CHAPTER 1

The Origin of Oil

This chapter is the foundation for understanding how oil and gas accumulations occur and what factors are involved in their discovery and development. A case history shows how analysis of oil and gas accumulations helps oil companies discover billion dollar assets.

Jurassic

If one looks at an outcrop or a core of the earth's formations, it's easy to see the natural beauty of differing rock types and deposited sedimentary layers. In the exploration for oil and gas, geologists or 'rock-doctors' often focus on 'ancient river deposits' or 'ancient marine reefs'. This refers to nature's legacy dating back through a geological timeline to when the continents were joined together in a single land mass known as Pangaea. Many sedimentary depositions and reservoir structures originated prior to continental drift when Pangaea was broken into separate land masses that form the continents we know today; for example, the western coastline of Africa and the eastern coastline of South America fit perfectly together. This explains the similarities found in oil and gas reservoirs in both areas today. Many millions of years ago, for instance, in the Jurassic and Cretaceous ages, eroded rocks, minerals and dead organic matter combined to form 'sediment' which was washed out onto seabeds. Imagine ancient heavy rainstorms at the top of a hill creating rainwater channels that collect sediment—minute particles of rock, earth and other debris—and deposit it into rivers which finally run to the sea[1].

Mapping Seabeds

Bathymetry, the science of mapping seabeds, can show the connection of islands to land masses and the influence of ancient river systems in carrying sediment stream to what were once marine areas or those that are underwater today. Currents and waves spread sediment over many miles with larger heavier grains staying close to the river mouth, while lighter smaller grains are deposited further away. Combined with the dips, basins and platforms on the seabed, depositional patterns and dunes are created with certain areas accumulating massive organically-rich deposits of what was once marine life. It is for these reasons that marine sedimentary rocks interest rock-doctors (see Figure 1 below).

These sediments are often linked to river systems, either existing or ancient. This is the reason why so much exploration is concentrated in the various offshore gulfs worldwide. Almost all of the easily accessed inland and deltaic reservoirs have been discovered[2].

Wind can also erode, transport and deposit rock particles and debris. Wind is particularly effective in arid areas and where there is a large supply of unconsolidated sediments. Although water is much more powerful, Aeolian or wind-based processes

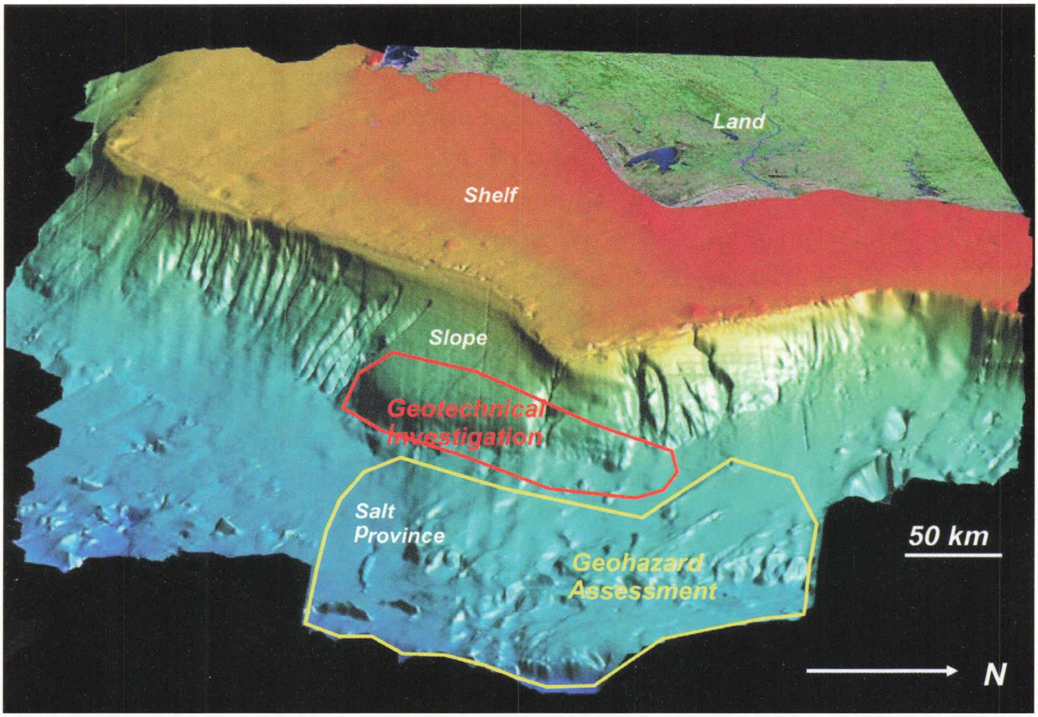


Figure 1 - Seafloor Under Investigation Offshore Brazil (Petrobras)

are important in deserts where they can form vast sand dunes. Aeolian deposition occurs once a sand dune becomes compacted and hardened forming a consolidated sandstone. In the southern part of the Arabian Peninsula, a region called the Empty Quarter (Rub-al-Khali) because of its lack of life, vast dunes can be found that routinely reach 93 miles (150 km) in length and 1,000 feet (300m) in height (see Figure 2 below).

