BHARATHIDASAN UNIVERSITY
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Programme : 6 year Integrated M.Tech in Geological Technology and Geoinformatics

Course title : Petroleum Geology
Course code : MTIGT 0701

UNIT – I
Hydrocarbon - Basic Principles

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What is oil?

We hear about it almost every day in the news. People around the world are very concerned with the rise of oil price; countries that are at war attempt to cut off the supply of oil to their enemies; countries like India, China 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 coal, iron or steel, all of which are important in our daily lives?

***Oil, petroleum, natural gas, hydrocarbon and crude oil** are terms that we commonly hear.*

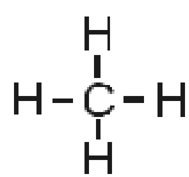
There are many kinds of oils. We have "oils" that are used for cooking. Some of these oils come from different types of plants (such as vegetable oil) and animals (cod liver oil).

*The oil we are concerned with here is derived from rocks within the earth. It is called **Petroleum**, a name taken from two Latin words ("Petra" meaning rock and "Oleum" - meaning oil).*

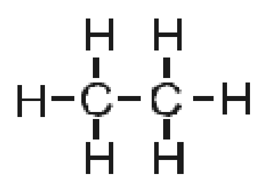
The term hydrocarbon refers to the chemical makeup of petroleum. Petroleum is a compound predominantly made up of atoms of hydrogen and carbon; thus the name hydrocarbon. though it also contains certain impurities such as Nitrogen, Sulphur and Oxygen.

These 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.

Natural gas is a mixture of hydrocarbons that are in a gaseous state at normal temperature and pressure.

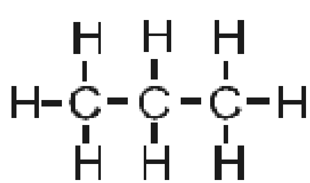


CH_4 Methane

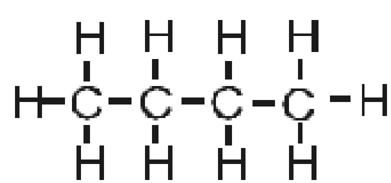


C_2H_6 Ethane

Hydrocarbon molecules



C_3H_8 Propane



C_4H_{10} Butane

Methane is the simplest hydrocarbon molecule with only one carbon (C) atom. The first four members of this hydrocarbon series (Methane to Butane) are gases under normal conditions.

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? (i.e., $C_{78}H_{?}$).

Natural gas contains mixtures of these molecules as well as certain impurities.

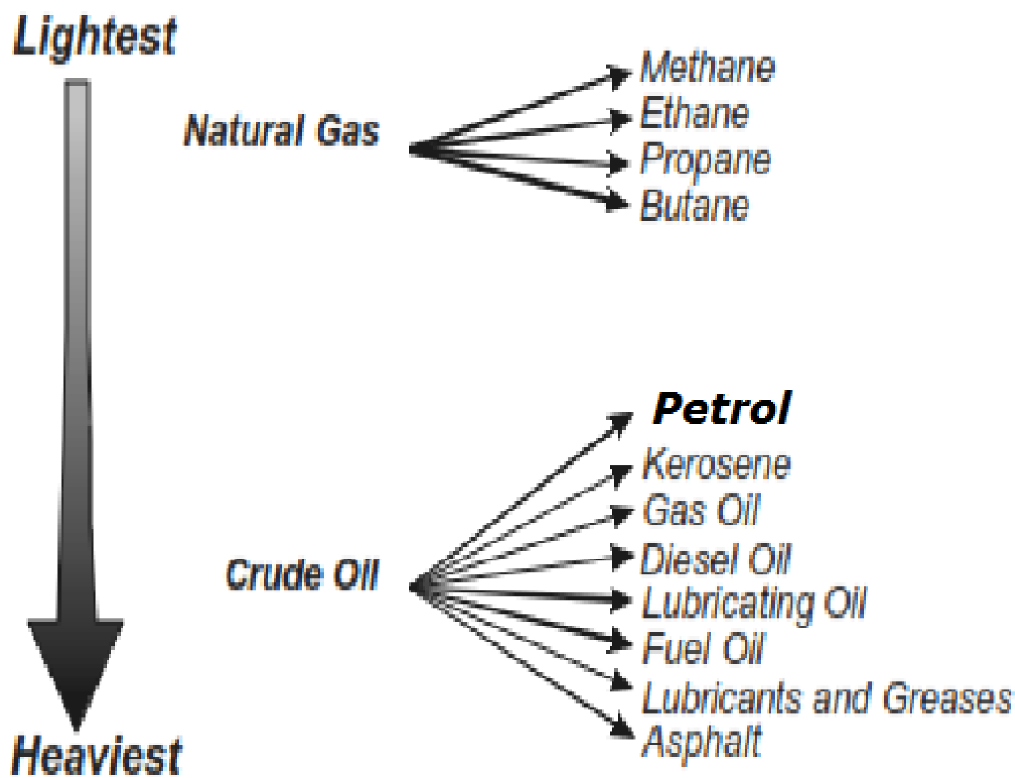
Natural gas consists mostly of methane, but also contains ethane, propane, butane and pentane, which are the simplest and lightest hydrocarbons.

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.

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 petrol, aviation fuel, etc. before it can be used by the consumer.

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



Other Constituents

***Nitrogen**: Nearly all crude oils contain small quantities of nitrogen, it is common inert constituent of natural gas, the nitrogen content of the crude oil may be contained in the dissolved gases. It is an unwanted component of both crude oil and natural gas.*

***Sulfur**: The presence of sulfur and sulfur compounds in gasoline causes corrosion, bad odor and poor explosion. Note, Crude oil is called "sweet" when the % of sulfur is low and "sour" when it is high.*

***Oxygen**: It is found in crude oil in various forms, generally averaging fewer than 2% by weight, and ranging between 0.1 – 4 %. It occurs in various forms such as free oxygen, phenols (C_6H_5OH), fatty acids and their derivatives, naphthenic acids ($C_nH_{2n-1}.COOH$) and asphalt substances.*

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. Our natural sources of oil are finite; there will come a time when we have used them up. 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.

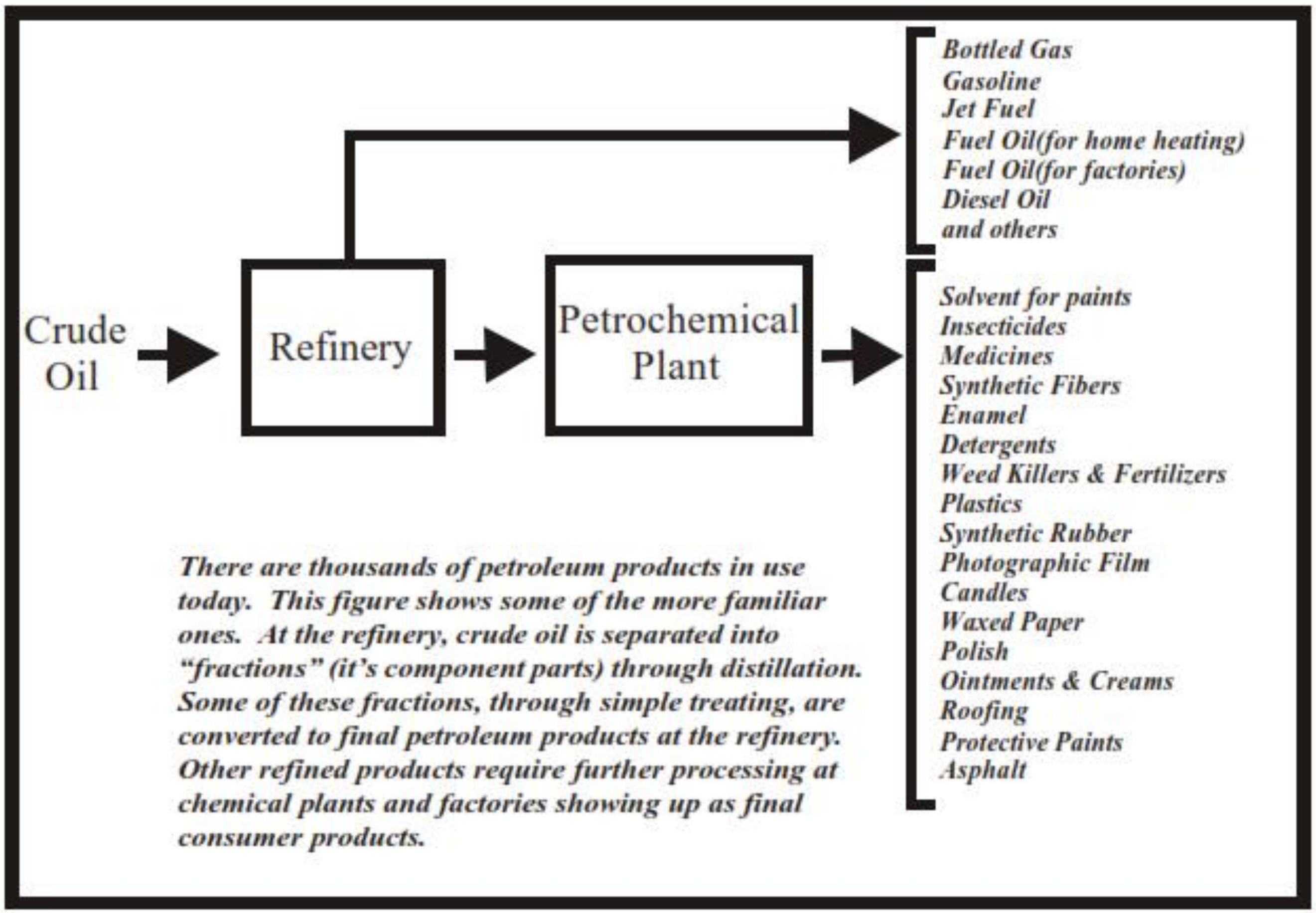
It should now be obvious why oil plays such a dominant role in today's world. If oil supplies were to be cut off, cars, boats and planes would grind to a halt.

