill string and the bit have been removed, the casing is lowered into the mud-filled hole by screwing together the 12 metre lengths of casing pipe end to end. The casing is slightly smaller in diameter than the borehole and is secured in place by pumping cement into the annular space between the outside of the casing and the borehole. When the cement sets, drilling will continue using a slightly smaller bit than before. As the well is deepened, additional casings of concentrically smaller diameters are added as needed to seal off the deeper formations.

Logging the Well

Although the wellsite geologist can get many hints of the types of rock formations in the well from the rock cuttings, and sometimes gets hints of the presence of oil or gas by the small amounts that come up with the drilling mud, more information is needed to properly analyse the rock formations that have been drilled. To help obtain this information, the geologist has some associates who go by the name of the *logging crew*.

This logging crew does not come equipped with chainsaws or axes, but with *geophysical logging devices*. These *logging tools* are lowered into the mud-filled hole (usually prior to casing being set in that part of the hole) and measure the electrical, acoustic, and radioactive properties of the different layers of rock. The results of these logging measurements are analyzed to determine which of these layers are porous and permeable, and likely to contain hydrocarbons.

Casing The Well

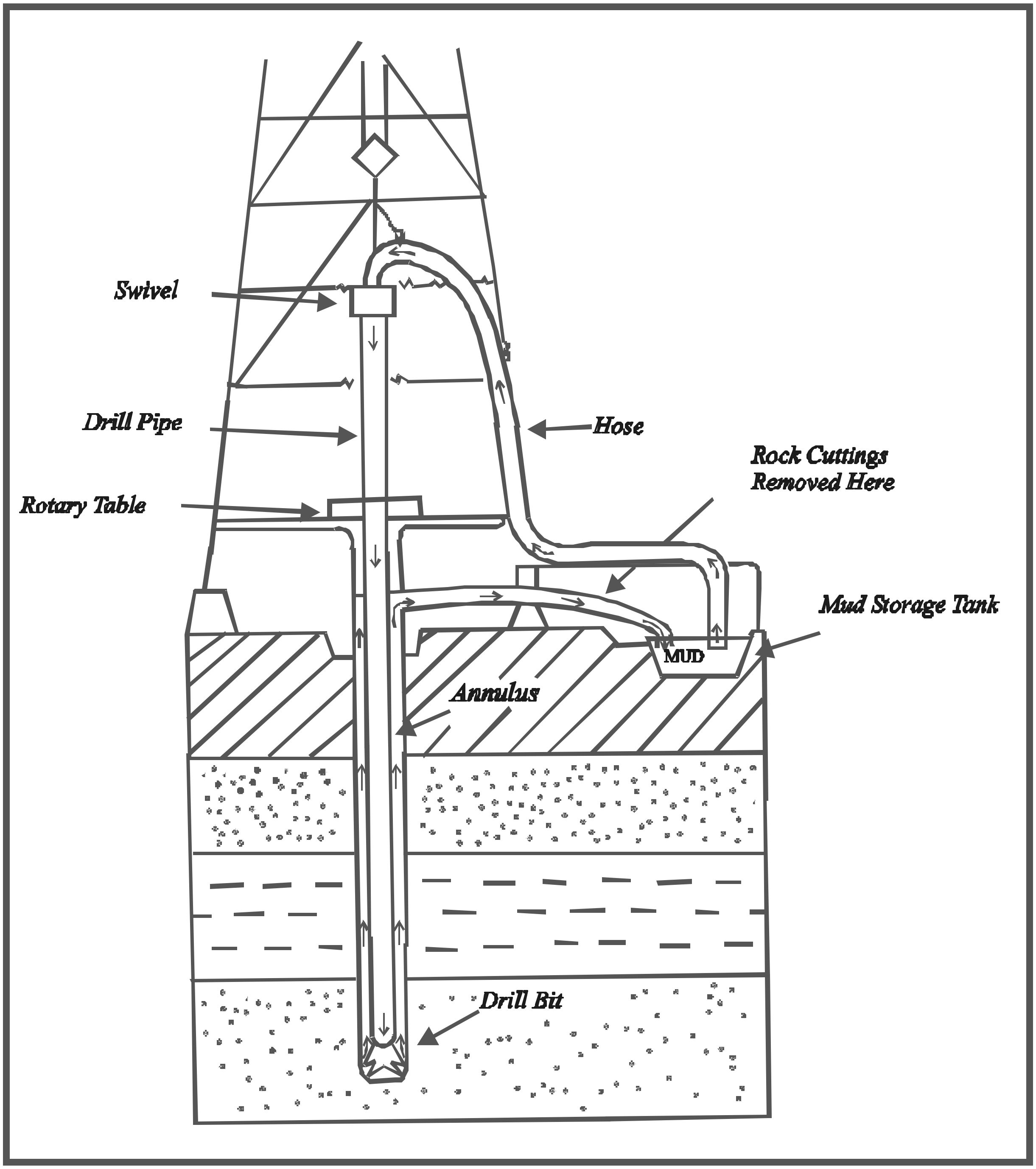

Figure 8.5 - Circulation Path of Drilling Mud

This figure shows the circulation path of the drilling mud. The mud is pumped from the storage tank through a hose and swivel and down through the drill string. It then passes through the drill bit and starts to move upward through the annulus carrying rock cuttings with it. Back at the surface, it travels through a hose and "shale shaker" (which removes the rock cuttings) and ends up back in the storage tank.

The Drill Stem Test

In the old days before the use of drilling mud, the drilling crew immediately knew when they had hit a good oil reservoir because the well would blow out. This would be an event of great excitement as well as great danger. Fortunately, things are done differently today. The excitement and tension of finally determining if the well is a discovery are still present, but much of the danger has been removed.

After the geologist has analyzed the logs and identified a formation that appears (from the log analysis) to be porous, permeable and contain hydrocarbons, the excitement begins to build. This is the time of reckoning for the well. It is time to do a *drill stem test* (DST). The DST involves the lowering of specialized equipment into the well bore that isolates the formation of interest from the pressure exerted by the drilling mud so as to allow the fluids within the formation to flow to surface. This determines the flow capability and the type of fluids (oil, natural gas or water) present in the formation. The DST also records valuable information on the formation pressure, which is critical to determining whether the well can produce at a high enough rate and for a long enough time to be profitable. For example, if a well flowed oil at a rate of 100 barrels an hour for 24 hours and showed very little decrease in reservoir pressure, one could conclude that this was a pretty good well and should produce for a long time. If, however, at the end of the test the pressure had dropped off by 50%, it would mean that this oil reservoir was small and could not produce for a long enough time to be profitable. A well that cannot produce hydrocarbons in commercial quantities is called a *dry hole*.

The Blowout Preventor

It should be evident, from our discussion thus far, that a drilling rig is a very complex piece of machinery containing a broad range of specialized equipment. Although we won't go into a detailed discussion on the workings of every part of a drilling rig here, there is one special piece of equipment that is critical to the safe operation of the rig and warrants special mention. Have you considered what would happen if the bit drilled into a porous and permeable formation, in which the pressure was so great that the weight of the mud column could not hold the formation fluids back? What would happen is that the fluids in the formation would enter the annulus and start heading for the surface. The first indication at the surface would be that the mud level would start to rise in the mud tanks because the mud would be coming out of the hole faster than it is being pumped back down the drill pipe. This is called a kick. If proper and decisive action is not taken by the driller, such a kick could lead to a blowout. When a kick occurs the driller immediately activates the backup system - the Blowout Preventor (BOP).

The BOP (Figure 8.4) is a system of powerful hydraulic rams anchored to the casing which can, at the flick of a switch, be closed and sealed around the outside of the drill pipe preventing any further flow of mud or formation fluid up the annulus. When the flow has stopped, weighting material is added to the mud making it heavy enough to hold back the formation fluids. When this is accomplished, drilling resumes.

Questions:

(1) *Is it possible to determine if petroleum is present in a geologic structure using only seismic data?*

(2) *Why do wells sometimes blow out?*

(3) *How is drilling mud used to prevent blowouts?*

(4) *What is the purpose of the casing in the well?*

(5) *How does a well site geologist figure out which zones should be drill stem tested?*

Exercise:

(1) Watch a video on oil well drilling. You may approach your local library, media outlets or large oil companies working in your area to see which videos are available.

Drilling Offshore

Since the modern oil industry began in the 1850's, hundreds of thousands of wells have been drilled. Gradually, the most easily accessible onshore areas have been drilled up and most of the easy-to-find fields have been found. The result is that it has now become increasingly difficult to find new oil and gas fields in the old familiar areas. This has lead to the search for new frontiers in which to explore for oil and gas. These new frontiers include offshore areas on the continental margins; areas like the Grand Banks of Newfoundland and the Labrador coast.

As stated in Chapter 8, the drilling industry is a major industry in its own right. This being the case, the offshore drilling industry is a major industry within the drilling industry. It is an extension of that industry into the unfamiliar and often unfriendly setting of the open ocean.

A Hostile Environment

Offshore drilling came about gradually as explorers first built jetties out from the land and later mounted entire rigs on barges that could drill in quiet shallow waters (Figure 9.1). Today, offshore drilling takes place on the open ocean and, in addition to dealing with the usual difficulties associated with drilling onshore, it must also contend with waves, currents, fog and deep water. In some areas, as on the Grand Banks, there are the additional complications of cold temperatures, icebergs, pack ice, storms that bring winds of more than 160 kilometres per hour, and waves that can be more than 30 metres high. In this chapter, we will learn how the drilling industry meets the challenges of drilling in such a hostile environment.

The Technology of Offshore Drilling

Perhaps the most obvious difference between drilling offshore and onshore is that an onshore rig sits directly on the surface through which it is to drill. However an offshore rig can be floating anywhere from a few tens of meters to a couple of thousand metres above the sea bed, and must therefore be attached to the sea floor by a large steel pipe called a *marine riser* (Figure 9.2). The riser then acts as a conduit for the drill string and the drilling mud. In essence, it is an extension of the casing that allows the drilling mud and rock cuttings to be isolated from the water column and circulated back to the rig.

Another complication in offshore drilling is that, since the sea is seldom calm, the rig is constantly heaving and rolling in the swell. Tensioners and motion compensators allow the riser and drill string to remain relatively stationary, and keep a constant weight on the drill bit while the rig moves with the swell. But what of the winds and currents that tend to move the rig off the drilling location? It is easy to imagine the problems that even a small amount of drifting would cause when the drill pipe is extended thousands of metres into the sea bed. The industry has adopted two solutions to this problem. The first involves an elaborate system of 8 to 12 anchors, each weighing up to 20 tons. Mooring lines comprised of heavy steel chains can extend a mile or more, depending on water depth.

A second system that is being increasingly used is the *dynamic positioning system* or DPS. The DPS can either supplement or replace the anchors with a computer controlled system of propellers or *thrusters*. Through an array of motion sensors, the computer can immediately detect any movement of the rig and then apply just enough power to the appropriate thrusters to compensate and keep the rig exactly on location. This type of system makes it possible to drill in much deeper water, where anchors would not be feasible. Wells can now be drilled in water depths exceeding 2000 metres.

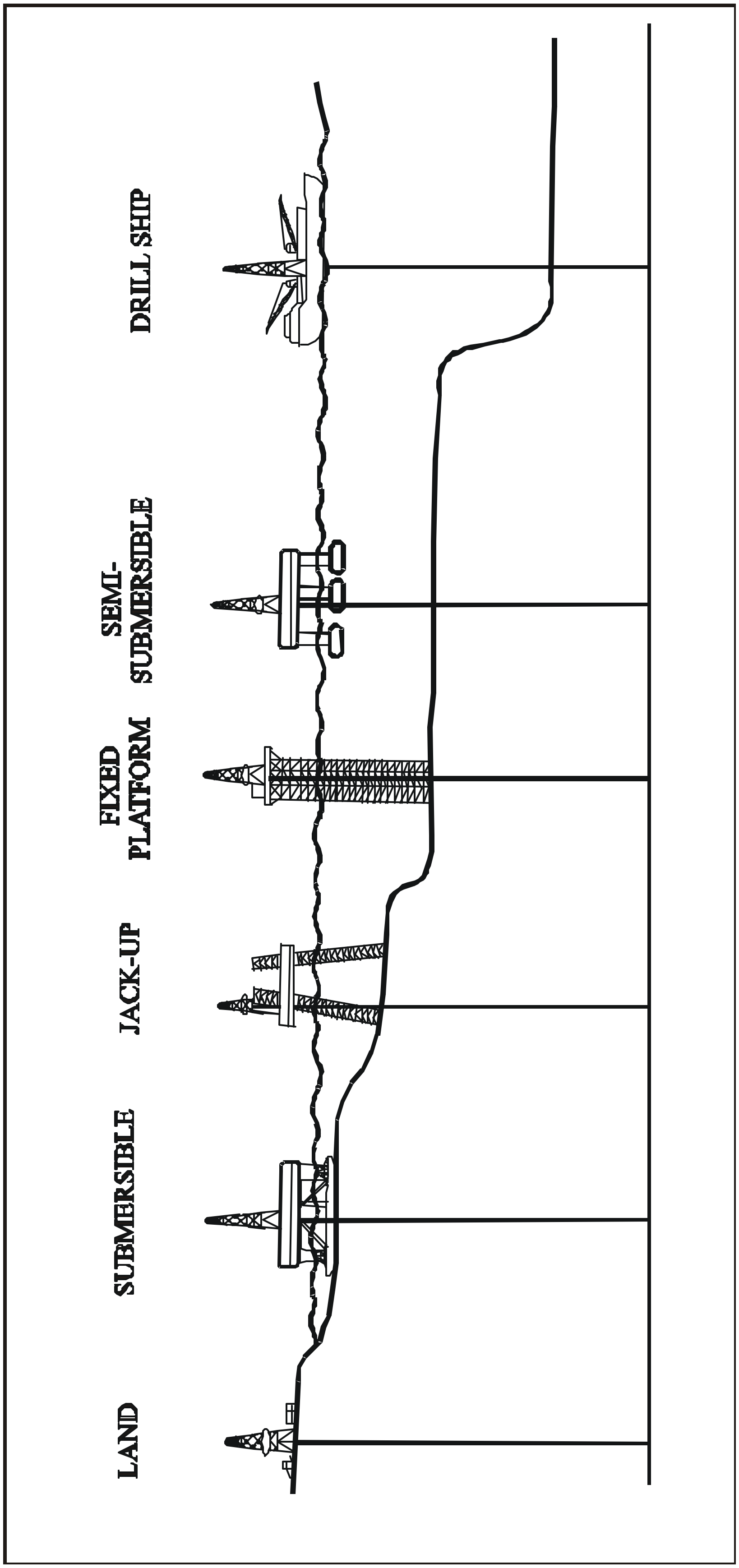

Figure 9.1 -Evolution of Offshore Drilling

(Modified after Shell Oil)

The Technology of Offshore Drilling (cont…)

Another important advantage of DPS is that it allows the drilling rig to quickly disconnect the riser and move off the location in case of an emergency (such as the approach of an iceberg). As you can imagine, the retrieval of several twenty-ton anchors would be quite time consuming and would require a lot more lead time when making the important decision to leave the drilling location. The significance of such a decision becomes apparent when one realizes that it costs in the neighbourhood of $250,000 per day to operate a rig on the Grand Banks. In this kind of operation, any time lost becomes very expensive.