Plate Tectonics

The earth's surface and seabed is made up of two layers: the lithosphere and the asthenosphere. The lithosphere is the upper layer and it is quite rigid. It is broken up into numerous distinct tectonic plates (see Figure 3 overleaf) which are moving, and this is exemplified by continental drift and seafloor spreading. Although solid, the lower layer or asthenosphere is considered to behave as a fluid over geological time. It is this fluidity that permits the movement of the tectonic plates in all directions creating earthquakes, volcanoes, mountains, and oceanic trenches along plate boundaries.

Figure 2 - Exploratory Rig in the Empty Quarter, Saudi Arabia (Saudi Aramco)

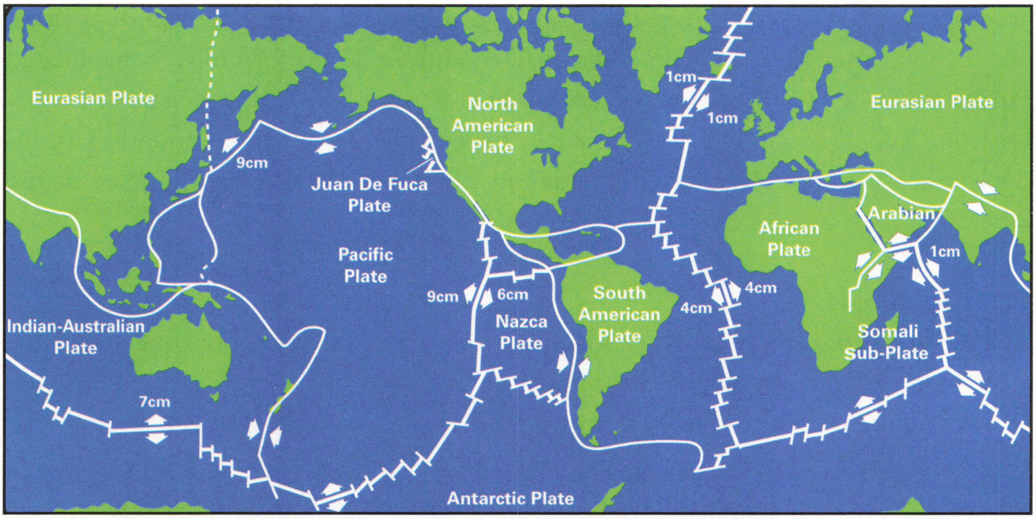


Figure 3 - Image of Tectonic Plates (Courtesy of British Geological Survey)

Deposits

Over geological time, ancient river systems carried and deposited millions of tonnes of sediment as they ran their courses to river outlets, deltas or gulfs. In order for sediment to be deposited, a low-lying area called a basin is required. The largest basins are the ocean basins, which currently cover about 70% of the earth's surface. In the past, however, the sea level often changed and the continents were covered by shallow seas (referred to as epiric or epicontinental seas). When sea levels rise to invade the continents, this is referred to as a transgression. Major transgressions occurred during the Cretaceous era, and from the early Cambrian through Mississippian eras. Plate tectonic movements create basins, and even the large transgressions appear to be related to tectonic factors, as increased spreading of ocean basins changes their configuration and leads to flooding of the continents[3].

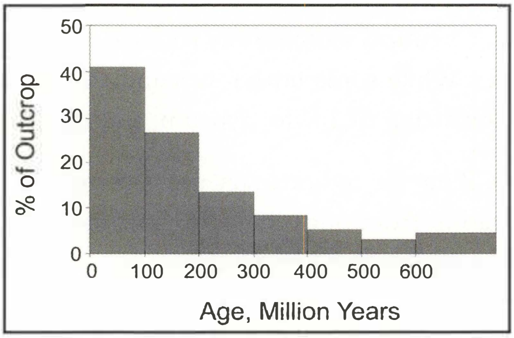
Layers of Earth

Over time, continuing deposits eventually formed numerous layers of sedimentary rock. These were pushed deeper and deeper under the seabed. Each successive layer (younger deposits) increased the pressure on earlier layers (older deposits) and tectonic plate movement deformed the layers creating folds, hills (anticlines) valleys (synclines), unconformities (eroded areas) and faults[4].

The Occurrence of Sedimentary Rocks

Sedimentary rocks have an average thickness of about 6,000 ft (1,800 m) on the continents. This thickness is quite variable; for example, some areas such as the Canadian Shield, have no sedimentary rock cover, while other areas such as the Louisiana and Texas Gulf coasts, have more than 65,600 ft (20,000 m) of sedimentary rock cover. Generally, about 66% of all continental areas have a cover of sedimentary rocks.

The graph opposite illustrates that as sediment gets buried it avoids further erosion; hence, older sedimentary rocks show less exposed outcrop area than younger sedimentary rocks. More than 40% of the exposed sedimentary rocks are younger than Cretaceous in age.



Name of Particle	Size Range	Scale	Loose Sediment	Consolidated Rock
Boulder	>256 mm	<-8	Gravel	Conglomerate or Breccia (depends on rounding)
Cobble	64 - 256 mm	-6 to -8		
Pebble	4 - 64 mm	-2 to -6		
Granule	2 - 4 mm	-1 to -2		
Very Coarse Sand	1 - 2 mm	0 to -1	Sand	Sandstone
Coarse Sand	0.5 - 1 mm	1 to 0		
Medium Sand	0.25 - 0.5 mm	2 to 1		
Fine Sand	0.125 - 0.25 mm	3 to 2		
Very Fine Sand	0.0625 - 0.125 mm	4 to 3		
Coarse Silt	0.031 - 0.625 mm	5 to 4	Silt	Siltstone
Medium Silt	0.016 - 0.031 mm	6 to 5		
Fine Silt	0.008 - 0.016 mm	7 to 6		
Very Fine Silt	0.004 - 0.008 mm	8 to 7		
Clay	<0.004 mm	>8	Clay	Claystone, Mudstone, Shale

Table 1 - Grain Sizes Table (After Prof. Stephen A. Nelson)

Types of Sedimentary Rocks

Table 1 (page 21) shows typical rock grain sizes. There are three basic types of sedimentary rocks:

1. Siliclastic sedimentary rocks are formed by the accumulation of mostly silicate mineral fragments. These include most sandstones, mud rocks, conglomerates, and breccias.