In cold countries, they need to find alternate means of heating many of the houses and generating sufficient electricity. Our personal security would also be threatened because our Police and military 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



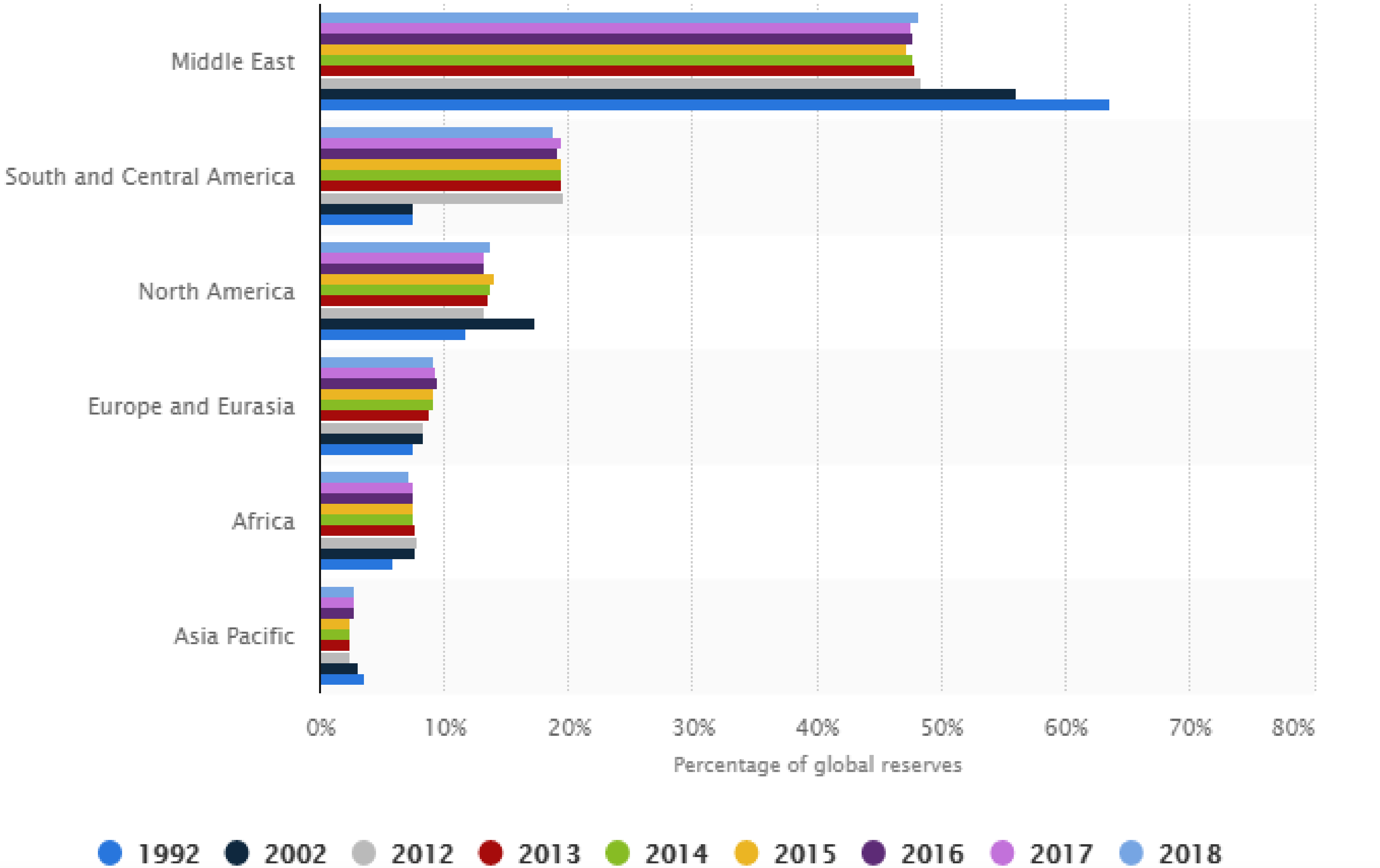
Will Society Always be Dependent on Oil?

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 all our cars will have electricity powered engines and run on batteries that must be recharged every few hundred kms. Or, perhaps the batteries will draw on the sun's energy and recharge even as we drive.

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 nonpolluting replacement energy source is one of the most important challenges faced by humankind.***

Distribution of proved oil reserves worldwide from 1992 to 2018, by region



Rank	Country	Oil Reserves (Barrels)
#1	Venezuela	300.9 billion
#2	Saudi Arabia	266.5 billion
#3	Canada	169.7 billion
#4	Iran	158.4 billion
#5	Iraq	142.5 billion
#6	Kuwait	101.5 billion
#7	United Arab Emirates	97.8 billion
#8	Russia	80.0 billion
#9	Libya	48.4 billion
#10	Nigeria	37.1 billion
#11	United States	36.5 billion
#12	Kazakhstan	30.0 billion
#13	China	25.6 billion
#14	Qatar	25.2 billion
#15	Brazil	12.7 billion

Measurement Units

Quantities of oil are expressed in barrels:

1 barrel = 159 liters
1 cubic meter = 6.37 barrels

1 metric ton = 6.8 to 7.6 barrels (dep. on gravity)

Gas is expressed in millions of cubic feet:

1 MMcf ≈ $3 \cdot 10^4$ m^3

Energy-wise, gas can be expressed in oil equivalents:

1 boe ≈ 6000 to 6500 cf

1 barrel = 159 liters

One barrel of **oil** (**BOE**) is generally deemed to have the same amount of **energy** content as 6,000 to 6,500 cubic feet of natural **gas**

World’s top Twelve Oil companies by revenue

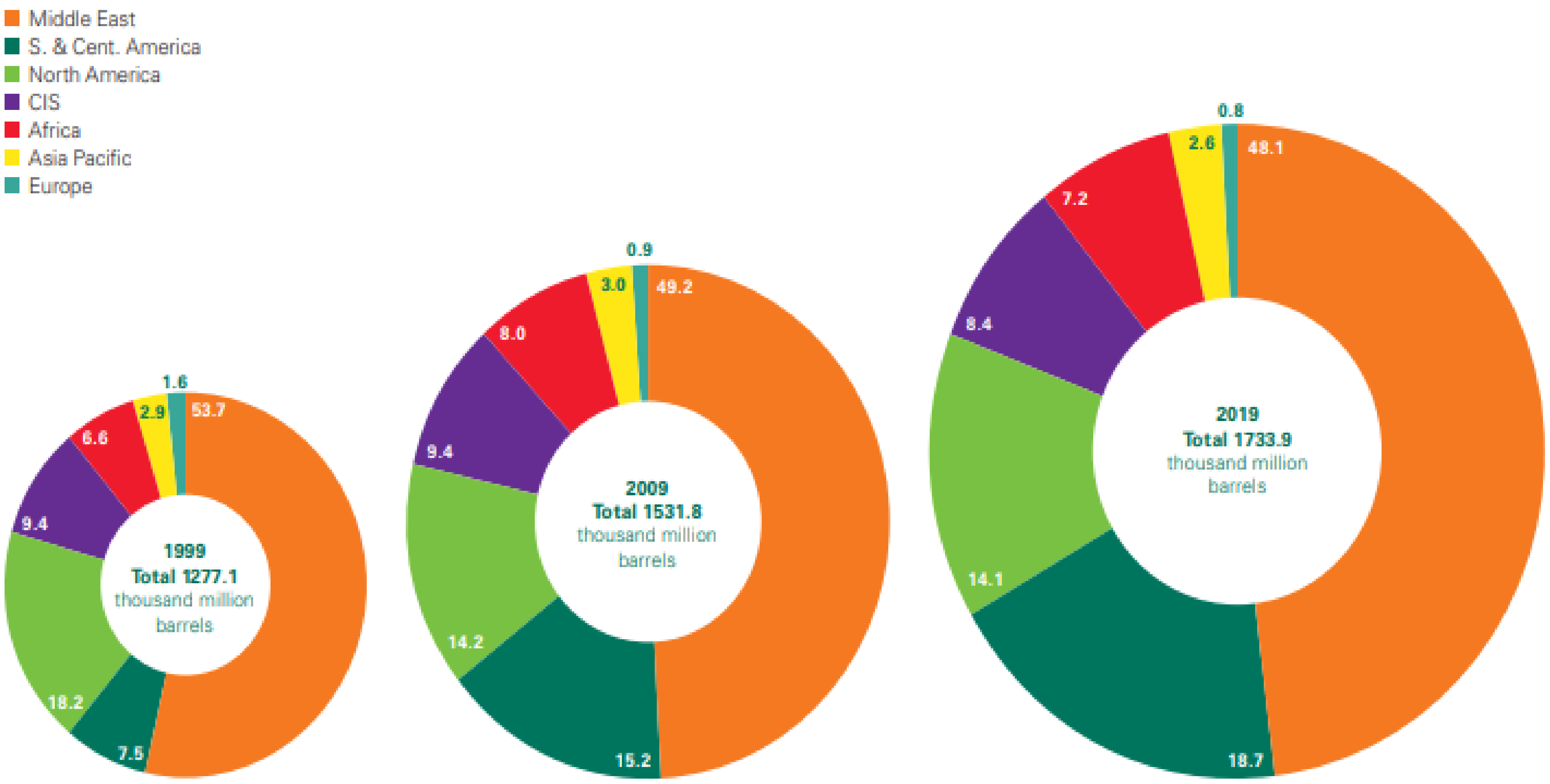
Country	Company name	Revenue 2017 (US$ billion)	Revenue 2018 (US$ billion)
	Saudi Aramco	314.4	414.6
	Royal Dutch Shell	265	396.5
	China National Petroleum Corporation	299.1	392.9
	BP	222.8	303.73
	Exxon Mobil	268.9	290.2
	Total SA	212	209.4
	Chevron Corporation	129.9	158.9
	Lukoil	144.17	127.7
	ONGC	119.6	127.5
	Gazprom	106.3	118.83
	Rosneft	88.44	118.46
	Valero Energy	130.84	117.033

World's top ten companies in oil production

Sl. No	Company	Oil Production (mbbl per day)
1.0	Saudi Aramco	Over 11 mbbl
2.0	Rosneft	over 4.2 mbbl
3.0	Kuwait Petroleum Company (KPC)	Over 3.4 mbbl
4.0	National Iranian Oil Company (NIOC)	Over 3.2 mbbl
5.0	China National Petroleum Company (CNPC)	~ 2.9 mbbl
6.0	ExxonMobil	~ 2.3 mbbl
7.0	Petrobras	~ 2.0 mbbl
8.0	Abu Dhabi National Oil Company (ADNOC)	Just under 2.0 mbbl
9.0	Chevron	~ 1.83 mbbl
10.0	Petroleo Mexicanos (Pemex)	~ 1.80 mbbl