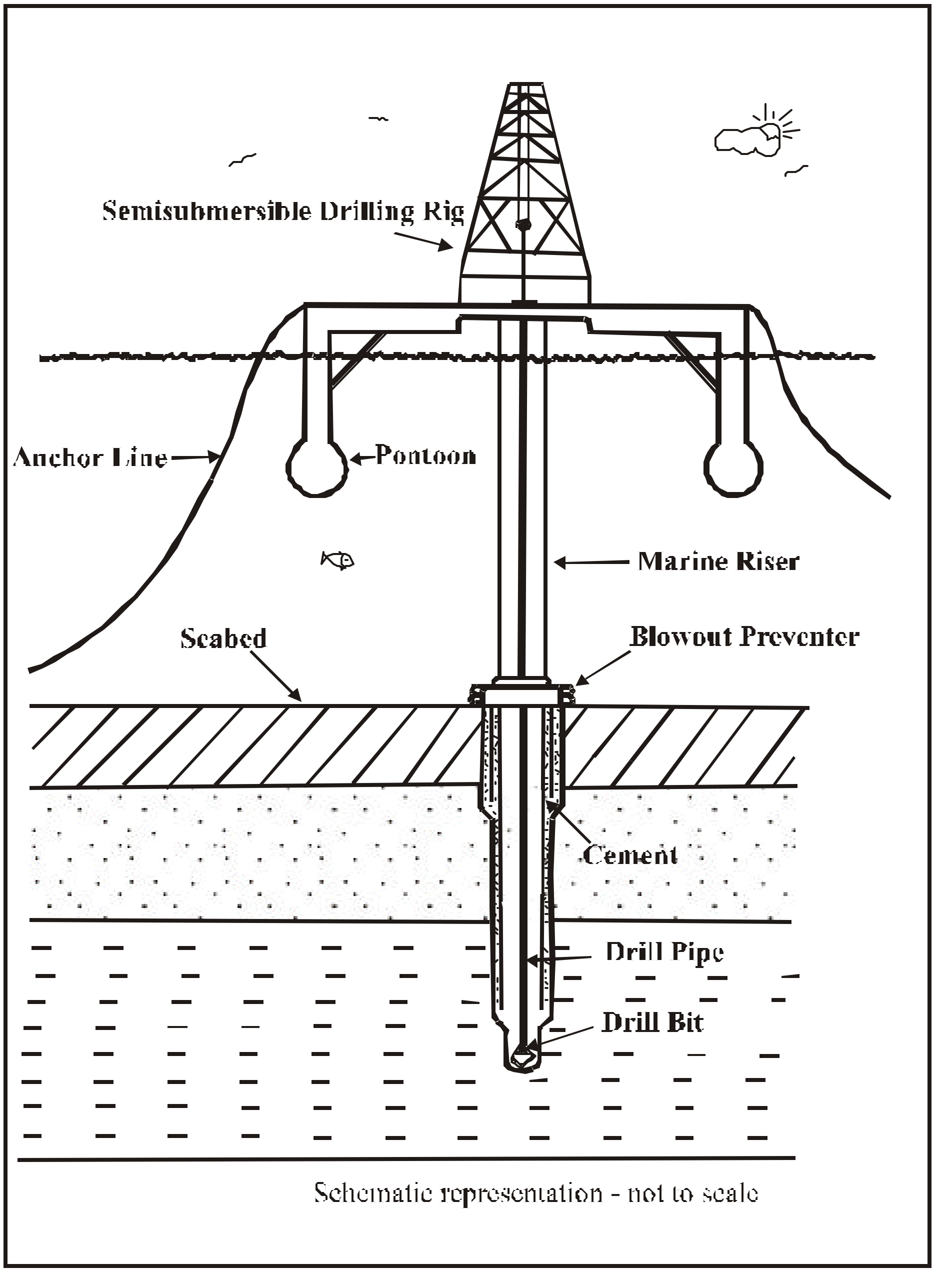

Figure 9.2 -Semisubmersible Drilling Rig

When drilling offshore, a drilling rig must be attached to the seabed by a marine riser. The drillpipe and drilling mud are isolated from the water column by the marine riser.

Supply Vessels

An offshore drilling rig located hundreds of kilometres from land with a crew of about 100 people, needs a lot of supplies. These include food for the crew, fuel for the engines and generators, sacks of cement and sacks of bentonite and barite which are mixed with water to make the drilling mud. It needs hundreds of tons of drill pipe, casing, and, of course, the huge and massive sections of pipe that are put together to form the riser. It is not always possible for a rig to store all of these provisions on board and so each rig has a supporting cast of two or three *supply vessels.*

The supply vessels, in addition to delivering supplies and equipment to the rig, perform other important duties. They assist in the deployment and retrieval of anchors and at least one vessel stands by the rig at all times in case it must be abandoned. They sometimes participate in the transfer of personnel to and from the drilling rig (the crew changes every 3 weeks), although this is usually handled by helicopters. They tow the rig, when it is not self-propelled, from one location to the next and in some areas, as on the Grand Banks, they are required to tow icebergs that may be drifting into the vicinity of the rig.

Types of Offshore Drilling Rigs

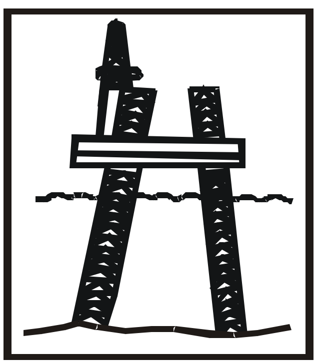

Figure 9.3
Jack-Up Drilling Unit

There have been many types of drilling rigs used since the industry took its first steps into the offshore areas. Figure 9.1 shows some of these variations. Today, however, there are three important types of mobile offshore drilling rigs that operate in the open marine areas. These are the jackup, the semi-submersible and the drillship (Figures 9.3, 9.4 & 9.5).

Jackup rigs (Figure 9.3) are usually towed to the drilling location. At the site, the legs are lowered to the seabed and the platform is jacked up to a safe level above the sea. When drilling operations are completed, the legs are "jacked up" high enough so that the rig can float freely and be towed to the next location. The maximum water depth in which jackup rigs are used is about 90 metres.

The *semi-submersible* rig (Figure 9.4) is comprised of a drilling platform mounted on columns above two large pontoons. During rig moves, only the pontoons are submerged. At the drillsite, the pontoons are partially flooded so that the rig rides deep in the water providing a remarkably stable drilling platform. Most semi-submersibles in existence today are moored by anchors, but an increasing number are adopting dynamic positioning systems.

The third type of mobile rig, the *drillship* (Figure 9.5), is comprised of a drilling platform mounted on a conventional ship's hull. These drilling units have also been moored by anchors in the past, but today most are using DPS technology. The drillship experiences greater heaving and rolling motion than the semi-submersible and, therefore, is more limited in the severity of seas in which it can operate. On the other hand, the greater mobility of the drillship gives it advantages in areas where it may have to move off location under short notice, such as in areas with a high iceberg population.

Types of Offshore Drilling Rigs (cont…)

Drillships and semi-submersibles have not yet reached their limits with regard to the water depths in which they can operate. Using dynamic positioning systems, they have been able to drill in water depths exceeding 2000 metres. Both semi-submersibles and drillships have been used on the Grand Banks. The jackup has not been used in the Newfoundland offshore, but has been routinely used off Nova Scotia.

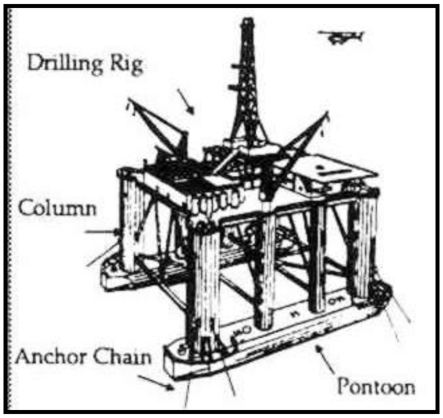

Figure 9.4
Semi-Submersible Rig

(Courtesy of Exxon Corporation)

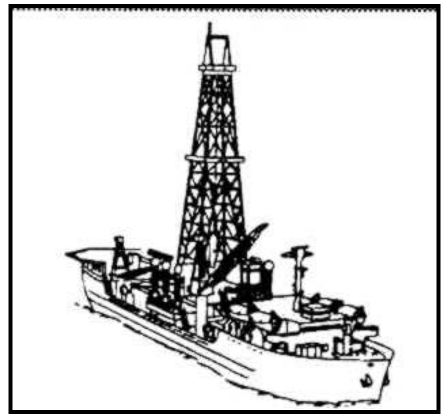

Figure 9.5
Drillship

(Courtesy of Exxon Corporation)

Costs

Drilling offshore is much more expensive than drilling onshore. The cost of drilling is very much influenced by environmental conditions. Factors such as distance from land, water depth, well depth, weather conditions, the presence of pack ice and icebergs all affect the cost of an offshore well. For example, on the Grand Banks of Newfoundland, in 1991, the average well takes from 60 to 70 days to drill and costs approximately $16 million. These well costs can only be justified in areas where there is a good chance of finding very large fields. Offshore Newfoundland and Labrador is one such area. Figure 9.6 shows other areas in the world where offshore drilling has occurred.

Questions:

(1) Which is more expensive, drilling onshore or offshore?

(2) Why did the oil industry start drilling offshore?

(3) What are the major differences between drilling offshore and onshore?

(4) What types of drilling rigs have been used offshore Newfoundland and Labrador?

(5) Which is better suited to very deep water, an anchor system or a dynamic positioning system?

Types of Offshore Drilling Rigs

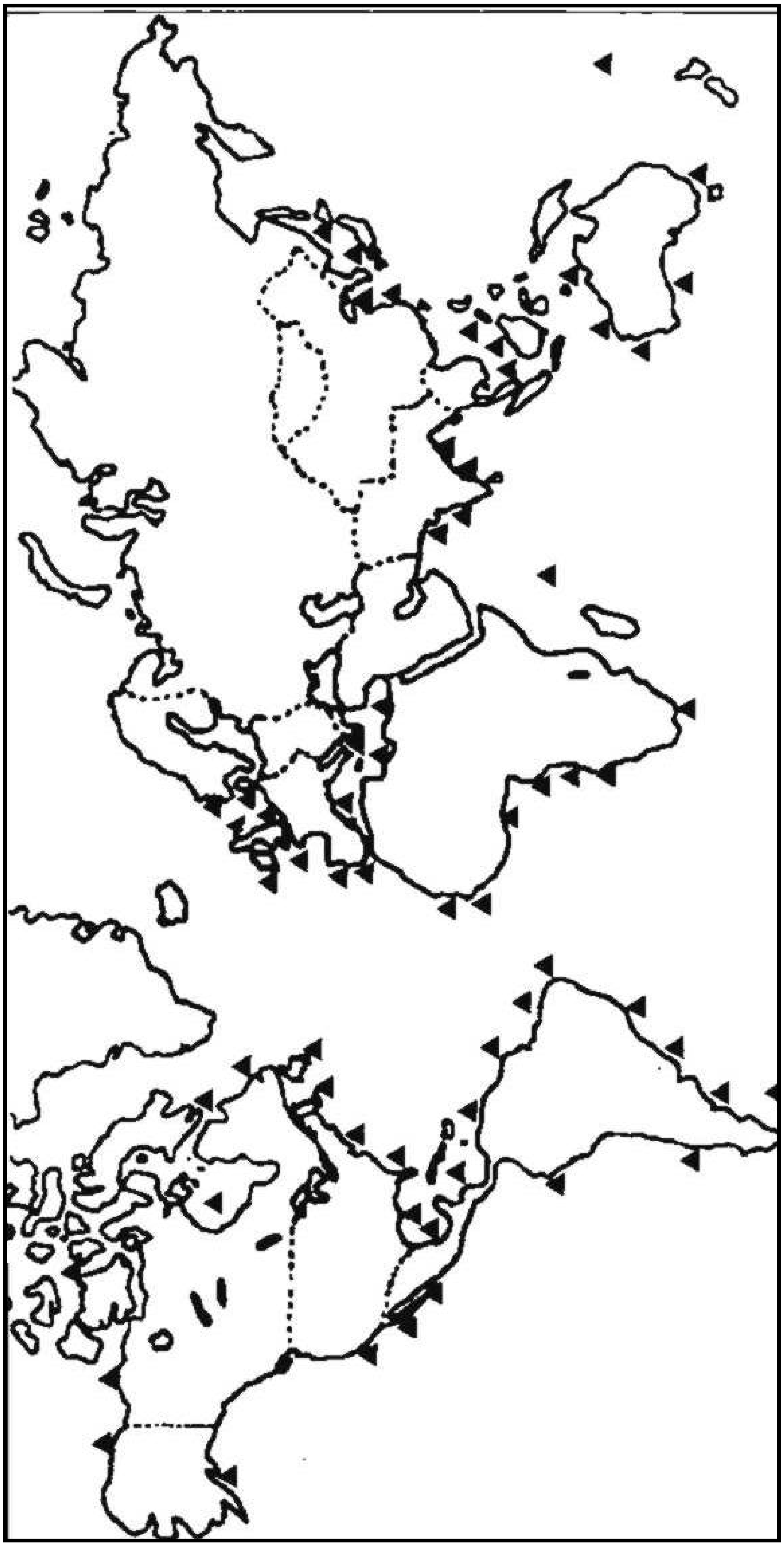

Figure 9.6 -Areas Where Offshore Drilling has Occurred

Exercises:

(1) View the film entitled "Shotpoint 260"; (30 minutes).