2. Chemical sedimentary rocks are formed by direct chemical precipitation from water. While some limestones and cherts may form in this manner, evaporite deposits consisting of halite, gypsum, and other salts are the most common.

3. Biogenic sedimentary rocks consist of fragments of particles produced by precipitation from once-living organisms. Most of these rocks are limestones and cherts.

95% of all sedimentary rocks consist of sandstones (made up of sand-sized fragments), mudrocks (made up of silt and clay-sized fragments) and carbonate rocks (made up of mostly calcite, aragonite, or dolomite). Mudrocks constitute 65% of sedimentary rocks, while sandstones make up 20% to 25% and carbonate rocks 10% to 15%.

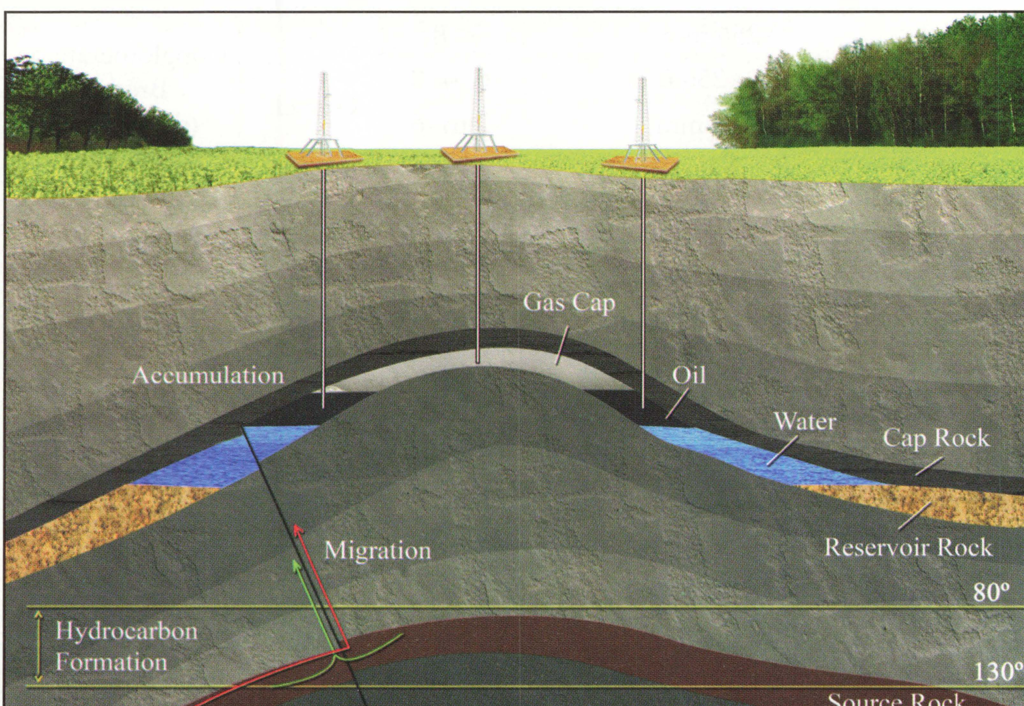


Figure 4 - The 'Window' for the Formation of Oil and Gas

Carbonate rocks largely consist of two types of rocks:

1. Limestones which are composed mostly of calcite ($CaCO_3$) or high magnesium calcite [$(Ca, Mg)CO_3$], and

2. Dolostones which are composed mostly of dolomite [$Ca\,Mg(CO_3)_2$]

Because carbonate minerals in general are soluble in slightly acidic waters, they often have high porosity and permeability, making them ideal reservoirs for petroleum. It is for this reason they are well studied[5].

Limestone can easily be recognised in hand specimens or outcrops because of its high solubility in hydrochloric acid (HCl). A drop of acid placed on the rock will cause it to fizz due to the generation of carbon dioxide (CO_2) gas. A dolostone, on the other hand, will not fizz until a fine powder is made from the rock or mineral.

Source Rock

For oil and gas to form, the deposits of organic matter must be converted to hydrocarbon compounds. A 'window' or specific set of conditions is required for the formation of oil and gas (see Figure 4 opposite). Even today, the formation of oil and gas as a process is not fully understood but the prevalent theory is that time, pressure and heat convert decomposed marine life into elemental hydrocarbons. Within a given rock structure, the younger deposits or later layers form 'overburden' pressure conditions. Additionally, each layer has a given temperature profile according to the True Vertical Depth (TVD) at which it is located. The general rule is: the greater the depth, the higher the temperature. These factors combine to form oil and gas deposits in certain rocks known as 'source-rock', which can often be seen in certain oil and gas provinces in outcrops[6].