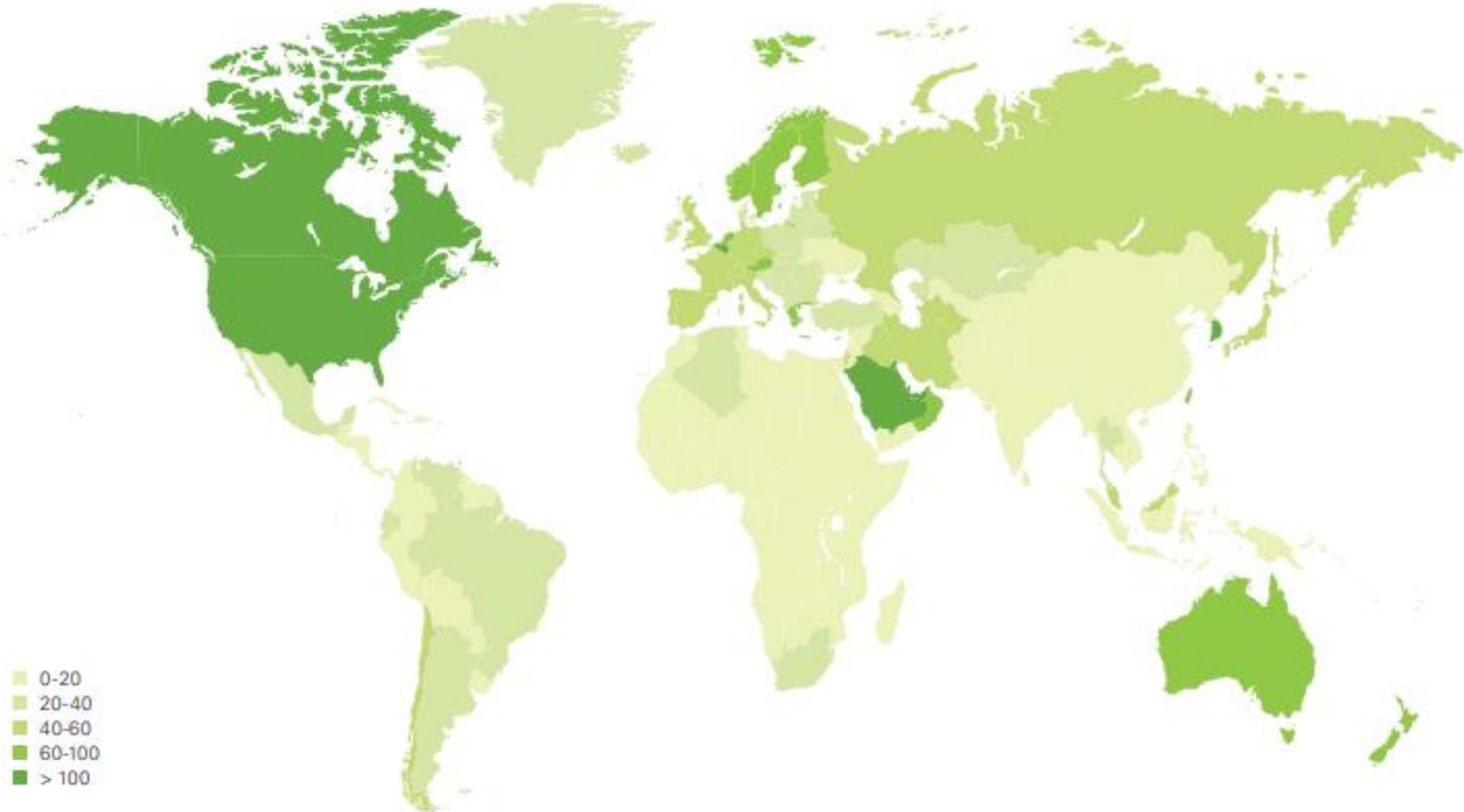
Distribution of proved reserves in 1999, 2009 and 2019

Percentage



Oil: Consumption per capita 2019

GJ per capita



Various theories have been advanced over the years as to the origin of petroleum proposing an animal, vegetable, volcanic and even meteoric origin. The origin of petroleum still has uncertainties despite the tremendous amount of research and studies devoted to it rather than any other natural substance.

There are two different theories for the origin of petroleum; Organic and Inorganic origin.

Inorganic or Abiotic origin

States that hydrogen and carbon came together under great temperature and pressure, far below the earth's surface and formed oil and gas where chemical reactions have occurred. The oil and gas then seeped through porous rock to deposit in various natural underground traps. It has also excluded the hypothesis that petroleum is a finite substance.

There are some different theories that describe the inorganic origin of petroleum which include:

Metal carbide theory

Developed by a Russian chemist and states that the deposition of petroleum is controlled by tectonic activities that occurred during the formation of sedimentary rock. To explain his observations, he has put forth "metal carbide theory". Metal carbides deep in Earth reacted with water at high pressure and temperature to form acetylene (a colorless gas) which condenses to heavier hydrocarbons.

Reaction equation is: $CaC_2 + H_2O = C_2H_2 + Ca(OH)_2$

Volcanic theory

Involves out gassing of the mantle via volcanic activity or eruption.

Earthquake theory : *Involves out gassing deep Earth's mantle via tectonic activities such as faults, and this is still happening till now.*

Serpentinization theory : *States that hydrocarbon is a by-product that came from a metamorphic transformation of the green dark Olivine mineral ,which was found in Earth's mantle.*

Evidences for inorganic origin of oil

The existence of methane on other planets of solar system, moons and comets.

Geographical location: *most of hydrocarbon producing regions are located close to belts of tectonic activities.*

Stability with depth: *Corresponding to what organic theory's supporters have admitted themselves; petroleum is a fossil fuel, and there has never been a real fossil found below 5 km. Nowadays, there is drilling for oil reservoirs carried out at 8 - 9 km where there is no remains of fossils.*

Organic or biotic origin

It is the most widely accepted. The oil and gas are formed from remains of prehistoric plants and animals. These remains were settled in the seas and accumulated on the ocean floor and buried under several kilometers of sediments.

Over several milion years, the layers of the organic material were compressed under the weight of the sediments above them. The increase in pressure and temperature with the absence of oxygen changed the mud, sand, silt or sediments into rock and organic matter into Kerogen. After further burial and heating, the kerogen transformed via cracking into petroleum and natural gas.

Kerogen is a solid, insoluble organic matter in sedimentary rocks that can yield oil upon heating.

First and foremost, is the carbon-hydrogen-organic matter connection. Carbon and Hydrogen are the primary constituents of organic material, both plant and animal. Moreover, carbon, hydrogen, and hydrocarbons are continually produced by the life processes of plants and animals.

Molecules thought to be of biological origin, e.g.: porphyrins, isoprenoids, hopanoids, etc. are present in petroleum, thereby providing support for the organic theory.

The organic carbon in plants is depleted in carbon-13 due to the process of photosynthesis. In dead organic material the C-13 is further depleted due to radioactive decay. Since, most petroleum and natural gas showed the same depletion, it was viewed as a strong proof in favour of an organic origin.

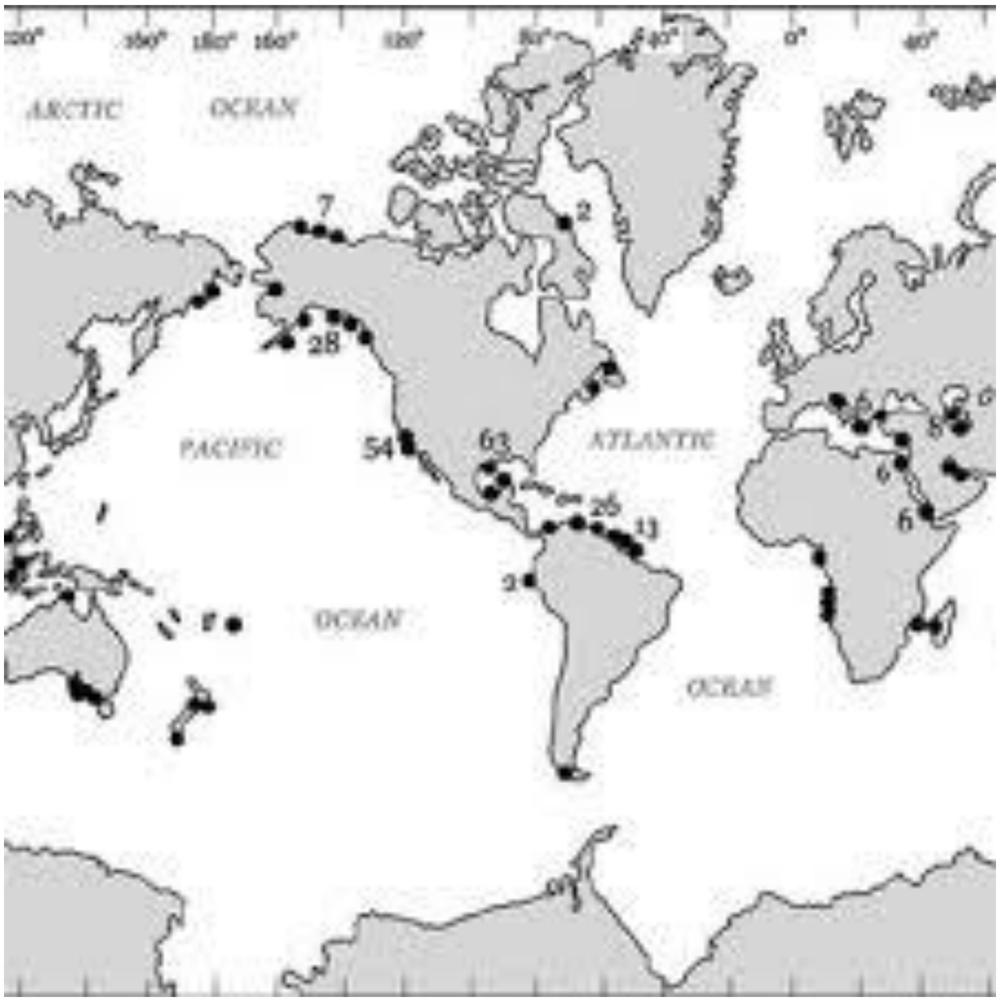
Sedimentary rocks are the most important host rocks yielding petroleum.