(2) Offshore wells have been drilled in water depths exceeding 2,000 metres (2 kilometres). Think of a couple of locations that are 2 kilometres apart so that you can get a feel for this water depth.

(3) An offshore well on the Grand Banks today costs approximately $16 million dollars to drill. In some situations, where problems were encountered and when oil prices were higher, certain wells cost more than $100 million to drill. By taking the average house price in your area, figure out how many houses you could buy for the average cost of an offshore well.

(4) A typical semi-submersible rig is about 95 metres long, 80 metres wide and approximately 95 metres high to the top of the derrick. Go to an open field and measure off these dimensions to get a feel for the size of these rigs.

Field Development and Production

We have now covered the major aspects of petroleum exploration. First of all, we had the geologists and geophysicists doing surface, gravity and magnetic mapping (reconnaissance work) to identify some areas of general interest. Then the geophysicists returned to do the detailed seismic work and found some geologic structures that looked good enough to drill. All the while the landman, who was in constant communication with the geologists, geophysicists and the company's head office, was acquiring the petroleum rights for the more attractive areas. Finally, we drilled a wildcat well and against long odds discovered oil.

Now that a field has been discovered, it must be developed so that it can be put into production and generate some cash. Developing a field involves the drilling of additional wells into the geologic structure and installing production equipment throughout the field to facilitate commercial production of the oil or gas. The production phase essentially involves getting the fluids (oil and/or gas) out of the ground, treating the fluids to remove impurities (such as sediment, sulphur and water), and taking whatever steps are necessary to keep the wells producing at a profitable rate for as long as possible. But we must now backtrack for a moment - for in between the exploration phase and the development phase there is quite often one other phase: the *delineation phase*.

Delineation Drilling - How Big is our Oil Field?

Thus far, we have drilled only one well (the discovery well) into the oil field. Seismic data is very helpful in mapping the size of the underground structure, but the only way to be certain of what parts of the structure contain oil is to drill *delineation* or *stepout* wells. Figure 10.1 shows us an example of a delineation drilling program. The first well (the discovery well) was drilled at the very crest of the structure. The wells chronologically numbered 2 to 8 were drilled in strategic locations to further define the extent of the oil reservoir. Each new well added more information about the field. This information was then used in planning the location of the next delineation well until finally there were enough wells to show the limits of the field.

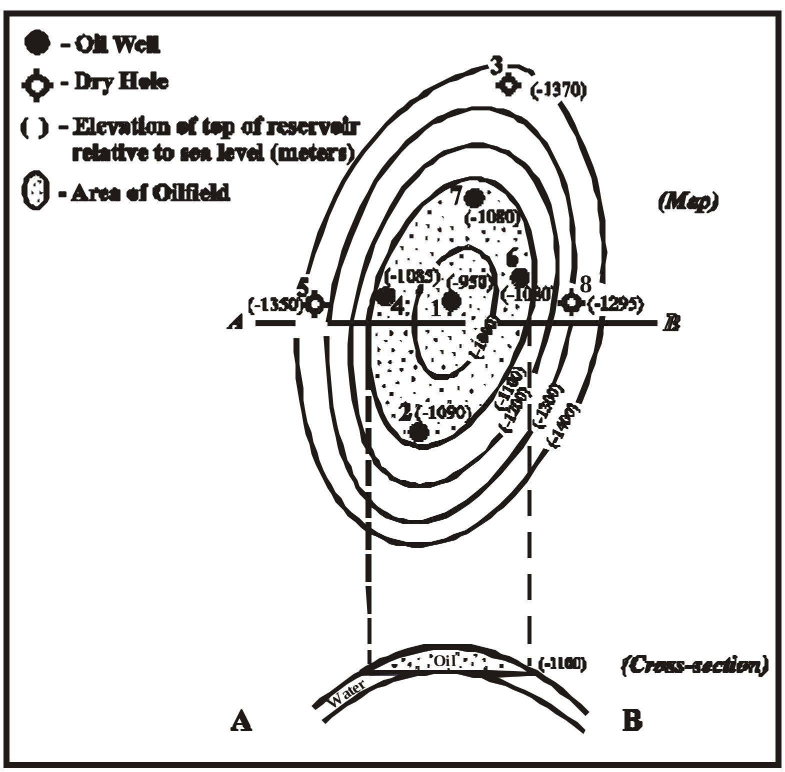

Figure 10.1 -Delineation Drilling Program

This figure shows a map and cross sectional view of an oilfield. The trap type is an anticline. Well number 1 was the discovery well. Wells numbered 2 to 8 are delineation wells that were drilled sequentially to determine the size of the field. Each successive well added more information that could be used in planning the next well location.

Development Wells

Now that we've determined the size of the oil field, the geologists, geophysicists and reservoir engineers must put their heads together and plan the location of the rest of the wells – ie., the *development wells*.

The object, at this stage, is to get the maximum amount of oil out of the ground with the minimum number of wells.

A key parameter to be considered is the *drainage area,* which is the area that can be drained by one well. Depending on the permeability and the pressure within a reservoir, a well may be able to draw oil from as far away as a couple of kilometres or from as near as only a few hundred metres. Taking these factors and the geology into account, a *well spacing grid,* showing the planned location of future wells, is designed.

Having settled on the position of future wells, the company must plan the sequence in which they should be drilled with two factors in mind. First, the wells must be placed so they can be produced into the *gathering system* as it develops. A gathering system is a system of pipelines that collects the oil as it is produced from different wells throughout the field and brings it to a central location. Secondly, each well should add the maximum amount of new information about the oil reservoir. As new wells are drilled and the knowledge of the field is refined, the original drilling plans can be adjusted in accordance with the new information.

Completing A Well

After a well has been drilled to total depth (TD) and has proven by drillstem test (DST) to be capable of producing oil or gas, it must be *completed*. "Completing a well" means installing equipment in the well to allow a safe and controlled flow of petroleum from the well. In addition to the casing that lines the well bore (recall Chapter 8), *tubing* and a system of flow valves must be installed (Figure 10.2). Tubing is a smaller pipe through which the oil or gas flows to the surface during production. It may be two to six inches in diameter, depending on the flow capability of the well.

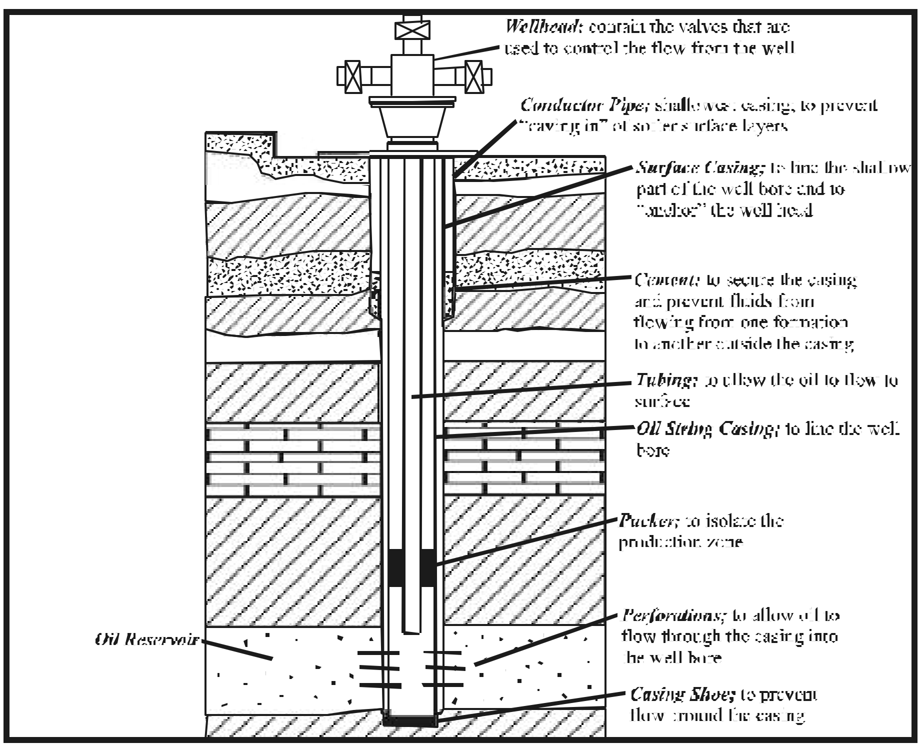

Figure 10.2 -The Completed Well

(Courtesy of Petroleum Extension Service (PETEX) The University of Texas at Austin)

Crude Oil Treatment

Crude oil usually contains impurities such as sediment, water, natural gas and sometimes hydrogen sulphide. Before the oil can be sold or delivered into a tanker or pipeline, these extra constituents must be removed to bring the crude up to the proper quality. To accomplish this, processing equipment must be installed, including such things as *separators*, to separate oil and gas from water and sediment. Where hydrogen sulphide (H_2S) is present, special chemical treatment facilities are required to remove it. Hydrogen sulphide is a very dangerous poisonous gas which also is highly corrosive to pipelines and tankers. It smells like rotten eggs, and if inhaled in high enough concentrations can cause death within two minutes.

Pressure Maintenance and Artificial Lift

When an oil well first starts producing oil, it can usually flow to surface naturally because of the high pressure in the reservoir formation. As oil is produced over the months or years, however, the reservoir pressure gradually decreases. This phenomena is normally counteracted by establishing a *pressure maintenance program* which involves injecting water or natural gas into the reservoir to balance the oil removed.

Without pressure maintenance, some form of *artificial lift* may be required to help raise the crude oil to the surface and obtain the maximum production from the field. A common form of artificial lift is to install a pump to pump the oil up to the surface. Figure 10.3 shows an example of a widely used type of sucker rod pump.

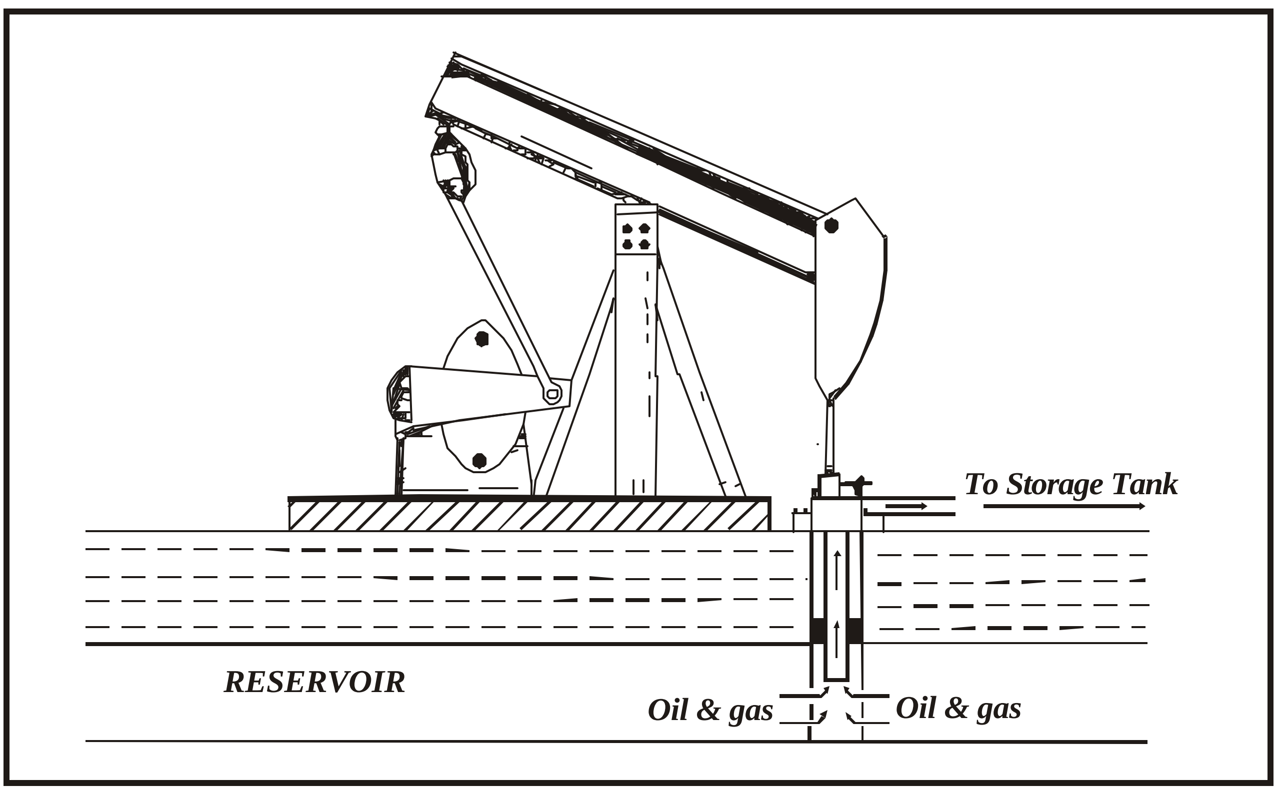

Figure 10.3 -Artificial Lift

Schematic illustration of the typical "horsehead" type sucker rod pump widely used for artificial lift in many onshore fields.

Offshore Production

Production of oil and gas offshore is similar to production onshore with the following major differences: (1) There is a need to provide some form of production platform; (2) Some of the production equipment must be installed on the seafloor instead of on dry land and; (3) Development wells are more often *directionally drilled* from the permanent platform in the offshore (Figure 10.4). These special needs create both enormous challenges and enormous costs.

Offshore platforms can be of a floating or fixed design. Fixed platforms, as the name suggests, are attached to the seabed (Figure 10.4). Floating platforms are held in place by some form of anchoring system or by a dynamic positioning system.