Migration

From their origins deep within the source beds, hydrocarbon molecules are squeezed by immense pressures caused by the overlying sediments similar to water from a sponge. They migrate to water-saturated porous and permeable beds where, being lighter than water, they start to rise. As they rise, they contact other hydrocarbon molecules and coalesce into droplets that keep rising until they encounter an impermeable layer called a cap rock. There, they accumulate, forming a reservoir.

Occasionally, the hydrocarbon makes it all the way to the surface without being trapped, forming a natural seep. It has been suggested that Christopher Columbus had moored off Trinidad to re-coat boats with pitch from La Brea (see Figure below). The discovery well drilled by Colonel Drake in Titusville, Pennsylvania, US in 1859 was said to have been encouraged by a seep the Indians pointed out to the Colonel. The natives had been using the oil as pitch to waterproof their canoes and dwellings. Much of the tar blobs found on beaches have surfaced from natural subsea seeps.

Cap Rock

For oil and gas to accumulate, and to prevent it from subsequently dispersing, a trap is required. Usually, this is an impermeable layer known as 'cap rock' that seals off oil and gas deposits ensuring that the oil and gas remains in place, until it is tapped by the drill bit, or subjected to other geological forces.

Climate changes, weathering, glaciers, volcanic eruptions, river flooding and other natural forces can change or erode surface rocks. Consequently, the depths, thickness and tilt of the layers vary from place to place. Buried layers of salt, created by the evaporation of seas and lakes, can be squeezed by pressure loads or made to flow with heat. Due to its relatively low density compared to other rocks, salt will flow and rise, often forming domes and distorting the overlying layers. Tectonic forces over time can cause upheavals that result in the rock folding, fracturing or faulting. These subsurface movements and changes can create or destroy traps, which, when combined with factors such as timing, temperature and pressure, will determine the existence of hydrocarbon reservoirs[7].

Figure 5 - Pitch Lake at La Brea, Trinidad and Tobago (EPRasheed)

Cap rock may be many layers higher than the original source rock, as oil and gas will always seek to leak or migrate upward unless it is stopped. Cap rock also plays a fundamental part in maintaining reservoir pressure.

Pitch Lakes

Pitch lakes are an instructive example of both reservoir pressure and the tendency of oil and gas to 'leak' to the surface of the earth. In this case, a dense heavy bituminous form of oil which is chemically attracted to minerals such as clay has 'flowed' to the surface in channels. Pitch lakes, tar sands or oil and gas seeps, were well known to ancient man who used the oil for a variety of uses from medicine to basic lighting. The term 'snake oil salesman' arose from the early pioneers who attributed healing powers to the 'surface oil'.

Driving Force

Underground pressure is the primary mechanism that drives oil and gas to flow to surface. The pressure of hydrocarbon reservoirs, prior to being tapped by the drill-bit, is similar to that of an unopened bottle containing a fizzy drink. If you shake the bottle and immediately open it, due to the built-up pressure, a certain volume of liquid will be driven to the bottle top and spill-over. Known as a depletion drive, this is similar to the natural pressure of an oil or gas reservoir and can be exemplified by what were historically known as 'gushers'. For decades now, reservoir pressures are carefully controlled for health, safety and environmental reasons and not least due to the value of the oil. Primary pressure, however, cannot be maintained indefinitely. Depending on the rate of depletion, the reservoir's pressure will drop, requiring secondary means of production[8]. It is always the case that producing fields see a reduction in the natural pressure or 'fizz' that drives hydrocarbons to the surface.

However, other drive systems exist also. These range from water drive which is by far the most common and prolific, the combined water drive with an expanding gas cap and the gravity drive. The depletion drive is very short-lived whereas water drives can be near infinite.

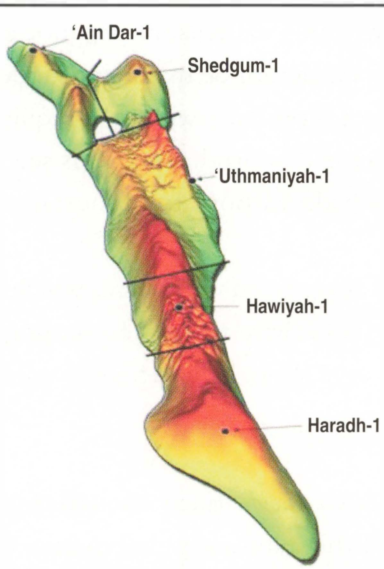
The drive systems are detailed in *Chapter 9: Mature Fields*. Each one affects the production of oil and gas in a different way and this ultimately determines reservoir recovery factors.

Porosity and Permeability

Although people may perceive that there are large underground lakes or caverns of hydrocarbons, this is not true. Oil and gas is stored in tiny voids, called pores, within the reservoir rock which together may extend several hundred feet horizontally or vertically; for example, the world's largest oilfield, Ghawar in Saudi Arabia, has a reservoir rock that is approximately 178 miles (280km) long[9] (see Figure 6).

The three rock classes—source, reservoir and cap—help to explain two key concepts. Firstly, the sedimentary process explains why oil and gas are contained in minute rock spaces or pores (porosity) and not in caverns. Imagine a dry sponge placed over water. The water is drawn in and contained within the voids of the sponge. This is why porosity is defined as the percentage of 'voids' in a volume of rock. Secondly, sedimentation shows the ability of a fluid to 'seep' or 'flow' through a given formation (permeability). Minute channels are created in the formations and, due to the pressurised nature of oil and gas and their relative lightness, there is always a tendency for the oil and gas to rise. This is illustrated by the migration of oil and gas from a source rock to a porous reservoir rock[10].