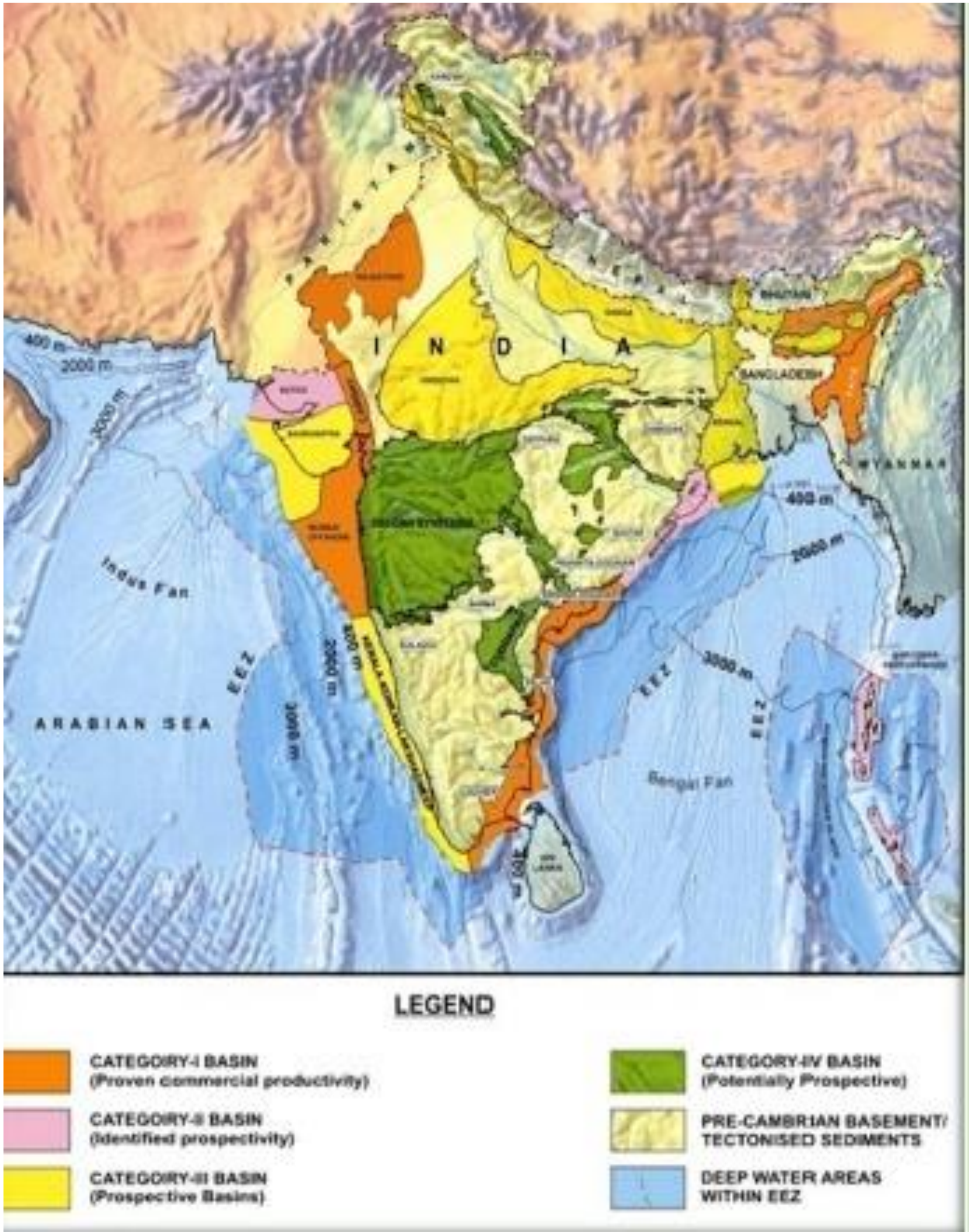
Petroleum Used by Ancient Civilizations

No one knows exactly when humans first used petroleum. It is known, however, that ancient peoples worshipped sacred fires fueled 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 BP 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.

Natural oil seeps





India has 26 sedimentary basins covering an area of 3.14 million sq.km.

The sedimentary basins of India, onland and offshore up to the 200m isobath, have an areal extent of about 1.79 million sq. km.

In the deepwater beyond the 200m isobath, the sedimentary area has been estimated to be about 1.35 million sq. km.

Thus, the total works out to 3.14 million sq. km. Broadly Indian sedimentary basins have been divided into four categories based on their degree of prospectivity as presently known.

Type of basins	Area (Sq. KM)	Hydrocarbons Prospectivity	Basins/ Region
Category I (7 Basins)	518500	Established commercial production	Cambay, Assam Shelf, Mumbai offshore, Krishna Godavari, Cauvery, Assam Arakan Fold Belt and Rajasthan
Category II (3 Basins)	164000	Known accumulation of hydrocarbons but no commercial production as yet	Kutch, Mahanadi-NEC & Andaman-Nicobar
Category III (6 Basins)	641000	Indicated hydrocarbon shows that are considered geologically prospectivity.	Himalayan Foreland, Ganga, Vindhyan, Saurashtra, Kerala-Konkan-Lakshadweep & Bengal
Category IV (10 basins)	461200	Uncertain potential which may be prospective by analogy with similar basins in the world.	Karewa, Spiti-Zanskar, Satpura-South Rewa-Damodar, Narmada, Decan Syneclise, Bhima-Kaladgi, Cuddapah, Pranhita-Godavari, Bastar, Chhattisgarh
Deepwater	1350000		East & west cost from 400 m water depth to EEZ
Total	**3134700**	-	

The oil and gas industry in India dates back to 1889 when the first oil deposits in the country were discovered near the town of Digboi in the state of Assam. The natural gas industry in India began in the 1960s with the discovery of gas fields in Assam and Gujarat. As on 31 March 2018, India had estimated crude oil reserves of 594.49 million tonnes (MT) and natural gas reserves of 1339.57 billion cubic meters (BCM).

India imports 82% of its oil needs and aims to bring that down to 67% by 2022 by replacing it with local exploration, renewable energy and indigenous ethanol fuel. India was the third top net crude oil (including crude oil products) importer of 205.3 Mt in 2018.

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, a 39 year old carriage maker from 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 m. 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 m. This discovery signaled the birth of the modern petroleum industry in the United States.

The Oil Boom

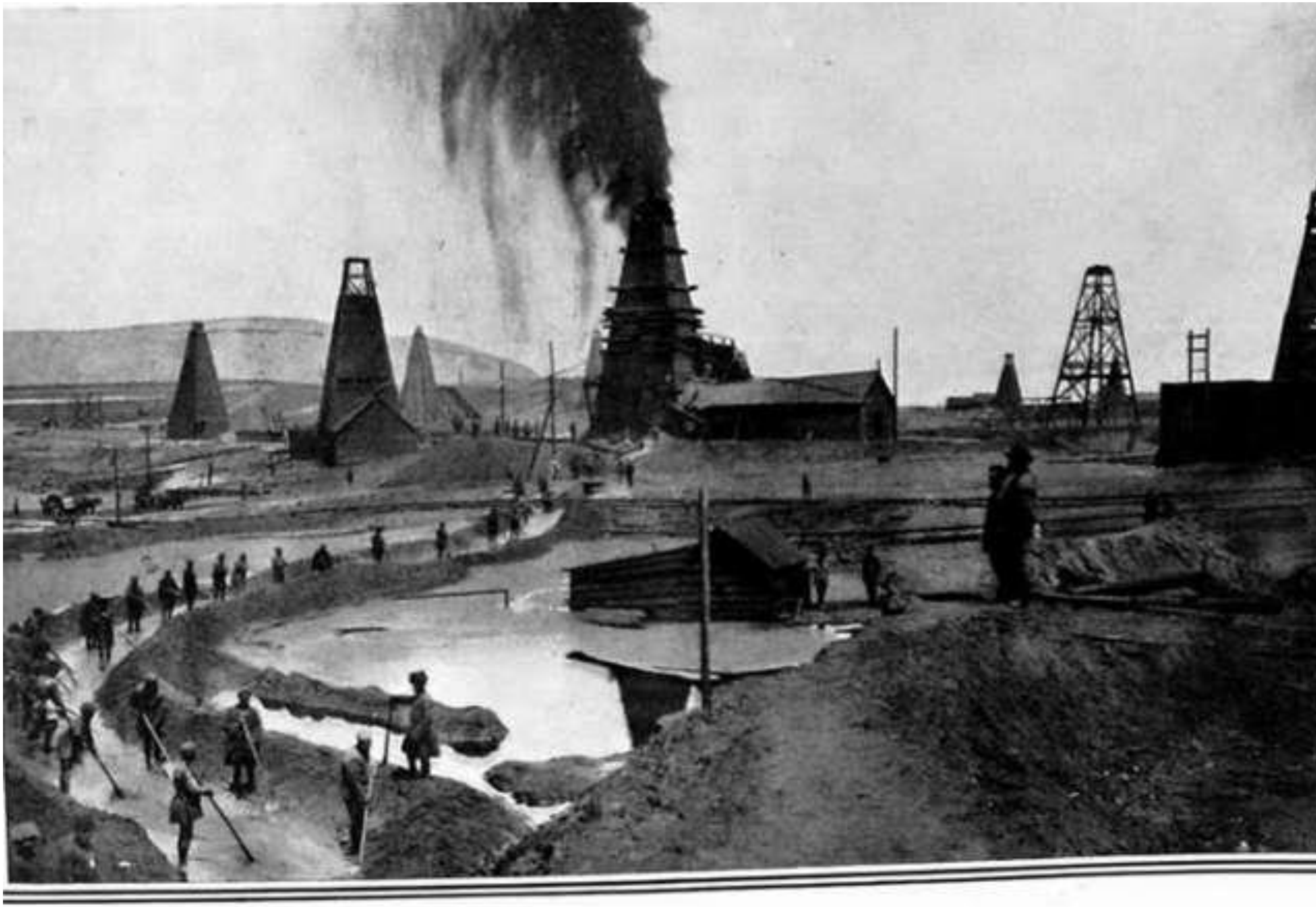
As a result of the oil discoveries of the 1850's, numerous refineries were built to turn crude oil into kerosene for lamps and into lubricating oils for the machines of the industrial revolution. Oil began to replace coal as the fuel for steam engines.