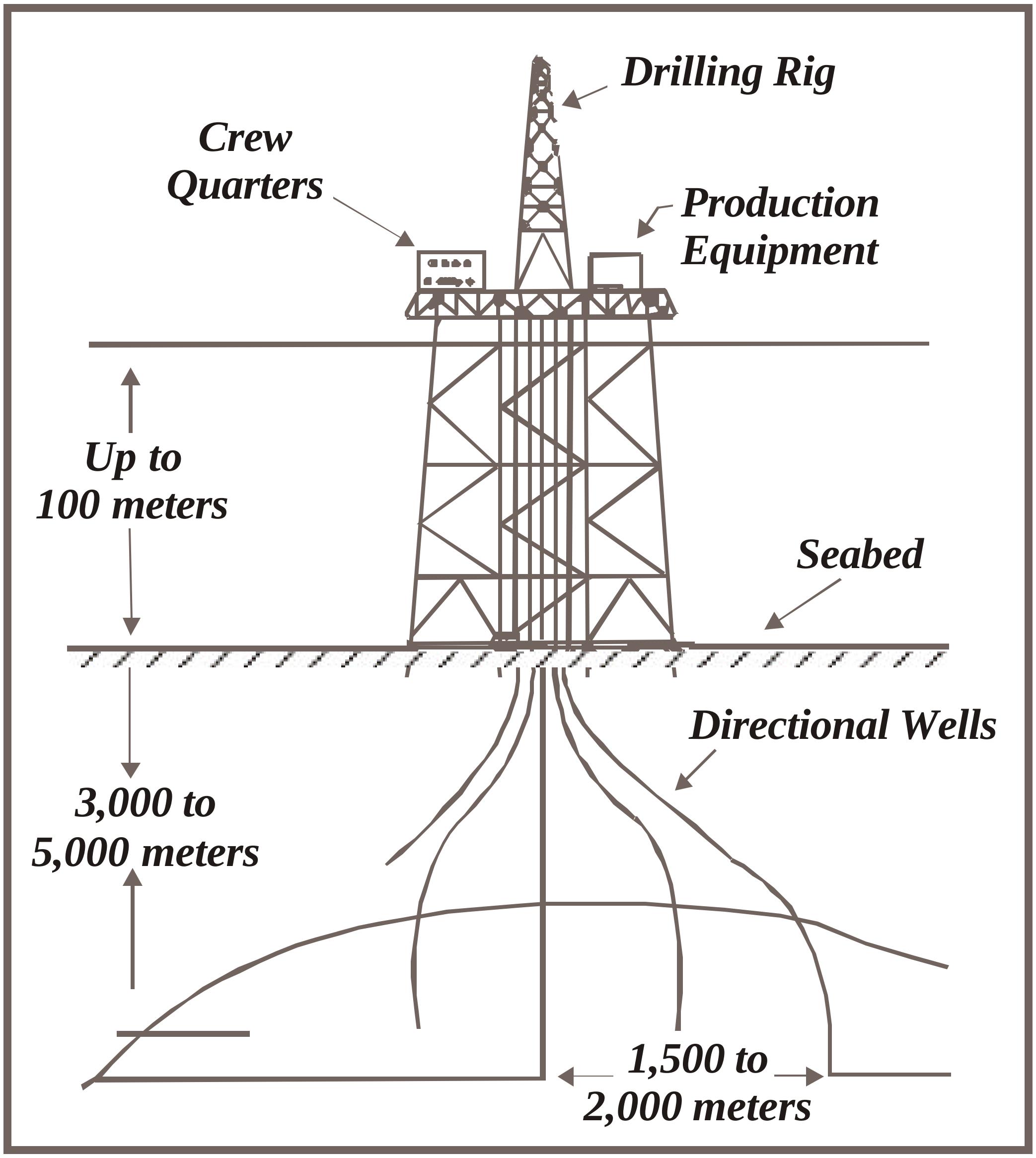

Figure 10.4 - Steel Tower Production Platform

(Modified after Petroleum Extension Service (PETEX), The University of Texas at Austin)

Fixed Platforms

Fixed platforms have been built of both steel and concrete. Steel platforms (Figure 10.4) are simply steel tower structures resembling oversized transmission towers with drilling and production facilities mounted on top. They have been used extensively in the Gulf of Mexico, the Persian Gulf and the North Sea.

Concrete platforms are built of massive semi-hollow cylinders of concrete (Figure 10.5). These platforms are floated into place and then ballasted with sea water to sit firmly on the bottom. They are held in place by their sheer mass and are, hence, called *Gravity Based Structures*.

The concrete platform to be built for the Hibernia field is to be of a new design (Figure 10.6). It will consist of drilling and production facilities mounted on one massive semi-hollow concrete cylinder. This design has been chosen for Hibernia because of the icebergs that are known to drift into the area. The system is designed to withstand the impact of icebergs of the size that are known to frequent this area.

The oil produced at Hibernia (up to 150,000 barrels per day) will be treated on the platform and stored inside the concrete column. It will then be transported from the site by shuttle tankers.

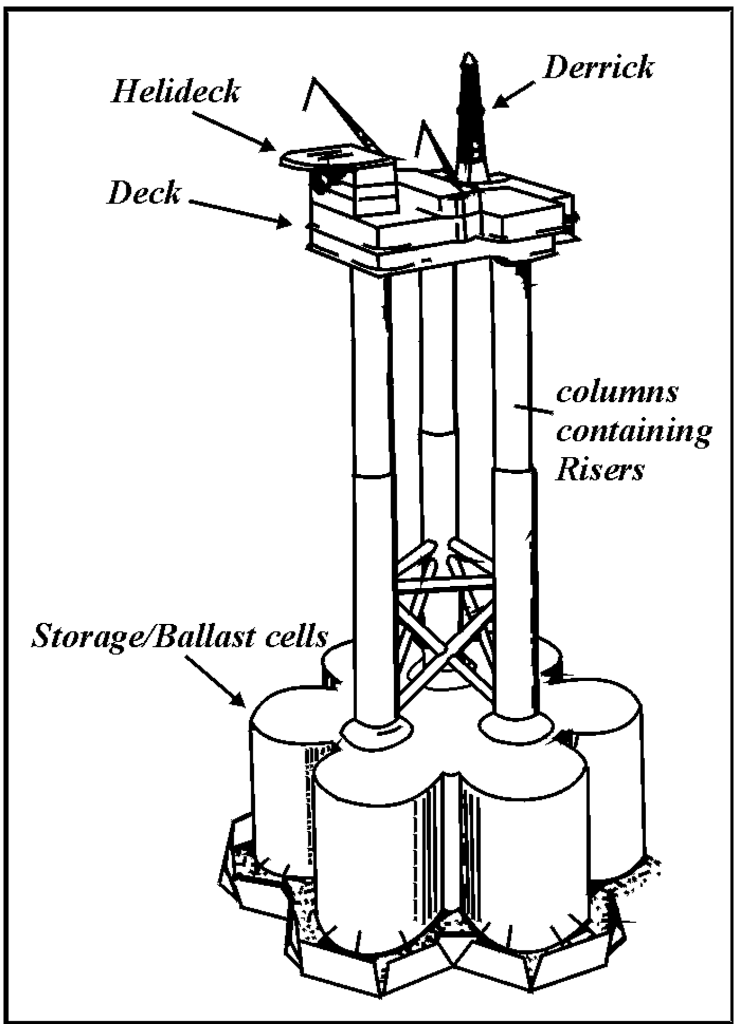

Figure 10.5 - Gravity Base Structure Production Platform

(From <u>An A-Z of Offshore Oil and Gas</u> by Harry Witehead. Copyright 1983 by Gulf Publishing Company, Houston, Tx. Used with permission. All rights reserved.

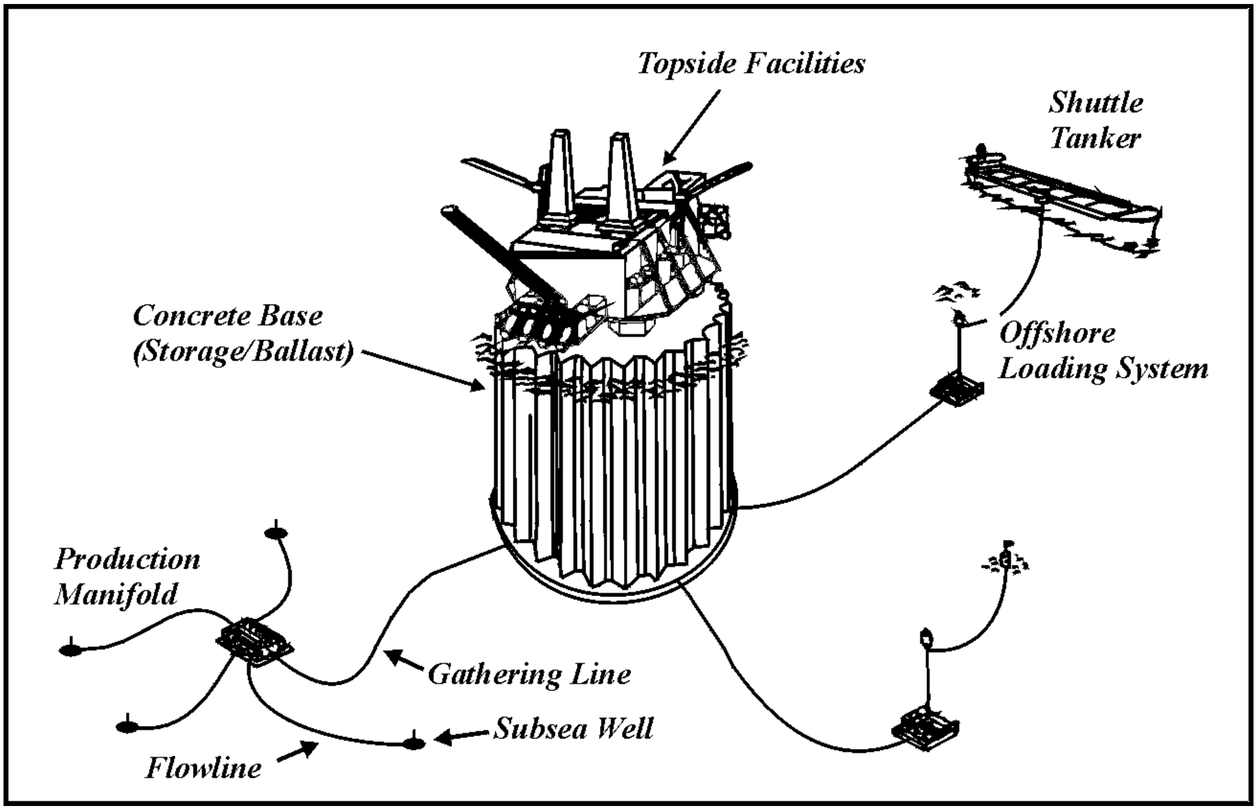

Figure 10.6 - Production System Components-Hibernia Field

(Courtesy of Mobil Oil)

Floating Production Systems

Some offshore fields are not large enough to justify the construction of either a concrete or steel platform. A cheaper method of development is to install production facilities on a semi-submersible platform or upon a ship-shaped hull (Figures 10.7 and 10.8).

Such floating production platforms are more weather sensitive than the fixed systems. They are also limited in their productive capacity by the limits on the weight of equipment that can be safely mounted on the floating platform.

These types of systems have been used in a number of offshore areas in the world, including Brazil, Spain and the North Sea. Floating platforms are expected to be used to develop some of the smaller fields on the Grand Banks.

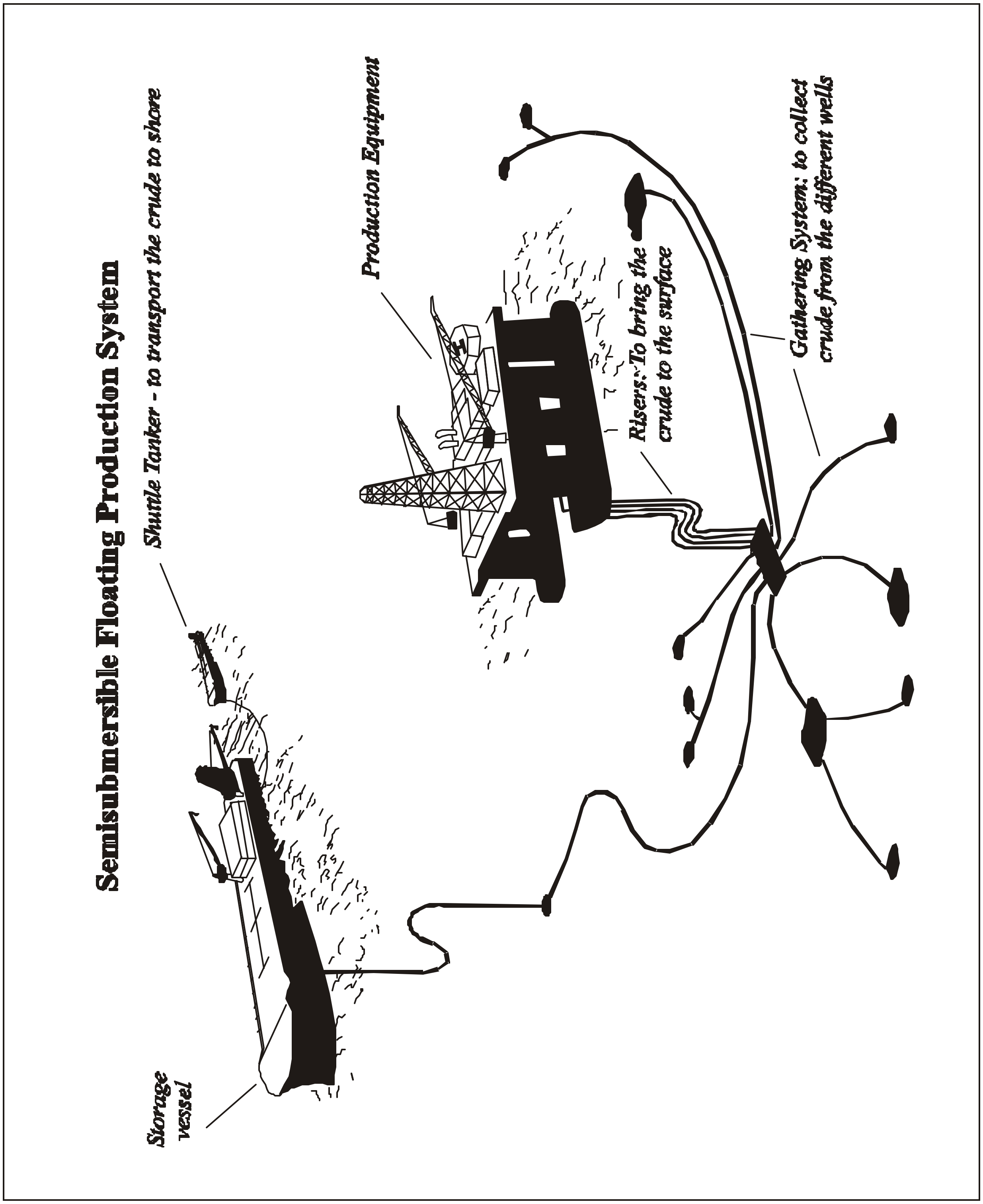
Semisubmersible Floating Production System
Shuttle Tanker - to transport the crude to shore
Production Equipment
Risers: To bring the crude to the surface
Gathering System: to collect crude from the different wells
Storage vessel