Permeability can be visualised by thinking of a coffee machine, and ground coffee being packed into an espresso chamber. Under pressure, hot water flows or trickles through creating coffee. The water-flow through the porous coffee grinds is due to



Ghawar helped catapult Saudi Arabia into its role as the world's leading oil producer. The super-giant field is 178 miles in length and consists of five contiguous oil fields from north to south: 'Ain Dar, Shedgum, 'Uthmaniyah, Hawiyah and Haradh.

Figure 6 - Representation of Ghawar Field (Saudi Aramco)

permeability, which is the relative interconnectivity of the pore spaces in the coffee pack. If we continue to pack in more coffee, a point is reached where the compaction (the equivalent being cementation in formation) is so great that it is progressively harder for coffee to flow through.

The ease or difficulty of 'flowability' is measured in 'millidarcies' (after Henri Darcy, a French scientist who promulgated Darcy's Law governing fluid flow through porous media in 1856).

Although porosity and permeability are key attributes of reservoirs, they are the most misunderstood concepts in reservoir engineering. Low permeability can mean that large reserves may not be produced economically, or even physically. Tight reservoirs are those that have low permeability. There are rocks (oolites) that have lots of porosity, but no permeability. Conversely, there are fractured formations that have little porosity, but flow like a fire hose because of fracture permeability. Porosity also explains why we say that not all reserves are recoverable; for all oil and gas to be recovered, we would have to extract the rock itself, and literally squeeze out every drop. Given that vertical depths of reservoirs routinely exceed 5,000 ft (1524 m) and can reach more than 25,000 ft (7620 m), it may not always be economically possible to pursue such targets[11].

Reservoir stimulation is a synthetic way to increase porosity and/or permeability. Due to their high solubility in hydrochloric acid (HCl), limestone reservoirs are often 'acidised'. The acid pumped into the reservoir etches channels which improve production. For sandstone reservoirs, specialised fluids are pumped into the formation until it literally cracks open, thereby permitting better flow.

Sands of Time

With the passage of time, the land and seas holding oil and gas accumulations became subject to territorial jurisdiction and were bid for as leases or exploratory blocks. Such blocks (see *Chapter 6: Properties, Players and Processes*) have led to the discovery of famous fields and formations such as the Austin Chalk, Brent, Ghawar and Shtokman. Commercial quantities of petroleum occur almost exclusively within sedimentary rocks (sandstones, limestones and, rarely, claystones). Some of these deposits became famous as they were associated with crude oil or gas production such as the Kimmeridge clay in the UK North Sea, the Khuff limestone in Saudi Arabia and the Jurassic sandstone of the Shtokman field in Russia.

To summarise the origin of oil:

1. Hydrocarbons are formed by decomposing organic life subjected to temperature and pressure, while sealed by a layer of impermeable rock. This leak proof seal ensures that the hydrocarbon reservoir is maintained until it is tapped by the drill bit.

2. Source rocks need to be, or have been, in the right range of depths (and hence temperature) for sufficient time for the deposits to change into oil or natural gas. A source rock has massive organic deposits.

3. Porous reservoir rocks can exist above or below the source rocks.

4. Impervious cap rocks lie above the reservoir rocks.

5. Traps are required for the hydrocarbons to accumulate.

Geological and Geophysical Mapping

Geological mapping and geophysical surveys allow oil companies to characterise acquired acreage and the age and sedimentation patterns of the rock formation contained therein. This process of characterisation can be reconstructed as a visual earth model that delineates the position and shape of the structure including anticlines, faults-stratigraphy, structure.

It is useful to distinguish between the terms 'reservoir description' and 'reservoir characterisation'. The former is the means by which the reservoir is described (using observable parameters i.e. models), while the latter explains how it will behave under production and includes petrophysical parameters.

Geophysics is the study of the earth by quantitative physical methods—principally by measuring the gravitational, magnetic, electrical and seismic-velocity properties of the earth's surface and interior. The principal objective of geophysics is exploration, i.e. searching for subterranean structures that could trap and hold hydrocarbons. Recently, geophysics has been expanded to include characterisation of reservoir drainage patterns.

Measuring differences in rock properties provides information about the distribution and the structure of rocks at surface and at a given depth, and gives a three-dimensional (3D) picture of the earth's crust. Scientists use this information to better understand the evolution and structure of the earth, thus leading to more effective exploration for hydrocarbons, water and mineral resources.

The most common types of surveys include:

- Gravity surveys
- Magnetic surveys
- Electrical surveys
- Electromagnetic surveys
- Radiometric surveys
- Seismic surveys
- Radar surveys
- Thermal imaging
- Geochemical imaging, and
- Downhole electrical and calliper surveys.

Surveys are conducted for different purposes: at regional scales to cover large areas both on the ground and from ships or aircraft and at local scales to cover specific sites such as mineral prospects on the ground, with marine or airborne instruments, or by using underground wellbores[12].

Stratigraphy
The stratigraphy of an area is obtained by measuring and describing the layers of rocks. This usually includes rock samples obtained using cores or cuttings or from outcrops (although this is becoming rarer due to the trend to deepwater and arctic areas).