The invention of the petrol engine (1885) and diesel engine (1892) allowed inventors of horseless carriages to adopt a new power source to replace steam and coal. Petrol which 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 the early years of the twentieth century.

In 1903, the Wright brothers utilized petroleum to realize what could only be imagined by previous generations - flight. Since that first flight petroleum has fueled every type of aircraft.

First Oil Well, Titusville, USA in 1859

Oil fields near Baku, Azerbaijan in 1885



ONE OF THE PONDS INTO WHICH THE OIL FALLS

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.

It was less than 500 years ago, in 1519, that Ferdinand Magellan set out with five ships to circumnavigate the world. This voyage cost the lives of most of Magellan's 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.

Indeed the world has become a much smaller place, largely due to petroleum - that had its beginnings in ancient seas millions of years before human walked the earth.

Geologic Age	% of Fields
Neogene	18
Palaeogene	21
Cretaceous	27
Jurassic	21
Permo-Triassic	6
Carboniferous	5
Devonian	1
Cambrian-Silurian	1
	Total 100

Formation of Sedimentary rocks

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 (weathering).

Some are simply broken up into small pieces by running water while others are dissolved slowly as weak acids as groundwater 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 transported further and further "downstream", it is broken into smaller pieces. Eventually, these 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 sea / ocean itself.

A large depressed area in which a lot of sediment has been or is being deposited is called a ***sedimentary basin****.*

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 kms 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. 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).*

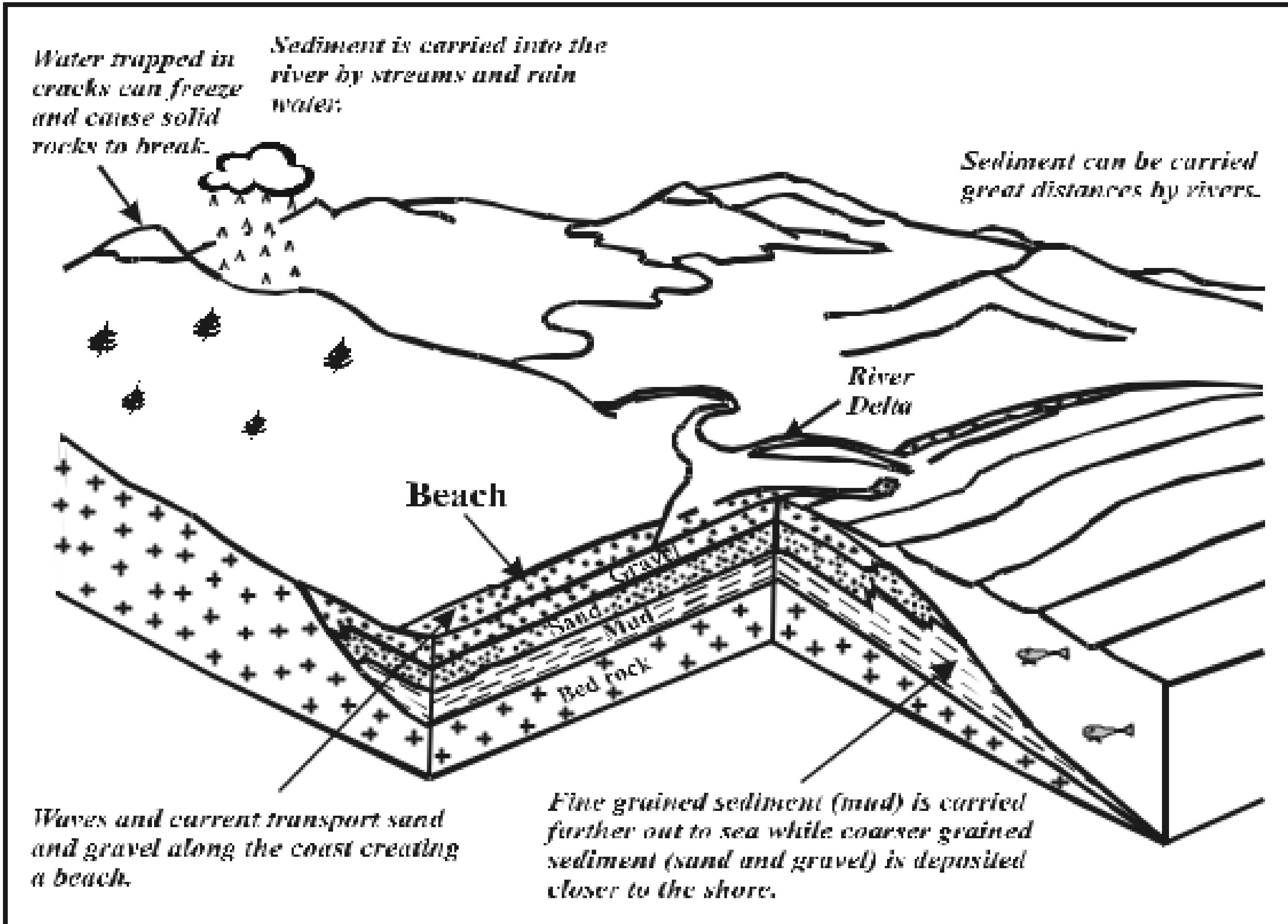
But, in addition to the rock fragments, running water also contain dissolved minerals such as calcium and salt. These minerals will eventually come out of solution and form precipitates (solids) when the conditions are right. Sedimentary rocks formed primarily from this precipitation process include limestone, gypsum and salt.

Sedimentation

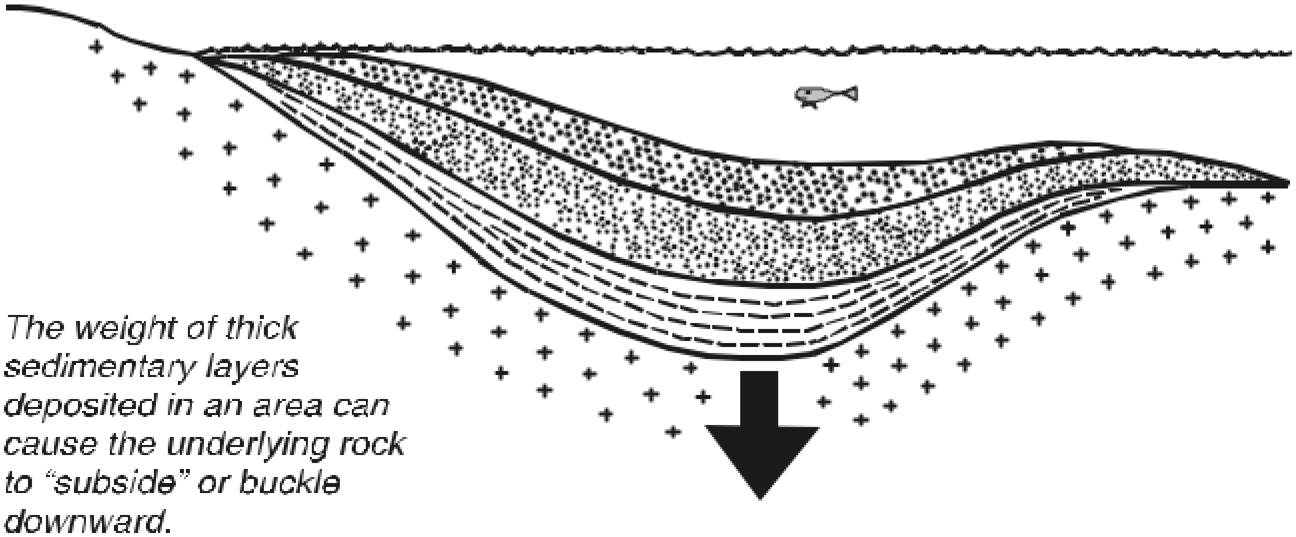
As sediment is continuously dumped into the ocean, it gradually sinks to the bottom and starts to form layers. Coarser, heavier material (gravel) is deposited close to the shore and fine sediments (fine sand and clay particles) is deposited further out, in the deeper water.

Sea levels rise and fall because of global climate changes or as a result of the raising or lowering of the land by tectonic movements.

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.



Water trapped in cracks can freeze and cause solid rocks to break.
Sediment is carried into the river by streams and rain water.
Sediment can be carried great distances by rivers.
River Delta
Beach
Gravel
Sand
Mud
Bed rock
Waves and current transport sand and gravel along the coast creating a beach.
Fine grained sediment (mud) is carried further out to sea while coarser grained sediment (sand and gravel) is deposited closer to the shore.



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. 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 meters of sediment to be deposited in an area even though the water depth may ever exceed a few hundred meters.

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 groundwater cements the sediment into solid rock.

Why Is It We Find Sedimentary Rock On Dry Land?

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

Hydrocarbon Generation and Source Rock

Source rock refers to the sedimentary formation in which oil and gas originate. Hydrocarbons are generated when large volumes of microscopic plant and animal material (phytoplankton) are deposited in marine, deltaic, or lacustrine (lake) environments. The organic material may either originate within these environments and/or may be carried into the environment by rivers, streams etc.

*The microscopic plant and animal material generally is deposited with fine clastic (**usually clay)** sediments**.** During burial the sediments protect the organic material by creating an **anoxic** (oxygen depleted) environment. This allows the organic material to accumulate rather than be destroyed by aerobic organisms such as bacteria. Over time, the organic remains are altered and transformed into gas and oil by the high temperatures and increased pressure of deep burial. This process can take millions of years to occur. The amount of petroleum generated is a function of the thickness of the accumulated sediments and organic material, the burial of these materials, and time.*

Organically rich, black-colored shales deposited in a quiet marine, oxygen depleted environment are considered to be the best source rocks.