Figure 10.7

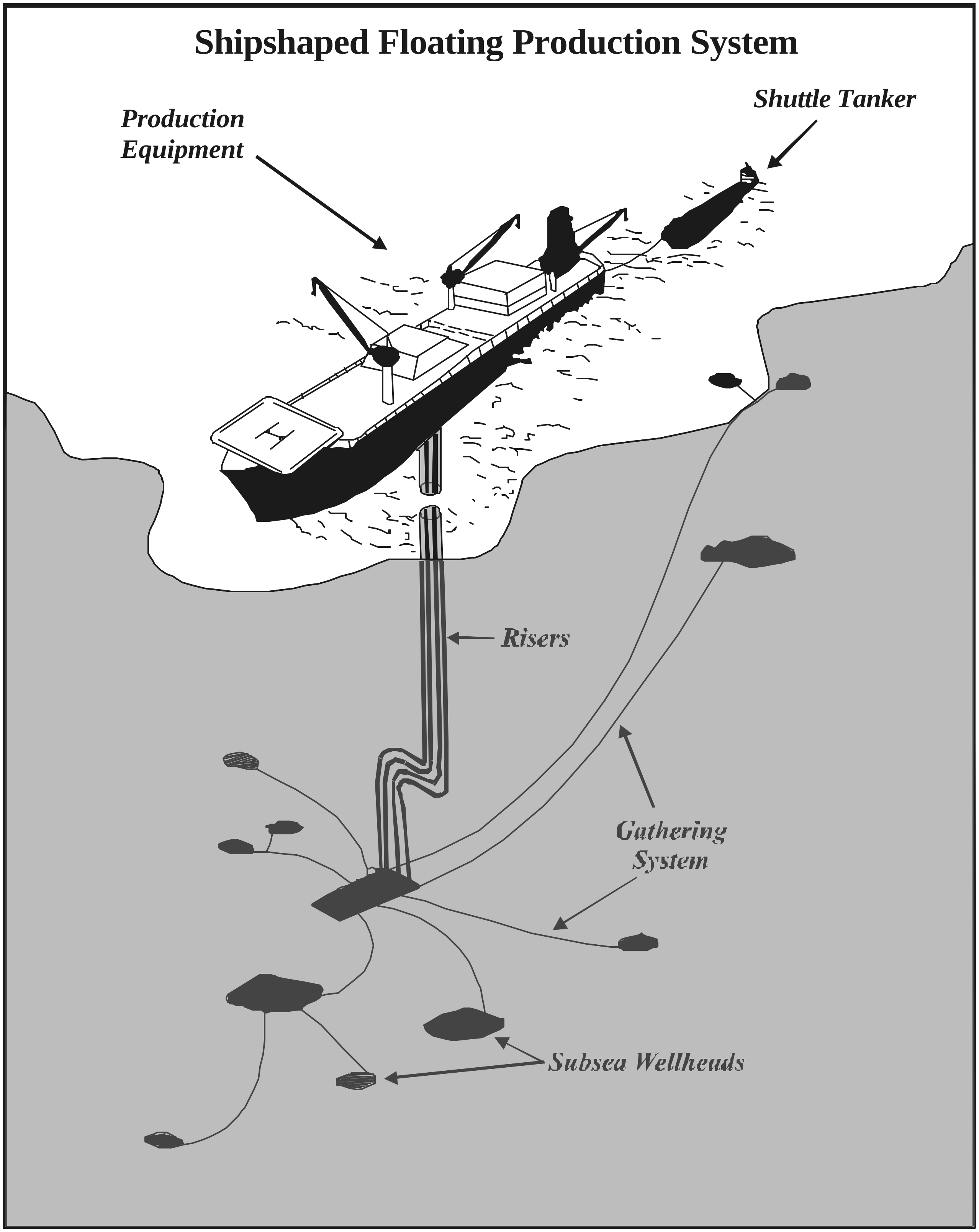
Shipshaped Floating Production System
Production Equipment
Shuttle Tanker
Risers
Gathering System
Subsea Wellheads

Figure 10.8

Questions:

(1) *What are delineation wells?; development wells?*

(2) *What does it mean to "complete" a well?*

(3) *What impurities must be removed from crude oil as soon as it comes out of the ground?*

(4) *What is artificial lift? When is it necessary?*

(5) *Which is more expensive, offshore or onshore development?*

Exercises:

(1) View the video entitled; "The Hibernia Development Project" (10 minutes).

(2) Study figure 10.1 and see if you can follow the logic that was used in choosing the locations of wells numbered 2 to 8.

(3) Oil Spill

Offshore oil development holds the promise of great economic benefit to the province of Newfoundland and Labrador. But, as with most major industrial development, it also presents certain risks to the environment. One of those risks is an oil spill.

This activity illustrates problems with oil spills, including their effects on wildlife and the difficulties involved with their clean-up.

There is no more obvious example of ocean pollution than that of a major oil spill. It spreads. It floats. And it is black. It also provides vivid examples of its impact on wildlife:

- a bird coated in oil cannot fly or float, and loses its insulation against temperate changes,
- oil which seeps into sand can remain there for years, and cause harm to coastal life,
- oil sometimes smothers communities of animals living on the ocean floor, and some organisms, particularly some shellfish cannot survive,
- oil kills seaweeds and other plants that animals such as birds feed on,
- oil can seep into eggs and kill unhatched animals.

Not only does an oil spill have negative consequences on animals and their environment but it is also extremely difficult to clean up. This activity allows students to act out the role of environmental managers, deciding on different ways of handling the oil spill clean-up. It also gives them an awareness of how seabirds are potentially harmed. It is very important to follow the exercise with a discussion of what was observed.

Materials:

- motor oil
- eye droppers
- hand lens
- bird feathers
- 10 cm lengths of string
- cotton batting
- container of sand
- shallow pans (e.g., aluminum pie plates)
- paper towels
- 3 hard-boiled eggs
- dishwashing detergent

Method:

(1) Divide class into small groups. Give each group a pan with a small amount of water in it, a pan with a small amount of oil, some paper towel, a magnifying glass, and a bird feather. Have the students take turns looking at the feather under the lens. Sketch it as seen. Dip feather in water for one to two minutes. Remove, examine under the hand lens, and sketch. Place the feather in oil for one to two minutes. Remove, examine with the lens and sketch. Compare all three sketches. Try to wipe the oil off the feather with the paper towel. Examine the feather again. What effect do you think the oil could have on a bird's activities?

(2) (*This demonstration could be done, by the instructor or a student, in conjunction with the class activity).* Place 3 hard-boiled eggs in a container of motor oil. After 5 min utes remove one egg. Peel off the shell and examine. After 15 minutes, remove an egg and do the same. After 30 minutes, examine the third egg. What did you observe? What effect do you think an oil spill could have on the eggs of birds that nest near the water?

(3) (Keep the same groups of students as in first part of activity. Discard feathers). Give each group an eye dropper, a small container of dishwashing detergent, a 10 cm piece of string, some sand, and a piece of cotton batting. Have students fill their eye droppers with oil, and add 5 to 6 drops to the middle of their pan of water. What happens to the oil? Does it look like more or less than when it was in the dropper?

Discussion:

Once your students have had a chance to experiment with different techniques, have them discuss their observations, and implications for their use with a real oil spill.

String:
The string may have been used, by some, to contain the oil. This in fact is often practiced after a spill, until something else is done with the oil. (The string is called a boom).

Discussion:

Eye Dropper:
If students did not contain the oil, they may have tried to remove it from the water with the eye dropper. (How much oil was able to be removed? Was there water mixed with the oil)?

Detergent:
Detergent removes oil from dishes and clothing but does it remove oil from water? Detergents are sometimes added to an oil spill to disperse the oil and reduce the concentration in any given area. This can have advantages in that the environment can deal more quickly with lower oil concentrations, but it has the disadvantage of spreading the spill over a larger area.

Sand:
If sand was added, most of the oil may have sunk. However, it does not disappear; it is merely displaced.

Cotton Batting:
If cotton batting is added to the oil, the oil sticks to all its surfaces. If dipped and removed several times, it should remove most of the oil from the water surface. This is the most effective method of the above options, but procedures based on this principle are often difficult to execute on the open ocean.

Everyone agrees that the best way to prevent damage from oil spills is to not allow them to occur. But we must also face the reality that oil is our primary source of energy and most of the ports of the world (including those in Newfoundland and Labrador) are frequented by oil tankers. In addition to the risk of oil spills from tankers, in Newfoundland we have the risk of blowouts in offshore wells. Recognizing that these environmental risks accompany the substantial economic benefits that come with offshore oil development, what can we do to minimize these environment risks? Be as imaginative and creative as possible.

(Adapted from SEEDS Energy Literacy Series)

Current Events in the Oil Industry

For this chapter, the students are to have been divided into small groups and each group is to have compiled a poster sized mural of headlines, photographs, drawings, short newspaper or magazine articles, write-ups of stories they heard on the news etc., that are associated with the oil industry. Items should touch the following facets of the petroleum industry:

(1) **Exploration;** Geophysical Surveys, Drilling.

(2) **Development;** News on field developments in Newfoundland's offshore within Canada or around the world.

(3) **Price;** What's happening with the price of oil?

(4) **Transportation;** News stories on oil and gas pipelines or oil tankers.

(5) **Security of supply;** Are we in danger of losing our supply of oil?

(6) **Environmental;** Any recent environmental incidents or studies released.

(7) Any other petroleum related topics that the students encounter and would like to work into their presentations (e.g., refineries, social impact of oil developments, alternate energy sources, etc.)

Students may go as far back in time, as they wish, to find articles to support a position or theme they may wish to express. But keep in mind that the goal of this exercise is to introduce the students to current issues in the oil industry. Too many older articles may give them a less than modern perspective. The students should be encouraged to use their imaginations to make the mural both informative and artistic. They should strive to grab people's attention and make a statement.

Perhaps a plan to display the murals in the school hallway for a few days would be useful in that it will give the artists a larger forum in which to display their talents and facilitate feedback from the school population.

Presentation of Murals

Each group should give an oral presentation and explanation of their mural of at least 10 minutes. Each member of the team should participate in the presentation and cover one or more of the topics addressed. The final speaker should give a brief summary and clearly state any positions or conclusions the team has reached as a result of the project.

Discussion

After all of the presentations have been made, initiate discussions on what has been said. Ask questions about what each person learned from the exercise. Did they enjoy it? Do they disagree with any positions taken or statements made by the other teams? Differing opinions is a healthy sign that the students are truly learning something and are willing to defend their ideas.

Public Hearing

A public hearing provides a forum in which a company, organization or government can listen to presentations from members of the general public on an issue. Public hearings are often held by governments to get the public's opinion and to help assess the impact of some decision or action that the government is about to take. The government then takes into consideration the information presented at the hearing when making its decision. An example of where a public hearing might be utilized is when the government is considering approval of a large offshore oil field development submitted by a company. Such a development plan would outline the type of production system to be built, where it was to be built, other related work involved in the construction and operation of the production system. It would also discuss the benefits to the province in terms of jobs and the measures that will be taken to mitigate the environmental and social impacts.

In a public hearing on such a development, people would present arguments for or against the approval of the plan, identify concerns, and perhaps suggest changes to the plan to address these concerns.

Exercise

In this exercise, the class will hold a mock public hearing on an offshore oilfield development. You are given a basic description of the development plan and a cast of characters. Students will be assigned roles as these characters in making their presentations to the hearing. Since there will probably be more students in the class than there are roles to assign, more than one student can be assigned the same role. Each student will just bring his or her own personality into the role. Also, there is no need to limit the roles to be played to the charters described here. It may be more meaningful to take on the role of real characters from within your own community.

The instructor will chair the hearings and should make notes on each speaker. Each presentation should be about 10 minutes long. Students should be encouraged to use diagrams, maps or other visual aids to help articulate their positions. When all of the presentations have been completed, the chairperson should take a few minutes to review the notes and then report what recommendation will be made to the government. Students should be encouraged to challenge the chairperson’s conclusions and try and influence the final recommendation. Once again, differing opinions will be a healthy sign.

Offshore Oilfield Development Plan

Oilfield Name: (Use your school's name)

Type of Production System: Fixed Concrete.

Details; Construction Phase: The production system will be constructed entirely in your area and will involve the following:

(1) The local docking facilities will have to be substantially upgraded to handle the increased ship traffic. This will involve dredging the harbour as well as upgrading the existing pier.

Offshore Oilfield Development Plan

(2) A large dry dock will have to be built. This is where the base of the GBS will be constructed. About 3 hectares (7.4 acres) of land will be required.

(3) A large cement mixing facility will be constructed adjoining the drydock.

(4) The main road into the area will have to be substantially upgraded to handle the increased traffic of very heavy equipment into the area.

(5) A portable work camp will have to be built near the community to house the nearly 2000 workers that will have to be brought in during the construction phase, which will last 5 years.

(6) A large wharf will need to be built for assembling the modules that will become the topsides. The individual modules will be constructed elsewhere.