Each rock sample is examined in the field and outcrop samples are taken to the lab where features are noted such as colour, grain sizes and mineral composition, fossil content, porosity and permeability. The samples are numbered and mapped so that their position in the sequence is known. They are then examined for small and large fossils by paleontologists.

In drill cuttings, only the microfossils are normally recovered since the large fossils are usually destroyed, although some may be recovered from cores. Sedimentologists will examine the samples to determine their nature and the environments in which they accumulated.

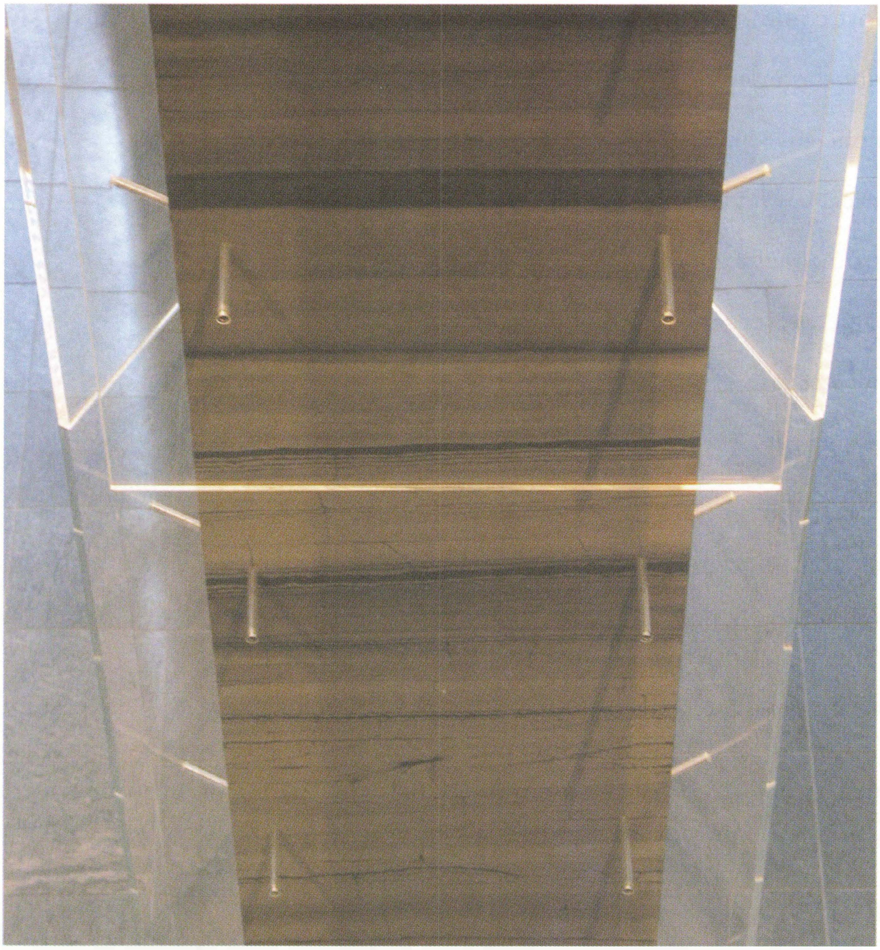


Figure 7 - A Stratigraphic Column in StatoilHydro Offices (EPRasheed)

Figure 8 - Outcrop In Bahrain Shows a Sedimentary Sequence (EPRasheed)

Geochemists will characterise changes in the organic material contained in rocks caused by time, heat and pressure. They will identify possible petroleum source rocks, assessing the burial history and hydrocarbon-bearing potential of the sediments. Geochemists also use spectroscopy logs to determine the elemental composition of the rocks, and subsequently their mineralogy. This information provides important clues as to the origin of the rocks, and enables cross-correlation with similar rocks in adjacent or 'offset' wellbores.