*Petroleum is derived mainly from organic material buried in sediments known as **Kerogen**. Kerogen is that part of the organic matter in a source rock that is insoluble in common organic solvents. It owes its insolubility to its large molecular size and heat is required to break it down.*

Kerogen is of no commercial significance except when it is abundant (greater than 10%) in shales. It is, however, of great geological importance because it is the substance that generates oil and gas. A source rock must contain significant amounts of kerogen.

Temperature Gradient

Temperature is generally a function of depth because of the earth's natural geothermal gradient (heat from the earth's interior to the surface). On average, the temperature increases by about 25°C for every km of depth. The temperature required to produce crude oil occur between ~ 1.5 and 6.0 km of depth.

Temperatures below 6.0 km are generally too high and only generate gas. Temperatures above 1.5 km are not usually sufficient enough to transform the material into crude oil.

There are, of course, exceptions to the rules. Geologic conditions such as volcanism and tectonics (folding and faulting) can change or effect the temperature gradient.

Pressure Gradient

The pressure that impacts the sediments in the subsurface is due to the weight of overlying materials and is called ***overburden pressure.*** *Overburden pressure is a function of depth.*

Hydrocarbons evolve from an immature stage to oil generation, oil cracking (wet gas stage), and finally to dry gas generation because of overburden pressure and the associated increase in temperature.

Maturity of Petroleum

The life cycle of organic matter passes thorough different stages which are:

Diagenesis (Temperature < 50 $^\circ$C)

Catagenesis (Temperature 50 to 200 $^\circ$C) and

Metagenesis (Temperature > 200 $^\circ$C)

Maturation of Organic Matter (Kerogen)

At about 60^o C transformation begins

- *Liquid hydrocarbons begin to form*

At 120^o C gas begins to form

At 140^o C organic matter is exhausted and gas only forms at higher T.

The formation of Petroleum

The Maturation of Organic Matter

Diagenesis

Compaction under mild conditions of temperature and pressure. When organic materials (proteins, lipids, carbohydrates) are deposited, they are saturated with water. Through chemical reaction, compaction, and microbial action during burial, water is forced out and proteins and carbohydrates break down to form new structures that comprise a waxy material known as "kerogen" and a black tar like substance called "bitumen". All of this occurs within the first several hundred meters of burial of the sediments.

Catagenesis

Catagenesis (or "cracking") turns kerogen into petroleum and natural gas. As temperatures and pressures increase, the process of catagenesis begins, which is the thermal degradation of kerogen to form hydrocarbon chains. The conditions of catagenesis determine the product, such that higher temperature and pressure lead to more complete "cracking" of the kerogen and formation of smaller hydrocarbons. Petroleum formation, then, requires a specific window of conditions; too hot and the product will favor natural gas (small hydrocarbons), but too cold and the plankton will remain trapped as kerogen.

Metagenesis

Metagenesis takes place at temperatures over 200◦C and is considered to be a type of very low-grade metamorphism. At the end of metagenesis, methane, or dry gas, is evolved along with non hydrocarbon gases such as CO2, N2, and H2S, as oil molecules are cracked into smaller gas molecules.

DEPOSITION OF ORGANIC-RICH SEDIMENTARY ROCKS

Petroleum source rocks are sedimentary rocks that contain sufficient amounts of organic matter to generate and expel commercial quantities of oil and/or gas when heated. Such organic-rich strata were deposited throughout Earth's history, in nearly all geologic environments, and in most sedimentary basins. Source rocks, however, typically represent only a minor amount of basinal strata and are formed only when specific conditions exist.

Three general factors control the deposition of organic-rich sediments: productivity, dilution, and preservation.

Biological productivity determines the amount of organic matter that is contributed to sediments.

Dilution refers to the amount of inorganic minerals that mixes with the organic matter.

Once deposited, the organic matter must be preserved in a form that may later generated petroleum.

These factors are interrelated and influenced by a number of geologic conditions.

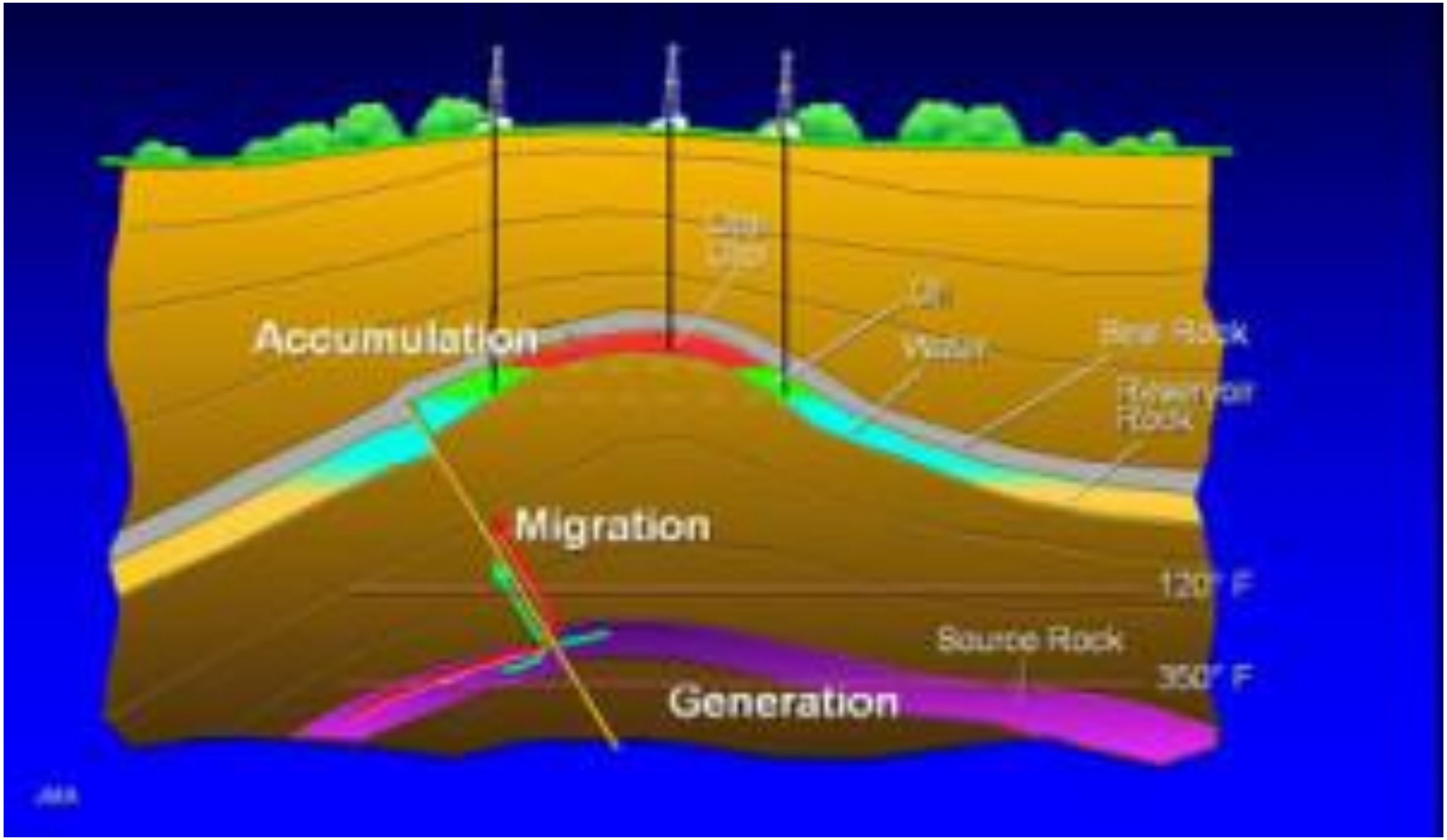
THE PETROLEUM SYSTEM

The accumulation of economic volumes of petroleum (oil and/or gas) in the subsurface requires that several essential geological elements and processes be present at specific time and space.

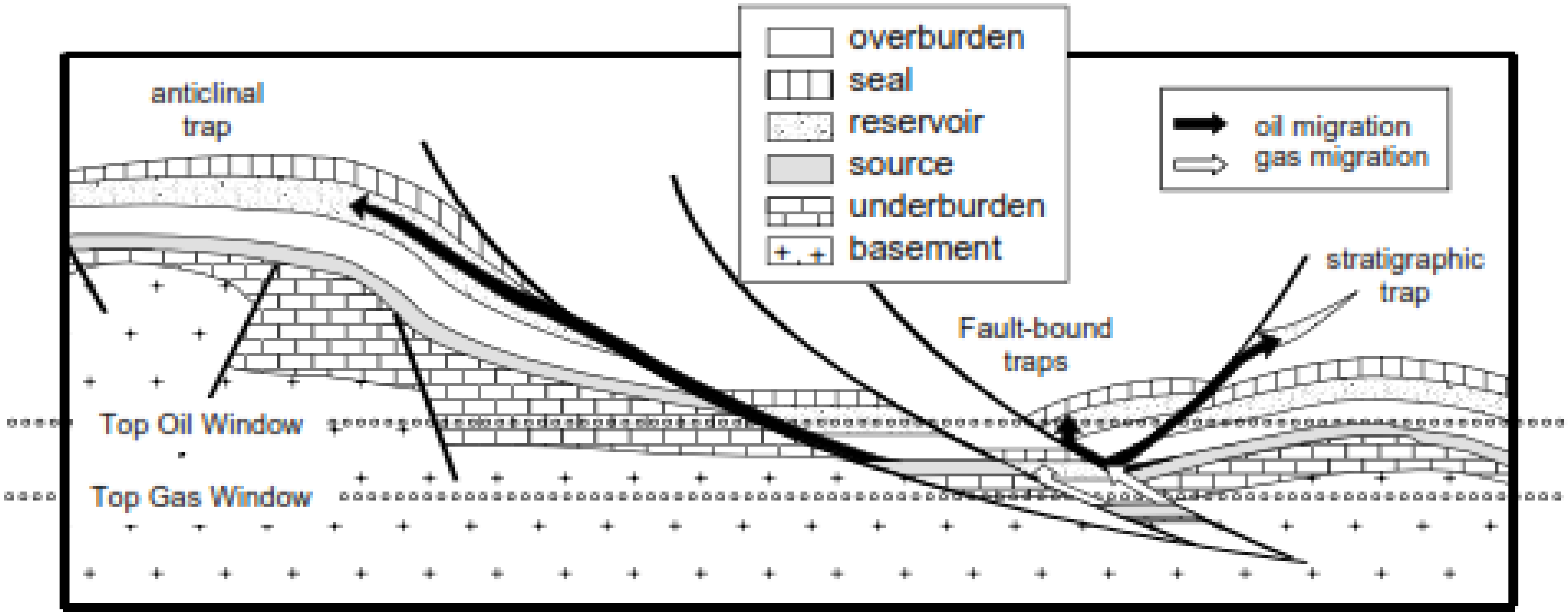
Source rocks generate and expel petroleum when sufficient thermal energy is imparted to the sedimentary organic matter (kerogen) to break chemical bonds. This heating is induced usually by burial by overburden rock. Once expelled, petroleum migrates either along faults and/or highly permeable strata. Accumulations form only when high porosity strata (reservoir rocks) are charged with migrating petroleum and the petroleum is prevented from further migration.