(7) A small airstrip will need to be built. There will be significant traffic in helicopters and small aircraft.

(8) Ship traffic in the area will increase significantly and this will prevent fishing in one of the traditional areas.

(9) Fishing will also have to be shut down for a three year period at the sheltered deepwater site where the GBS will be completed approximately 200 metres offshore, 2 kilometres up the coast from the dry dock.

(10) A tanker terminal will have to be constructed a couple of miles from the community. The terminal itself will be one kilometre from the shore and the oil will be pumped ashore through a pipeline (yet to be constructed) where it will be stored in a number of large tanks (yet to be constructed).

(11) A pipeline will have to be built to transport the oil to the refinery (already in place) 30 kilometres away.

(12) The oil tankers that will be used will be built at the shipyard 200 kilometres away.

Details; Operating Phase: When the production system is in place 300 kilometres offshore, the field will start producing oil and is expected to produce for 20 years at an average rate of 100,000 barrels per day. Your community will be affected in the following way:

(1) When the construction phase ends, all of the construction related jobs will be lost. The 2000 imported workers will leave and the portable camp will go as well. (It is possible, however, that as new fields are to be developed offshore, there will be other systems constructed in your area, using the new facilities that will be in place).

Offshore Oilfield Development Plan

(2) Ship traffic will decrease somewhat but will still be quite brisk, as your port is also the offshore supply base. Supply boats will therefore dock frequently to pick up supplies for the offshore platform and to sometimes bring the crew ashore during crew changes. Crew changes will, however, usually be handled by helicopter.

(3) Two to three times per week, a tanker will dock at the terminal. It will take 24 hours to unload its cargo of oil. Fishing in the tanker shipping lanes and near the terminal will not be allowed.

(4) Fishing will not be permitted within a 10 mile radius of the production system 300 km offshore.

Note: *Also read the article entitled; "The Hibernia Production System" included in this chapter's* text.

CAST OF CHARACTERS

Environmentalist

You are the leader of a local organization that is concerned with protecting the environment. You fear that a potential blowout or tanker accident could pollute the local beaches, kill thousands of sea birds, and damage the fishery.

High School Student

You will soon be graduating from high school and you are uncertain what you want to do after graduation. You are considering going to university, but you don't like the idea of leaving home. Ideally, you would like to find a well-paying job in your home community, but you are wary of the five year time limit on most of the jobs associated with this project. You have an older brother and sister who have both found steady work in the fish plant. They are doing reasonably well for themselves, but are always faced with the unpredictability of the fishery. Besides, you want to do something different with your life.

Hotel Owner

In anticipation of this major development, you have invested everything to build a small hotel in the community. If the project does not proceed, there is a substantial risk that you will lose everything.

Politician

You are the MHA for the area. Most of your constituents are fishermen. You want to create jobs in the area, but many of the fishermen are uneasy about the risk of oil spills and the loss of some of their traditional fishing grounds. On the other hand, unemployment in the region has been running about 30% for a number of years. This project will provide thousands of construction jobs in the area. Your political party, which is presently in power, also strongly supports proceeding with the development. This project is so large that it promises to benefit the economy of the entire province.

Construction Worker

You were raised in this community, but spent a number of years in Toronto working in the construction industry. You returned to Newfoundland 3 years ago to work on a major project in Corner Brook. Since returning, you have married your childhood sweetheart, built a house in your home town and you have a child on the way. Work has been intermittent since the project in Corner Brook finished last year, but you are reluctant to return to Toronto. You don't want to raise a family in the big city if you can help it.

Teacher

You are married and settled in this community, although you originally came from another part of the province. You have made this community your home and taken an active role in the affairs of the community. You have always encouraged your students to further their education after high school. You are pleased to see that this project will create a lot of jobs in the area, but you fear that students leaving high school will be tempted to forego their education for the quick dollars to be made from the construction jobs. You are especially concerned that most of these jobs will potentially disappear after 5 years and the students will then be unlikely to resume their education.

Local Contractor

You started your business 20 years ago when the refinery was being built. When times were good, you had a variety of equipment and employed 10 people full time. Times have been tough for the past ten years though, and you now own one backhoe, one bull dozer and one dumptruck. You employ one person on a part-time basis. If this project proceeds, it will be a major boost for you. You've already made arrangements to lease more equipment from one of the larger centers should the project proceed and have contacted your former employees.

Fish Plant Owner

You are quite concerned about the possible loss of some of the traditional fishing grounds. You depend on a steady supply of fish to keep the plant operating. You are also very concerned about the potential loss of your employees to the construction jobs. You understand that these will be high-paying jobs and there is no way you will be able to compete in terms of salaries.

Social Scientist

You are a social scientist who was born and raised in the area and who has been hired by the community council to look at the possible social consequences of the project. You realize that the population of the area has been gradually declining over the past thirty years, as most of the young people have had to leave to find jobs. Some of the communities in the area are already close to becoming ghost towns. This project has the potential to revitalize the entire area. On the other hand, you know that there will be a social cost. People in the area will be drawn away from their traditional occupations, the influx of outsiders will cause disruption, and the high salaries that are paid to the oil workers compared to those who stay with the traditional industries may cause inflation and some dissention within the community.

Fisherman

You are an inshore fisherman. You are concerned about the possible environmental consequences of an oil spill and about the loss of some of your traditional fishing grounds. You are pleased, however, to see that there will be some substantial improvements made in the dock. You have 4 children (2 boys & 2 girls). The oldest son went to Calgary three years ago to work in the oil industry. The oldest daughter is with a computer firm in Montreal. You would love to see the other two find employment in your area so that they will not have to leave as well.

Other characters you may wish to consider are;

- Shopkeeper
- Mayor
- Doctor
- Chairperson of the Local Business Association
- Police Officer
- Fishplant Worker
- Senior Citizen
- Tradesman
- The Community's Religious Leader

In each case try and visualize how the project will affect the character you are playing personally. It may even be useful to talk to the type of person you will be portraying to get his or her opinion on such a hypothetical development.

Consider the entire project and let your imagination go. There are many potential effects that have not been described above. Some of them are not obvious and may only come into play because of the uniqueness of the area in which you live. When you have weighed all the pros and cons, decide to either support or reject the project. If you are going to support the project, but have certain concerns, state those concerns and try to think of ways of dealing with your concerns. In other words, say "I believe the government should approve this project, but under the following conditions ..." If you reject the project you should also state your reasons clearly.

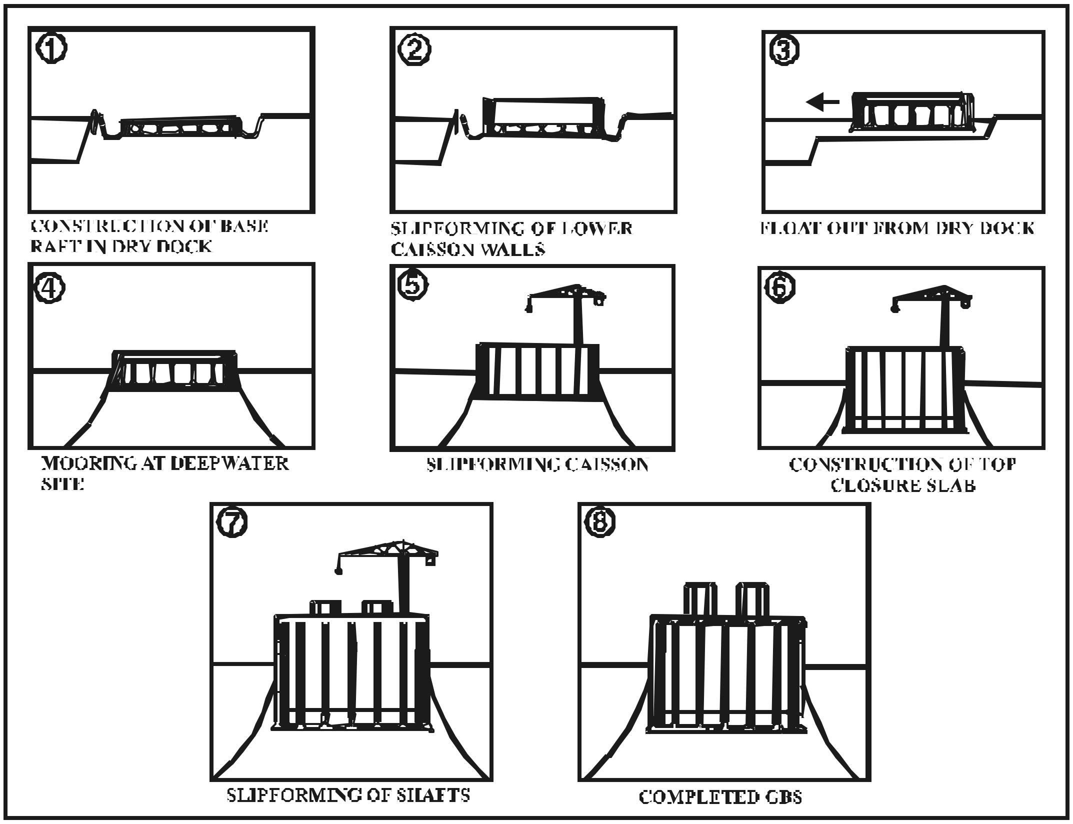

Figure 12.1 - Construction Sequence for GBS

Courtesy of Mobil Oil

The Hibernia Production System

At the time of the writing of this manual, Mobil Oil and its partners had submitted and received approval for a development plan for the Hibernia field in the Newfoundland offshore. The production system is the fixed concrete type consisting of a cylindrical base (the GBS) and topsides supported by four shafts.

Frames 1 and 2 of Figure 12.1 show how the base of the Gravity Based Structure (GBS) will be built in the drydock. When the "lower base raft" is completed, the drydock will be flooded allowing the base to be floated out to the deepwater site. Frames 4 to 8 show how the rest of the GBS will be constructed at the deepwater site using a concrete slipforming technique. The four shafts are also to be installed at the deep-water site.

The concrete to be used in the construction will be mixed in a concrete mixing facility to be constructed near the drydock. Cement from this plant will be transported to the deepwater site, possibly by barge.

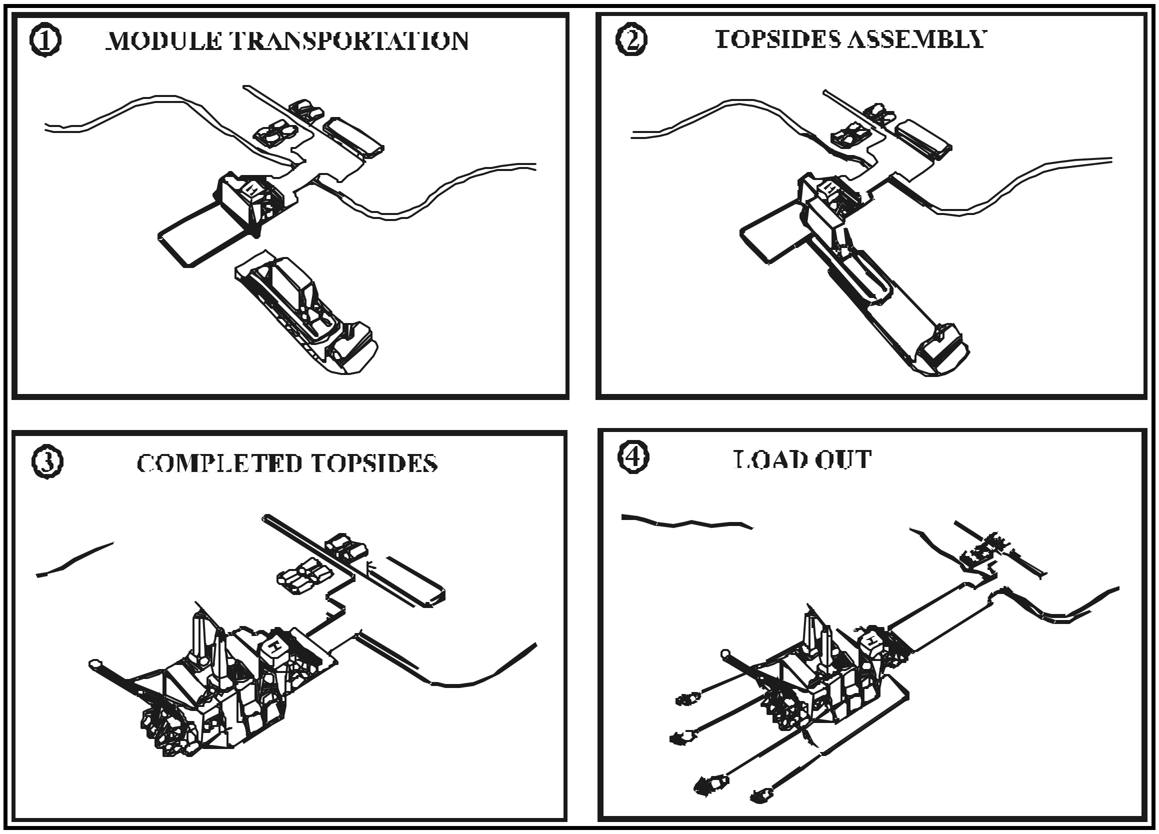

Figure 12.2 - Assembly Sequence for Topsides Facilities

Courtesy of Mobil Oil

At the same time that the GBS is being built, the modules that will be assembled to form the topsides will be constructed. These topsides modules will be brought together and assembled as shown in Figure 12.2.

Figure 12.3 shows the mating of the topsides to the GBS. The partly hollow GBS is first ballasted with water so that it sinks below the surface thus exposing only the top of the shafts above water. The topsides are then floated over the submerged GBS using a specially shaped barge. The GBS is then gradually deballasted so it rises up and connects with the topsides. The now completed production platform is then further deballasted and towed to the Hibernia field approximately 300 km offshore. At the pre-planned site on the field, the platform is ballasted again so as to submerge it to sit firmly on the seabed. The platform is now in a position to drill the required development wells and be prepared for the production phase. It will produce oil for an estimated 20 to 25 years.