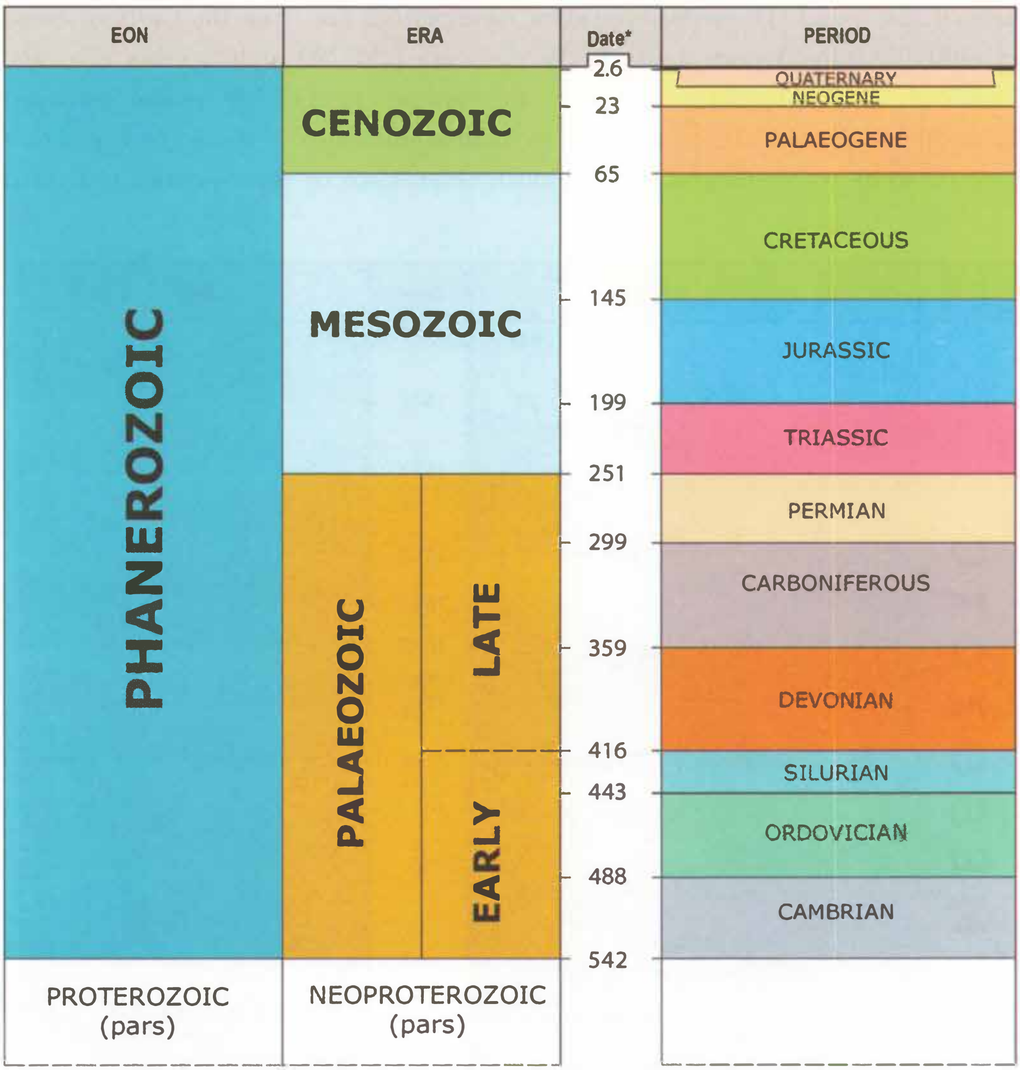


Table 2 - Stratigraphic Chart of Rock Types and Age in the United Kingdom. Courtesy of BGS (British Geological Survey)

Stratigraphy, and the study of fossils, will help determine the geological age of rocks. This in turn enables the correlation of a given formation with other areas, sections and boreholes. The stratigraphic sections are then correlated with each other for the area that is being mapped.

Stratigraphic Charts

A stratigraphic chart of the types and age of rocks can be created and is presented in Table 2 which shows the data for the UK. Different nomenclatures have been used by different geologists to describe the same age and type of rock found in other parts of the world. The most important time periods are from the Carboniferous era (299-359 million years ago), the Permian era (251-299 million years ago), the Triassic era (199-251 million years ago), the Jurassic era (145-199 million years ago [Table 3]) and the Cretaceous era (65-145 million years ago). It should be noted that there are some accumulations that are much older. Each of these periods is divided

ERA	PERIOD	EPOCH	Date*	AGE
MESOZOIC	JURASSIC	LATE	145.5	TITHONIAN
			150.8	KIMMERIDGIAN
			155.7	OXFORDIAN
		MID	161.2	CALLOVIAN
			164.7	BATHONIAN
			167.7 170	BAJOCIAN
			171.6	AALENIAN
		EARLY	175.6	TOARCIAN
			183	PLIENSBACHIAN
			189.6	SINEMURIAN
			196.5	HETTANGIAN
			199.6	

Table 3 - Mesozoic Stratigraphy of the UK. Courtesy of BGS (British Geological Survey)

distinctive sub-period epochs and then ages. The rock characteristics can also be grouped by changes in rock type. In the early Jurassic period in the Middle East, for example, the Hith, Arab, Jubaila, Diyab and Hanifa formations can be found. They can be dated by the fossils, including pollens, found in them. The depositional environments, together with the diagenesis (changes after deposition), are reflected in rock characteristics (e.g. how grain sizes or permeability change with depth)[13].

Distinctive rock types, known as facies, can be identified in the depositional layers. Changes occurring over a few metres within the reservoir provide clues as to the earth's history at that particular time and whether deposition occurred in a river delta, lagoon, seashore or desert. Each of these depositional environments creates unique properties of porosity, permeability and other reservoir characteristics which ultimately dictate hydrocarbon recovery.

Facies analysis is used by petroleum geologists to derive a model of the subsurface, i.e. a reservoir description. This model of the multilayered reservoir is essential for the reservoir engineers when designing an optimum well completion or reservoir development and production policy. For instance, major intervals are often separated by seals of impermeable anhydrite or shale[14]. 'Marker beds' chronicle major events in the evolution of the earth; for example, huge volcanic eruptions blanketed huge areas of the earth's surface with characteristic ash that can be identified in cores and correlated with similar marker beds in other wells. This provides an indisputable reference that fixes the rock's age in geologic time. Paleomagnetics studies the residual effect of magnetic polarity changes in the earth's evolution where the earth's magnetic poles swapped polarity back and forth over eons of time. By understanding these factors, wells can be constructed using techniques and know-how that have already been proven in similar formations. This saves time and money allowing oil companies to reach production faster.

Identification of Rocks

There may be considerable doubt whether rocks, which are similar in both chemical and physical nature, are of the same geological age. The doubt can only be removed, if at all, by detailed laboratory work. Initially, rocks are compared to see whether the constituent minerals are chemically and physically similar. Even if they are, the same types may be repeated during geological time and a study of the fossils (paleontology) will be essential to reduce the uncertainties. Most species of fossil organisms lived for a considerable span of geological time before becoming extinct.