These petroleum traps are formed only when geologic movements result in subsurface topographies (structural and stratigraphic) that block migration and when the reservoir rocks are covered by low permeability strata (seal rocks).

The mere presence of these geologic elements is insufficient to form petroleum reserves. Traps must be available at the time of oil expulsion and, once charged, their integrity must be preserved until exploited. These elements and processes constitute the Petroleum System.



Accumulation
Migration
120° F
Source Rock
350° F
Generation



Elements of a Petroleum System. All petroleum systems contain:

1. *at least one formation of organic-rich sediments that has been buried to a sufficient depth by overburden rock such that petroleum is generated and expelled,*

2. *Pathways (permeable strata and faults) that allow the petroleum to migrate,*

3. *Reservoir rocks with sufficient porosity and permeability to accumulate economically significant quantities of petroleum, and*

4. *Sealing rock (low permeability) and structures that retain migrated petroleum within the reservoir rock.*

What is a reservoir?

A reservoir is a subsurface volume of porous and permeable rock that has both storage capacity and the ability to allow fluids to flow through it. Thus, reservoir rock is a formation in which oil and gas accumulates, it must have:

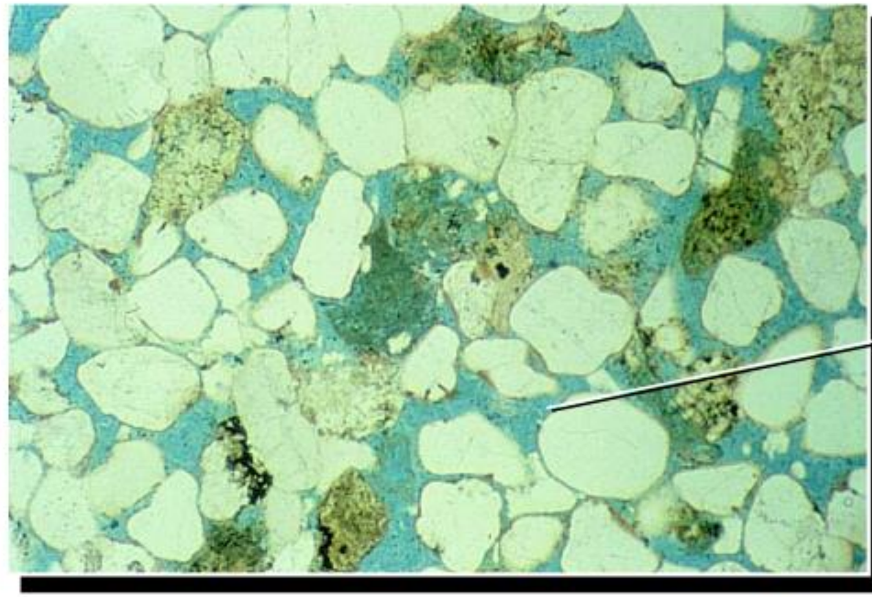
- *Porosity - space between rock grains in space between rock grains in which oil accumulates.*

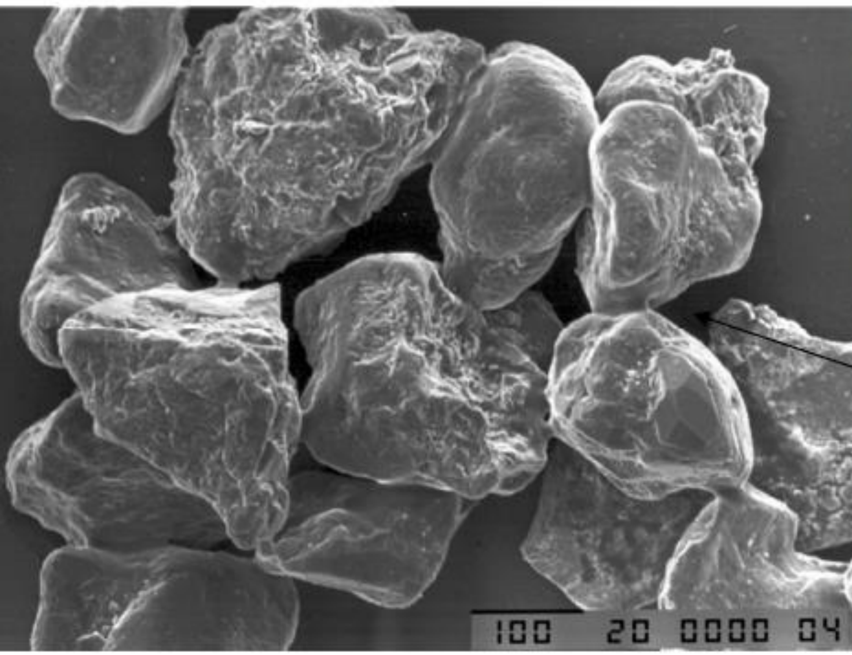
- *Permeability – passage ways between pores through which oil and gas moves*

Hydrocarbon migrates upward through porous and permeable rock formations until it either reach the surface as seepage or become trapped below the surface by a non-permeable cap rock which allows it to accumulate in place in the reservoir.

Porosity and permeability are influenced by the depositional pore-geometries of the reservoir sediments and the post-depositional diagenetic changes that take place.

Porosity is the amount of void spaces in a rock





Permeability is how easy fluids move through a rock

The molecular and isotopic composition of produced petroleum is determined by the chemical, physical, and biological processes. Generation and expulsion of petroleum from the source rock, phase behavior as the petroleum moves from source to reservoir and secondary alteration processes all influence oil and gas compositions.

Each source facies generates oil with distinct chemical composition that reflects biotic input, depositional setting, and thermal history.

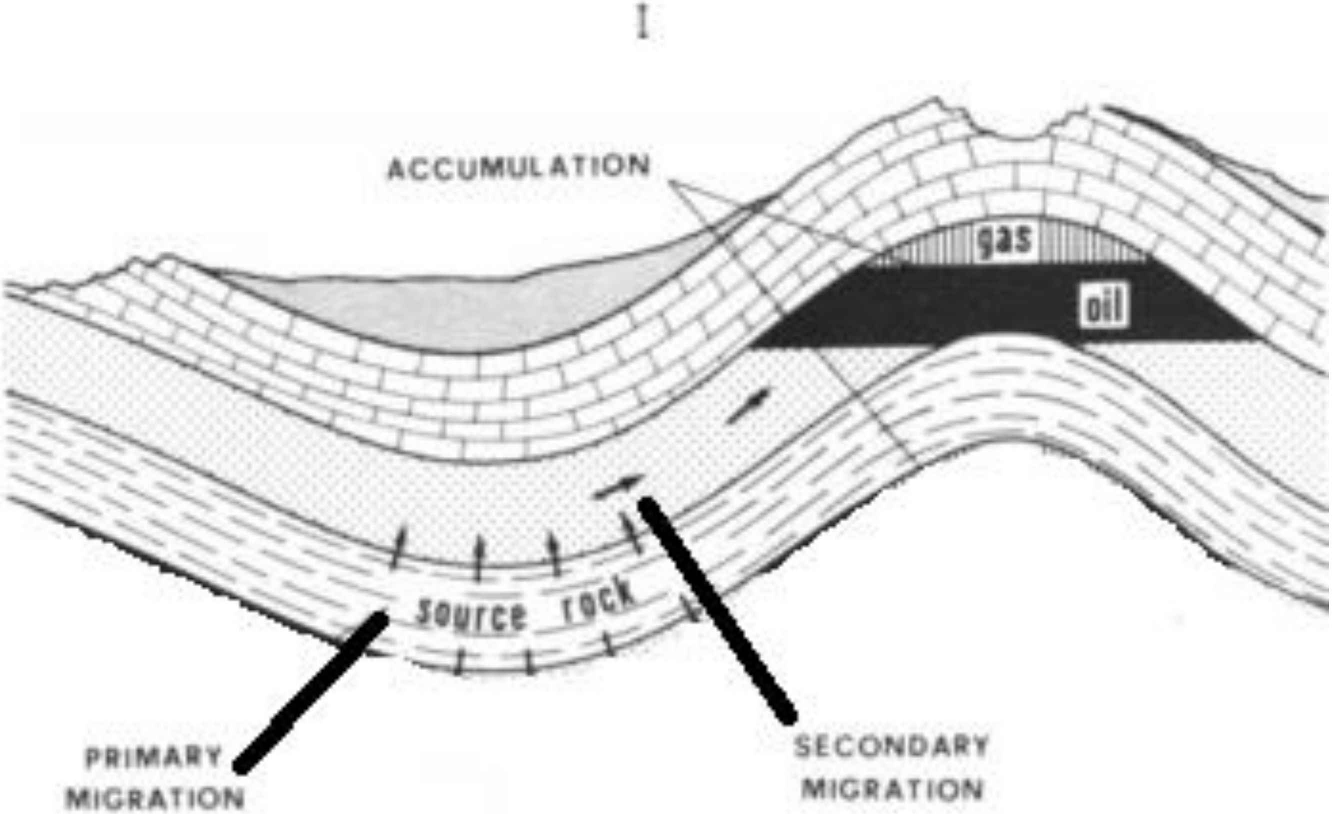
For example, lacustrine environment source rocks generate waxy, low-sulfur crudes, while carbonate and evaporite source rocks generate asphaltic, high-sulfur crudes.