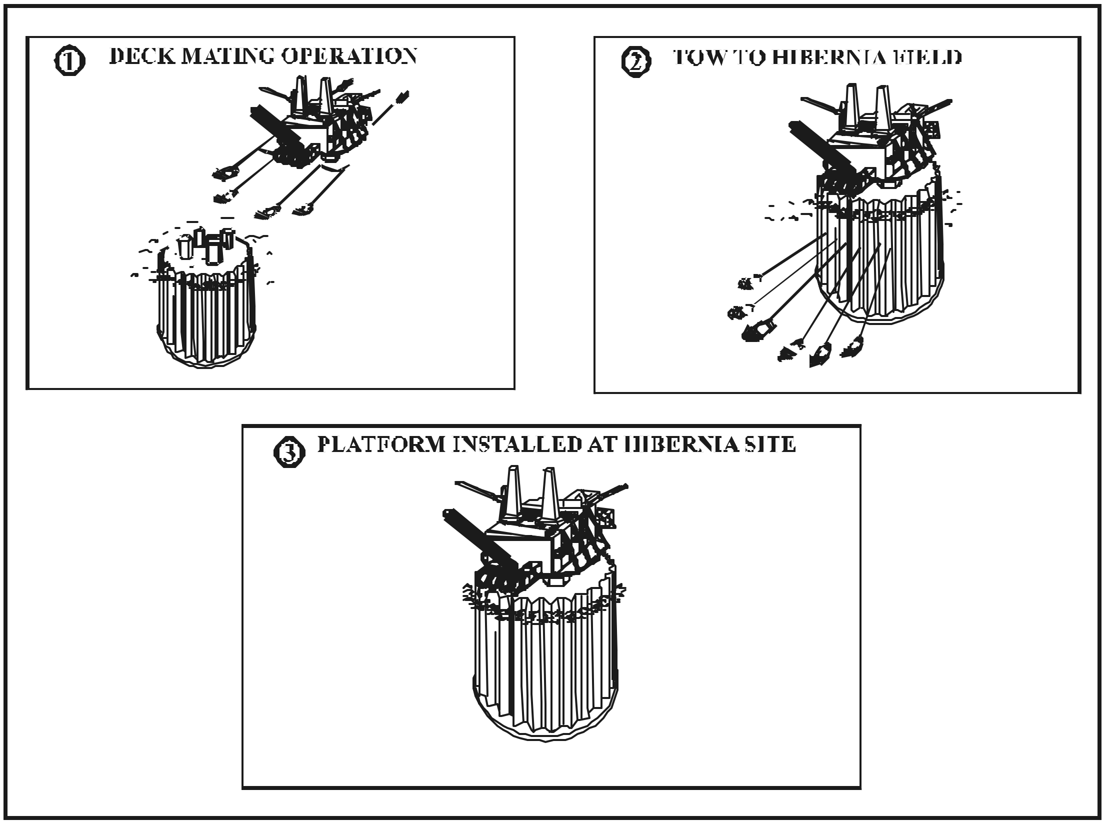

Figure 12.3 - Deck Mating and Platform Installation

Courtesy of Mobil Oil

Appendix I

Glossary

Glossary

ABANDONED WELL

A well no longer in use; a dry hole that, in most jurisdictions, must be properly plugged.

AEROMAGNETIC SURVEY

A magnetic survey, made from an aircraft.

AIR GUN

A seismic signal source which utilizes compressed air to create a sonic wave.

ANNULUS

The annular space between the drill pipe and the well bore.

ANTICLINE

A subsurface geological structure in the form of a gentle arch or an elongated dome. Historically this type of formation has been found favourable to the accumulation of oil and gas. The ideal location to find production is on the crest of the anticline; less favourable are the flanks where one may encounter less oil as well as quantities of salt water which usually underlie the oil in the reservoir.

APPRAISAL OR DELINEATION DRILLING

Wells drilled in the vicinity of a discovery or wildcat well in order to evaluate the extent and the importance of the find.

ASPHALT

A solid hydrocarbon found as a natural deposit. Crude of high asphaltic content when subjected to distillation to remove the lighter fractions such as naphtha and kerosene leave asphalt as a residue. Asphalt is dark brown or black in colour and at normal temperatures is a solid.

BARREL

A unit of measure for crude oil and oil products equal to 42 U.S. gallons (159 litres).

BASEMENT ROCK

Igneous or metamorphic rock lying below the sedimentary formations in the earth's crust. Basement rock does not contain petroleum deposits.

BASIN

(See Sedimentary Basin).

BLOWOUT

A well that comes in with such great pressure that the oil blows out of the well and up into the derrick, like a geyser. With improved drilling technology, especially the use of drilling mud to control downhole pressures, blowouts are rare today.
Out of control gas and/or oil pressure erupting from a well being drilled; a dangerous, uncontrolled eruption of gas and oil from a well; a wild well.

BLOWOUT PREVENTER

An assembly of heavy-duty valves attached to the top of the casing to control well pressure.

BONUS

The bonus is the money paid by the lessee for the granting of an oil and gas lease by the landowner.

BUNKER "C" FUEL OIL

A heavy, residual fuel oil used in ships' boilers and large heating and generating plants.

CASING

Steel pipe used in oil wells to seal off fluids from the borehole and to prevent the walls of the hole from sloughing off or caving. There may be several strings of casing in a well, one inside the other. The first casing put in a well is called surface pipe which is cemented into place and serves to shut out shallow water formations and also as a foundation or anchor for all subsequent drilling activity.

CASING SHOE

A reinforcing collar of steel screwed onto the bottom joint of casing to prevent abrasion or distortion of the casing as it forces its way past obstructions on the wall of the borehole. Casing shoes are about 3 cm thick and 25 to 40 cm long and are about 3 cm larger in diameter in order to clear a path for the casing.

CEMENT

To fix the casing firmly in the hole with cement, which is pumped through the inside of the casing and up into the annular space between the casing and the walls of the well bore.

CLASTIC ROCK

One of the categories of sedimentary rock; a so-called secondary rock which consists of particles that are fragments of pre-existing rocks. They may range in size from blocks the size of boxcars down to particles so fine as to remain in suspension almost indefinitely. The three classes of clastic sedimentary rocks are sandstone, conglomerate and shale.

COMMERCIAL WELL

A well of sufficient production that it could be expected to pay for itself in a reasonable time and yield a profit for the operator. A shallow, 50-barrel-a-day well in a readily accessible location on shore could be a commercial well whereas such a well in the North Sea or on the Grand Banks would not be considered commercial.

COMPLETE A WELL

To equip a well so that it is ready to produce oil or gas. After reaching total depth (TD) casing is run and cemented; casing is perforated opposite the producing zone, tubing is run, and control and flow valves are installed at the wellhead. Well completions vary according to the kind of well, depth, and the formation from which it is to produce.

CONDUCTOR PIPE

A well's surface pipe used to seal off near-surface water, prevent the caving or sloughing of the walls of the hole, and as a conductor of the drilling mud through loose, unconsolidated shallow layers of sand, clays, and shales.

CONTOUR LINE

A line (as on a map) connecting points that have the same elevation above or below sea level.

CONTOUR MAP

A map showing elevations by the use of contour lines. Structure contour maps are used by geologists and geophysicists to depict the "topography" of underground layers.

CROWN LANDS

Lands for which petroleum or mineral rights belong to the government. The government can then lease these petroleum or mineral rights to a company who may wish to explore for petroleum or minerals.

CRUDE OIL

Oil as it comes from the well; unrefined petroleum.

DELAY RENTAL

Money payable to the lessor by the lessee for the privilege of deferring drilling operations or the commencement of production.

DELINEATION WELL

(See Stepout Well).

DERRICK

A wooden or steel structure built over a well site to provide support for drilling equipment and a tall mast for raising and lowering drillpipe and casing; a drilling rig.

DERRICK FLOOR

The platform (usually 3 metres or more above the ground) of a derrick on which drilling operations are carried out; rig floor.

DERRICK MAN

A member of the drilling crew who works up in the derrick racking tubing or drillpipe as it is pulled from the well and unscrewed by other crew members on the derrick floor.

DEVELOPMENT

The drilling and bringing into production of wells in addition to the discovery well on a lease. The drilling of development wells may be required by the express or implied covenants of a lease.

DEVELOPMENT WELLS

Wells drilled for the purpose of producing petroleum from a proven field. Development wells are strategically located to get maximum production from the field.

DIESEL ENGINE

A four-stroke cycle internal combustion engine that operates by igniting a mixture of fuel and air by the heat of compression, and without the use of spark plugs.

DIESEL FUEL

A fuel made of the light gas-oil range of refinery products. Diesel fuel and furnace oil are virtually the same product. Self-ignition is an important property of diesel fuel, as the diesel engine has no spark plugs; the fuel is ignited by the heat of compression within the engine's cylinders.

DIESEL, RUDOLPH

The German engineer who invented the internal combustion diesel engine that bears his name.

DIRECTIONAL DRILLING

The technique of drilling at an angle from the vertical by deflecting the drill bit. Directional wells are drilled for a number of reasons: to develop an offshore lease from one drilling platform; to reach a pay zone beneath land where drilling cannot be done; eg., beneath a railroad, cemetery, a lake; and to reach the production zone of a burning well to flood the formation.

DISCOVERY WELL

An exploratory well that encounters a new and previously untapped petroleum deposit; a successful wildcat well. A discovery well may also open a new producing formation in an established field.

DISSOLVED GAS

Gas contained in solution with the crude oil in the reservoir.

DRAINAGE

The movement of oil and gas toward the well bore of a producing well.

DRAINAGE AREA

The maximum area in an oil pool or field that may be drained efficiently by one well so as to produce the maximum amount of recoverable oil or gas in such an area. A reservoir with good permeability will have a larger drainage area than one with less permeability.

DRILL BIT

The tool attached to the lower end of the drillpipe; a heavy steel "head" equipped with various types of cutting or grinding teeth, some are fixed, some turn on bearings. A hole in the bottom of the drill permits the flow of drilling mud being pumped down through the drillpipe to wash the cuttings to the surface and also cool and lubricate the bit.

DRILLER

One who operates a drilling rig; the person in charge of drilling operations and who supervises the drilling crew.

DRILLING CONTRACTOR

A person or company whose business is drilling wells. Some wells are drilled on a per foot basis, others are contracted on a day rate.

DRILLING MUD (MUD)

A special mixture of clay, water and chemical additives pumped downhole through the drillpipe and drill bit. The mud cools the rapidly rotating bit; lubricates the drillpipe as it runs in the wellbore; carries rock cuttings to the surface; and serves as a plaster to prevent the wall of the borehole from crumbling or collapsing. Drilling mud also provides the weight or hydrostatic head to prevent reservoir fluids (oil, gas or water) from entering the well bore and to counter the downhole pressures that can lead to a blowout.

<u>DRILLING PLATFORM (STEEL)</u>

An offshore structure with legs anchored to the sea bottom. The platform, built on a large-diameter pipe frame, supports the drilling of a number of wells from the location. As many as 60 wells have been drilled from one large offshore platform.

<u>DRILLING RIG (MECHANICAL)</u>

The most common type of drilling rig is the mechanical compound rig. Mechanical rigs use diesel engines coupled directly to the equipment or through compound shafts to drive the rotary, draw works, and mud pumps. Separate engine-AC generator sets provide lighting and power for auxiliary functions.

<u>DRILLPIPE</u>

Heavy, thick-walled steel pipe used in rotary drilling to turn the drill bit and to provide a conduit for the drilling mud. Joints of drill pipe are about 10 metres long are screwed together to form the drill-stem.

<u>DRILLSHIP</u>

A self-propelled vessel; a ship equipped with a derrick amid ships for drilling wells in deep water. A drillship is self-contained, carrying all of the supplies and equipment needed to drill and complete a well.

<u>DRILLSTEM (OR DRILLSTRING)</u>

The drillpipe. In rotary drilling, the bit is attached to the drillstem or drill column which rotates to "dig" the hole.

<u>DRILLSTEM TEST (DST)</u>

A method of obtaining a sample of fluid from a formation using a "formation-tester tool" attached to the drillstem. The tool consists of a packer to isolate the section to be tested and a chamber to collect a sample of fluid. If the formation pressure is sufficient, fluid flows into the tester and up the drillpipe to the surface.

The DST is used to determine if any oil or gas is present, the reservoir pressure and the possible flow rate of the well. This information is critical in determining if the well will be a commercial discovery or a dry hole.

<u>DRY HOLE</u>

An unsuccessful well; a well drilled to a certain depth without finding petroleum in commercial quantities; a "duster".

DYNAMIC POSITIONING

A method of keeping a drillship or semisubmersible drilling platform on target, over the hole during drilling operations where the water is too deep for the use of anchors. This is accomplished by the use of thrusters activated by underwater sensing devices that signal when the vessel has moved slightly off its drilling station.

EXPLORATION ACTIVITIES

The search for oil and gas. Exploration activities include aerial surveying, geological studies, geophysical surveying, coring, and the drilling of wildcat wells.

EXPLORATION VESSEL (SEISMIC VESSEL)

A seagoing, sophisticated research ship equipped with seismic, gravity, and magnetic systems for gathering data on undersea geologic structures. On the more advanced vessels of this type there are onboard processing and interpretation capabilities for the information gathered as the vessel cruises the oceans of the world.

FAULT

A fracture in the earth's crust accompanied by a shifting of one side of the fracture with respect to the other side.

FIELD

The area encompassing a group of producing oil and gas wells; a petroleum pool. An oil field may include one or more petroleum pools, and have wells producing from several different formations at different depths. A roughly contiguous grouping of wells in an identified area.

FOSSIL FUEL

Includes oil, natural gas and coal. Fossil fuels are formed in sedimentary beds from the remains of plants and animals that lived millions of years ago.

FREEHOLD LAND

Land for which the petroleum or mineral rights are owned by a person rather than the government. The owner of the land then has the right to lease such petroleum or mineral rights to a company who may wish to explore for petroleum or minerals.

GAS

(See Natural Gas).

GASOLINE

A volatile flammable liquid hydrocarbon mixture used as a fuel for internal combustion engines.

GATHERING SYSTEM

A system of pipelines within an oilfield that collects oil from the different wells and brings it to a central location where it can be treated to remove impurities.

GEOLOGICAL STRUCTURE

Layers of sedimentary rocks which have been displaced from their normal horizontal position by the forces of nature. Folding, fracturing, and faulting are geological processes that often form structural traps that are logical places to look for accumulations of oil and gas.