The study of fossilised pollen and plant spores or 'palynology' has become an important means of correlating rocks to geological time as they are often identifiable in rocks that present no other fossil content. This is because spores and pollen remain remarkably well preserved over geological time due to their almost indestructible husks. The palaeontologist will use X-rays and electron microscopes to compare fossil assemblages rather than individual species which allows for accurate correlation of fossils within geological time-scales. The ultra-microscopic plates from the bodies of minute marine organisms have complex shapes characterised by different geological periods and allow approximate geological dating of even small rock debris. Radiometric age-dating is also used and is based on estimates of the decay of radioactive isotopes of specialised minerals in the rocks.

Rock Analysis Using Cuttings

When an area is being drilled, the rock cuttings from nearly all exploration and appraisal wells are examined. Analysis of the cuttings encompasses fossil and minerals content including clays, geochemical content and the physical appearance or description of the rock (e.g. shape and size distribution of rock grains). These elements provide important clues as to the rock's age and depositional environment.

Rock Analysis Using Petrophysical Logs

Most wells have petrophysical logs routinely taken. Petrophysical logs are measurements of various electrical, nuclear and acoustical properties recorded as a function of depth and are made with special downhole tools.

Rock Analysis Using Cores

Coring is conducted using a drill bit that employs Polycrystalline Diamond Compact (PDC) cutting elements and has a hollow centre. This allows the cutting element to obtain a core of the formation that is being drilled. Cores are fragile and require special handling and storage techniques; however, they are not readily available. They are often used as a complementary method of formation analysis and can be used to help calibrate logs and provide information for reservoir modelling. Consequently, cuttings, logs and cores are the production geologist's primary sources of data and enable them to describe the nature of the rocks that have been drilled (the stratigraphy—the sedimentary sequence in terms of lithological characteristics and rock properties)[15].

Development

Despite development data being partial, and at times unreliable, key decisions to develop a prospect and spend millions of dollars have to be reached. Several appraisal wells are drilled to determine the size of the accumulation and to test the reservoirs for production capacity and quality. At this stage, geologists must work closely with the well log analyst, the reservoir engineers and production engineers. Refinements, or even gross revisions of the original reservoir assessments, are made as new data are obtained.

To plan a development of an oil or gas field, information is needed about the structure of the oil and gas reservoir such as the:

- Shape, size, volume and connectivity of the accumulation
- Porosity, pore geometry and permeability of the rock
- Fraction of the pore space filled with hydrocarbons
- Nature of the hydrocarbons
- Cost of wells, facilities, pipelines, installations etc., and
- Health, safety and environmental matters[16].

As a result of obtaining all the appropriate data, the oil company developing the field seeks to save millions of dollars and reach production faster by knowing how many wells to drill and where best to locate them. This is precisely what happened in the exploration and drilling project in the Dnieper-Donets Basin in the Ukraine as is indicated in the case history below.

Billion Barrel Case History

Careful study of the geology of the Dnieper-Donets Basin resulted in the discovery and development of 12 petroleum fields with oil reserves equal to 1.4 billion barrels of oil equivalent, the major part of which is produced from the Precambrian crystalline basement. These fields were discovered in a narrow strip approximately 22 miles (35 km) wide and 250 miles (400 km) long near the Northern Marginal Deep Fault where the oil and gas-bearing rocks are Middle and Lower Carboniferous period sandstones and Precambrian granites, amphibolites, and schists of the crystalline basement complex. This exploration project also generated the discovery of a new gas-producing area near Kharkiv for which the proven gas in place has been calculated to be 100 billion cubic metres (Bm^3).

The oil produced from all reservoirs was analysed for correlations of trace metallic elements; for example, the ratios of nickel and vanadium, and of either methane or nitrogen were measured. The abundance of the trace metals showed a clear correlation and it was established that the oil from different reservoirs shared a common, deep source characterised by diffusive separation (regardless of the age, type or circumstance of the particular reservoir rocks).

Paleontology in Oil and Gas Discoveries

Paleontological analyses of the oil in the Permian and Carboniferous sandstone formations demonstrated the presence of spore-pollen and other microphytofossils of the Devonian and Proterozoic ages, thereby establishing upward migration from deeper formations. By examining micro-sized traces of pollen contained in the rock pores, scientists concluded that the oil migrated upwards to its present location from much older, deeper sediments.

Bacteriology in Oil and Gas

The oil produced from the reservoirs in the crystalline basement rock of the Dnieper-Donets Basin has been examined particularly closely for the presence of either porphyrin molecules or 'biological marker' molecules, the presence of which used to be misconstrued as 'evidence' of a supposed biological origin for petroleum. None of the oil contains any such molecules, even at the parts per million (ppm) level. There is also research presently under progress, which has established the presence of deep, anaerobic, hydrocarbon metabolising microbes in the oil from the wells in the uppermost petroliferous zones of the crystalline basement rock in the Dnieper-Donets Basin.

These results, taken either individually or collectively, helped optimise the drilling and production strategy within the Dnieper-Donets Basin[17,18].

Now that we understand how oil and gas is formed, it is time to ask two important questions: Are we running out of oil? And given that oil and gas reserves are miles below ground, how are they actually measured?