GEOLOGIST

A person trained in the study of the earth's crust. A petroleum geologist, in contrast to a hard-rock or mining geologist, is primarily concerned with sedimentary rocks where most of the world's oil has been found. In general, the work of a petroleum geologist consists of searching for structural traps favourable to the accumulation of oil and gas. In addition to deciding on locations to drill, he or she may supervise the drilling, particularly with regard to coring, logging, and running tests.

GEOLOGY

The science that deals with the history of the earth by studying the evidence preserved in rocks.

GEOPHONES

Sensitive sound-detecting instruments used in conducting seismic surveys. A series of geophones are placed along the ground to detect and transmit, to an amplifier-recording system, the reflected sound waves created by explosions set off in the course of seismic exploration work.

GEOPHYSICIST

A person who applies geophysical methods to the study of the earth. A specialist in geophysics.

GEOPHYSICS

The application of certain familiar physical principles - magnetic attraction, gravitational pull, speed of sound waves, the behaviour of electric currents - to the science of geology.

GRAVIMETER (GRAVITY METER)

A geophysical instrument used to measure the minute variations in the earth's gravitational pull at different locations. To the geophysicist, these variations indicate certain facts about subsurface formations.

GRAVITY BASE STRUCTURE

An offshore drilling and production platform made of concrete and of such tremendous weight that it is held securely on the ocean bottom without the need for piling or anchors.

GRAVITY MAP

The results of a gravity survey contoured and displayed on a map.

HYDROCARBONS

Organic chemical compounds of hydrogen and carbon atoms. There are a vast number of these compounds and they form the basis of all petroleum products. They may exist as gases, liquids, or solids. An example of each is methane, hexane, and asphalt.

HYDROPHONES

Sound-detecting instruments used in underwater seismic exploration activities. Hydrophones are attached to a cable towed by the seismic vessel. Sound waves generated by blasts from an airgun reflect from formations below the sea bottom and are picked up by the hydrophones and transmitted to the mother ship.

IGNEOUS ROCK

Rocks that have solidified from a molten state. Those rocks that have reached the surface while still molten are called lavas; they can form volcanic cones or spread out in flows or sheets, they can be forcibly thrust up between beds of other kinds of rocks in what are called sills, or they can fill crevices and then solidify as "dikes." Rocks that have solidified deep beneath the earth's crust are referred to as plutonic, from the Greek god of the lower regions, Pluto. Granite is an example of plutonic rock.

INTERNAL-COMBUSTION ENGINE

A heat engine in which the combustion which generates the heat takes place inside the engine itself instead of in a furnace. Examples are the gasoline or diesel-powered engines used in automobiles.

JACKUP RIG

A barge-like, floating platform with legs at each corner that can be lowered to the sea bottom to raise or "jack up" the platform above the water. Towed to a location offshore, the legs of the jack-up rig are in a raised position, sticking up high above the platform. When on location, the legs are run down hydraulically or by individual electric motors.

JET FUEL

A specially refined grade of kerosene used in jet propulsion engines.

LANDMAN

A person whose primary duties are managing an oil company's relations with its landowners. Such duties include securing of oil and gas leases, lease amendments, and other agreements.

LEASE

The legal instrument by which a leasehold is created. A contract that, for a stipulated sum, conveys to an operator the right to drill for oil or gas. The petroleum lease is not be confused with the usual lease of land or a building. The interests created by a petroleum lease are quite different from a realty lease.

MARINE RISER SYSTEM

A string of specially designed steel pipes that extends down from a drillship or floating platform to the subsea wellhead. Marine risers are used to provide a return fluid-flow conductor between the well bore and the drill vessel and to guide the drillstring to the wellhead on the ocean floor. The riser is made up of several sections including flexible joints and a telescoping joint to absorb the vertical motion of the ship caused by wave action.

METAMORPHIC ROCK

Rocks formed by the metamorphosis of other rocks. When either igneous or sedimentary rocks are subjected to enough heat, pressure, and chemical action, their character and appearance are changed. These factors act to cause recrystallization of the minerals of the rock. Granites may become gneisses or schists; sandstones become quartzites; shales become slates; limestone becomes marble.

MUD

(See Drilling Mud)

MUD HOSE

The flexible, steel-reinforced, rubber hose connecting the mud pump with the swivel and kelly joint on a drilling rig. Mud is pumped through the mud hose to the swivel and down through the kelly joint and drillpipe to the bottom of the well.

MUD PITS

Excavations near the rig into which drilling mud is circulated. Mud pumps withdraw the mud from one end of a pit as the circulated mud, bearing rock chips from the borehole, flows in at the other end. As the mud moves to the suction line, the cuttings drop out leaving the mud "clean" and ready for another trip to the bottom of the borehole.

MUD PUMP

A large, reciprocating pump that circulates drilling mud in rotary drilling. The duplex (two-cylinder) or triplex (three-cylinder) pump draws mud from the suction mud pit and pumps the slurry downhole through the drillpipe and bit and back up the borehole to the mud settling pits. After the rock cuttings drop out in the settling pit, the clean mud gravitates into the suction pit where it is picked up by the pump's suction line. In rotary drilling there are at least two mud pumps, sometimes more. In case of a breakdown or other necessary stoppages, another pump can be immediately put on line.

MUD TANKS

Portable metal tanks to hold drilling mud. Mud tanks are used where it is impractical to dig mud pits at the well site (as in the case of offshore drilling).

NATURAL GAS

Gaseous forms of petroleum consisting of mixtures of hydrocarbon gases and vapours, the more important of which are methane, ethane, propane and butane; gas produced from a gas well.

OIL

Crude petroleum and other hydrocarbons produced at the wellhead in liquid form.

OIL SPILL

A mishap that permits oil to escape from a tank, an offshore well, an oil tanker, or a pipeline. Oil spill has come to mean oil on a body of water where even small amounts of oil spread and become highly visible.

OIL-SPILL BOOM

Any of various devices or contraptions to contain and prevent the further spread of oil spilled on water until it can be picked up. A curtain-like device deployed around or across the path of a drifting oil spill. The curtain is weighted on the bottom edge to hold it a foot to two below the surface and has floats on the upper edge to hold the curtain a foot or more above the surface. Once surrounded, the oil is sucked up by a vacuum cleaner-like suction pump.

OPEN HOLE

An uncased well bore; the section of the well bore below the casing; a well in which there is no protective string of pipe.

ORGANIZATION OF PETROLEUM EXPORTING COUNTRIES (OPEC)

Oil producing and exporting countries in the Middle East, Africa, and South America that have organized for the purpose of negotiating with oil companies on matters of oil production, prices and future concession rights.

OUTCROP

A subsurface rock layer or formation that, owing to geological conditions, appears on the surface in certain locations. That part of a strata of rock that comes to the surface.

PERMEABILITY

A measure of the resistance offered by rock to the movement of fluids through it. Permeability is one of the important properties of sedimentary rock containing petroleum deposits. The oil contained in the pores of the rock cannot flow into the well bore if the rock in the formation lacks sufficient permeability.

PETROLEUM

In its broadest sense, the term embraces the whole spectrum of hydrocarbons - gaseous, liquid, and solid. In the popular sense, petroleum means crude oil.

POROSITY

The state or quality of being porous; the volume of the pore space expressed as a percent of the total volume of the rock mass; an important property of oil-bearing formations. Good porosity indicates an ability to hold large amounts of oil in the rock. And with good permeability, the quality of a rock that allows liquids to flow through it readily, a well penetrating the formation should be a good producer.

PRECIPITATE

A substance separated from a solution by chemical or physical change such as a change in temperature or salinity. Examples of precipitate rocks are salt, limestone and gypsum.

PRESSURE MAINTENANCE PROGRAM

A program whereby fluids or gases are injected into a reservoir to maintain the pressure required to keep the petroleum flowing to the surface.

PRODUCTION PLATFORM

An offshore structure built for the purpose of providing a central receiving point for oil produced in an area of the offshore. The production platform supports receiving tanks, treaters, separators, and pumping units for moving the oil to shore through a submarine pipeline or by shuttle tanker.

RECONNAISSANCE SURVEY

A general survey of an area to ascertain its main features, usually preliminary to a more detailed survey.

RESERVOIR

A porous, permeable sedimentary rock formation containing quantities of oil and/or natural gas overlain by a layer of less permeable or impervious rock.

RESERVOIR ROCKS

Sandstone, limestone, and other porous, permeable rock formations in which petroleum has accumulated.

ROUGHNECKS

Members of the drilling crew; the driller's assistants who work on the derrick floor, up in the derrick racking pipe, tend the drilling engines and mud pumps, and operate the pipe tongs when unscrewing the sections of drillpipe.

ROUSTABOUT

An oil rig worker who works on a lease or around the drilling rig doing manual labour.

ROYALTY

A share of the minerals (oil and gas) produced from a property belonging to the owner of the property. Originally, the "royalty" was the percentage of the gold or silver taken from the realm that belonged to the king or queen. Today, the "sovereign" is the landowner who traditionally receives 12.5 percent or one-eighth of the oil and gas produced from his or her land. Although 12.5 percent has been the traditional royalty on oil and gas lease, this varies widely today. In very profitable areas, the royalty may be much higher. In marginally profitable areas, it may be much lower and in some cases there may be zero royalty.

SAMPLE

Cuttings of a rock formation broken up by the drill bit and brought to the surface by the drilling mud. Rock samples are collected from the shale shaker and examined by the geologist to identify the formation and the type of rock being drilled.

SCOUT

A person hired by a company to seek out information about the exploration activities of other companies, including the location of geophysical surveys and the results of wells being drilled.

SEDIMENTARY BASIN

An extensive area (often covering thousands of square kilometres) where substantial amounts of sedimentary rocks are present. Most sedimentary basins are geologically depressed areas (shaped like a basin). The sediment is thickest in the middle and tends to thin out at the edges. There are many kinds of such basins, but it is in these areas that all the oil produced throughout the world has been found.

SEDIMENTARY ROCK

Rock formed by the laying down of sediment by seas, streams, or lakes; sediment (mineral fragments, animal matter) deposited in bodies of water through geologic ages. Limestone, sandstone, shale and salt are examples of sedimentary rock.

SEISMIC SECTION

A plot or display of data acquired during a seismic survey with surface locations plotted horizontally and reflections from subsurface layers displayed vertically (See Figure 6.6).

SEISMIC SURVEY

The investigation of underground rock layers by analyzing shock waves artificially produced at the surface and reflected from the subsurface layers of rock.

SEMI-SUBMERSIBLE

A large floating drilling platform with a buoyant substructure; part of which is beneath the surface of the water. Semi-submersibles are virtually self-contained, carrying on their main and lower decks all supplies and personnel for drilling and completing wells in hundreds of metres of water at great distances from shore. Some of these huge platforms are self-propelled and are capable of moving at 6 to 8 knots. As they often drill in waters too deep for conventional chain and cable anchors, they sometimes maintain their position over the borehole by the use of propellers or thrusters, controlled by onboard computers.

SEPARATOR

A pressure vessel (either horizontal or vertical) used for the purpose of separating well fluids into gaseous and liquid components. Separators segregate oil, gas, and water with the aid, at times, of chemical treatment and the application of heat.

SET CASING

To cement casing in the hole. The cement is pumped downhole to the bottom of the well and forced up a certain distance into the annular space between casing and rock wall of the drillhole. It is then allowed to harden, thus sealing off upper formations that may contain water. The decision to set production casing is an indication that the operator believes the well is a commercial discovery.

SHOT HOLE

A small-diameter hole typically of 10 to 30 metres depth, usually drilled with a portable, truck-mounted drill, for "planting" explosive charges in seismic operations.

SOURCE ROCKS

Those sedimentary layers that contain the organic material that has been transformed into hydrocarbons by heat, pressure, and time.

STEP-OUT WELL

A well drilled adjacent to a proven well but located in an unproven area; a well located a "step out" from proven territory in an effort to determine the boundaries of a producing formation.

STRATIGRAPHIC TRAP

A type of reservoir capable of holding oil or gas, formed by a change in the characteristics of the formation - loss of porosity and permeability, or a break in its continuity - which forms the trap or reservoir.

STRUCTURAL TRAP

A type of reservoir containing oil and/or gas formed by movements of the earth's crust which seal off the oil and gas accumulation in the reservoir forming a trap. Anticlines, salt domes, and faulting of different kinds form structural traps.

SUBSIDENCE

The process whereby the earth's crust buckles downward under the weight of sedimentary layers being deposited in the area.

SURFACE SEEP

A location where petroleum is seeping out of rocks at the surface.

TAR PIT

An area where a significant amount of petroleum has seeped out of the surface rocks and collected in a depression or pit. The lighter, more liquid fractions would have evaporated leaving a heavy tarry deposit.

THRUSTER

A propeller used in manoeuvring a ship.

TOOL PUSHER

A supervisor of drilling operations in the field. A tool pusher may have one drilling well or several under his or her direct supervision. Drillers are directed in their work by the tool pusher.

TOPOGRAPHIC MAP

A map which shows in detail the physical features of an area of land, including rivers, lakes, streams, roads, and the elevation of those features.

TRAP

A type of geological structure that retards the free migration of petroleum and concentrates the petroleum in a limited space. A mass of porous, permeable rock which is sealed on top and down both flanks by nonporous, impermeable rock thus forming a trap.

WELL

A hole drilled or bored into the earth, usually cased with metal pipe, for the purpose of discovering or producing gas or oil. Also, a hole for the injection under pressure of water or gas into a subsurface rock formation for the purpose of maintaining the necessary reservoir pressure to keep the petroleum flowing to the surface.

WELL COMPLETION

The work of preparing a newly drilled well for production. This is a costly procedure and includes setting and cementing the casing, perforating the casing, running production tubing, hanging the control valves, connecting the flow lines, and erecting storage tanks.

WELL SPACING GRID

A plan showing the best locations for the drilling of wells into a field with regard to getting maximum production for minimum cost.

WILDCAT WELL

A well drilled in an unproved area, far from a producing well; an exploratory well in the truest sense of the word; a well drilled out "where the wildcats prowl and the hoot owls mate with the chickens".