Petroleum Migration

After hydrocarbon has formed it must migrate out of the source rock and into a reservoir where it can be stored. Some hydrocarbons form close to the reservoir but in most cases they migrate many kilometers before coming to rest in the reservoir.

The main driving force for petroleum migration is buoyancy because it is less dense than water. The forces acting against migration are the capillary forces and the resistance to flow though rocks with low permeability. Migration of oil and gas will therefore nearly always have an upwards component.

Petroleum migrates as a mixture of oil, gas and water. In the reservoir rock these phases separate according to density with the most dense, water on the bottom, least dense gas on top and oil between the two.



Here, we can distinguish two types: primary migration and secondary migration.
Primary migration is the flow of petroleum out of the source rock.

Secondary migration is the continued movement (lateral) of the hydrocarbon within the reservoir rock .

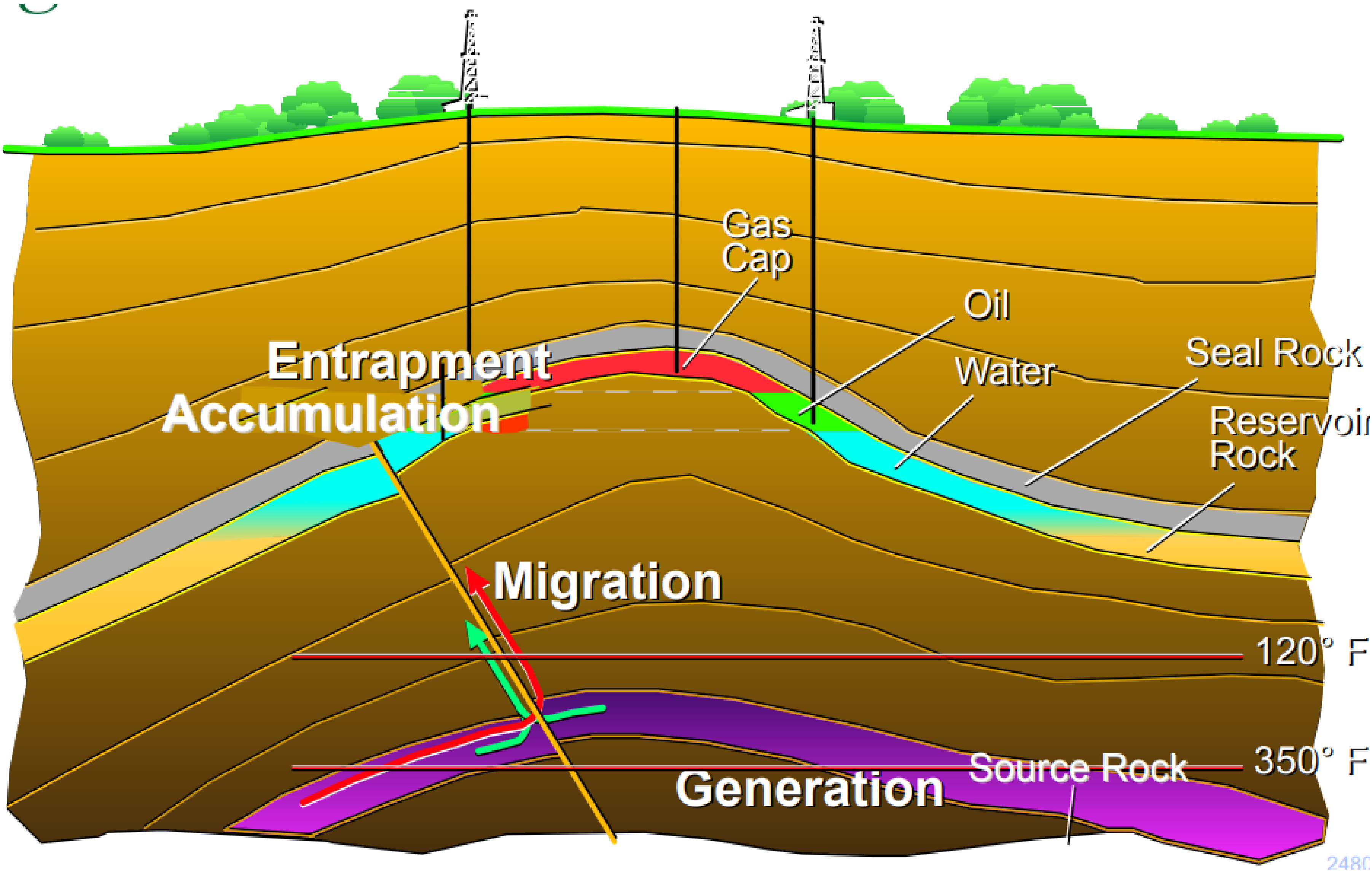
What causes primary migration

Kerogen is 5-10% of source rocks. Maturation transforms solid kerogen into a liquid and gaseous hydrocarbons.

The change in phase is accompanied by an increase in volume, that results in the over pressuring of the pore system within the source rock that fractures the source rock unit and results in the escape of hydrocarbons through micro cracks into the surrounding formations. Cracks close up until a new episode of generation takes place.

The migration of hydrocarbons from the source rock requires some kind of energy. The two most common driving forces present in source rocks to cause this are temperature and pressure.

Thus, the movement of hydrocarbons from the source rocks is primarily caused by the presence of pressure gradients and to a lesser extent by the temperature gradients.



Gas
Cap
Oil
Entrapment
Seal Rock
Water
Accumulation
Reservoir
Rock
Migration
120° F
350° F
Source Rock
Generation

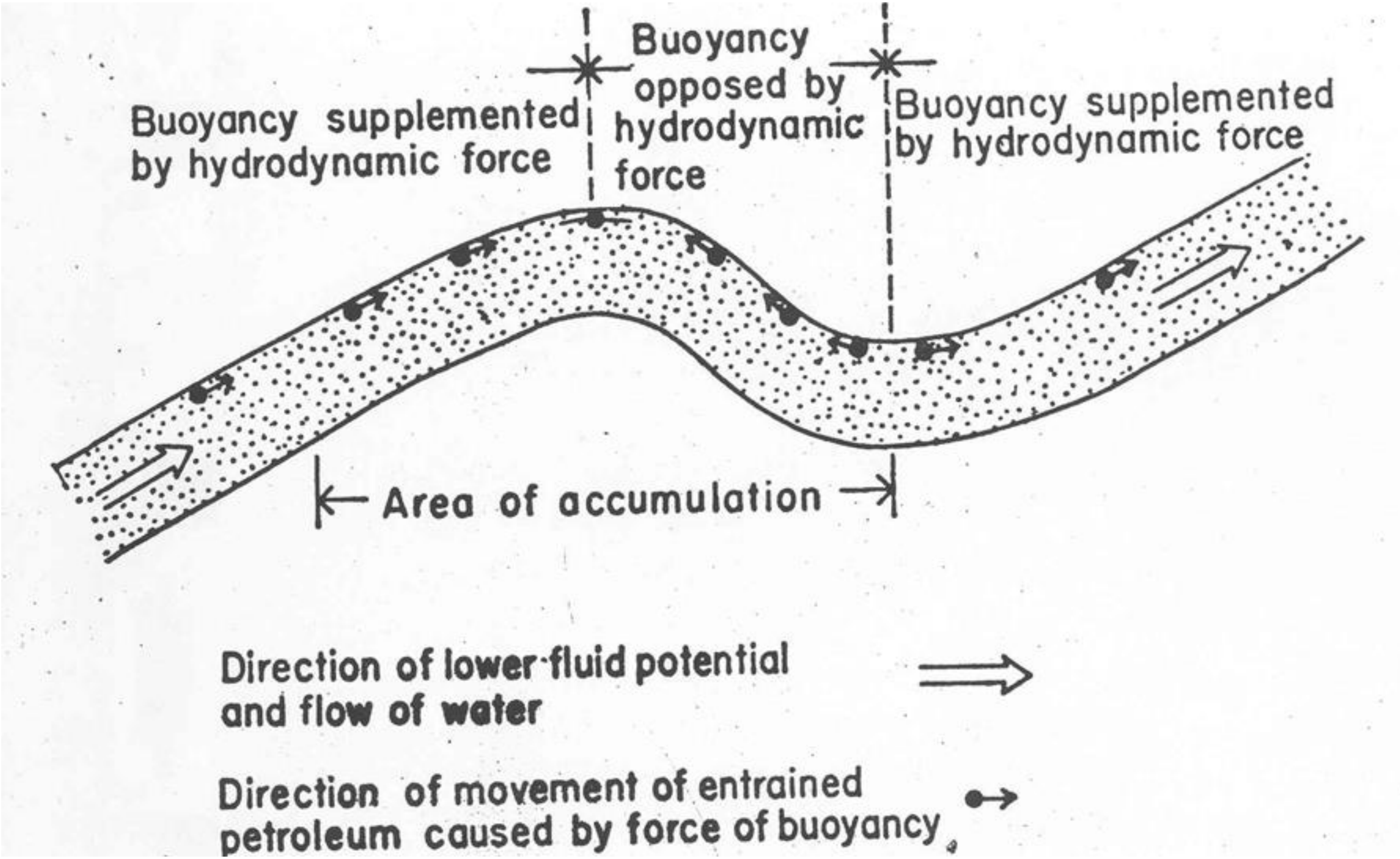
Secondary migration

Secondary migration is defined as the movement of petroleum compounds through more permeable and porous carrier beds and reservoir rocks, as opposed to primary migration through less permeable source rocks.

Secondary migration might terminate in reservoir rock, but tectonic events such as folding, faulting or uplifting may cause an additional phase of secondary migration. When this results in a new accumulation it is sometimes called remigration or tertiary migration.

There are three important parameters that control secondary migration:

- *Buoyancy , the rise of oil and gas in water-saturated porous rocks,*
- *capillary pressures that determine multiphase flow and, as an important modifying influence and*
- *hydrodynamic water flow.*


Buoyancy supplemented by hydrodynamic force
Buoyancy opposed by hydrodynamic force
Buoyancy supplemented by hydrodynamic force
Area of accumulation
Direction of lower fluid potential and flow of water
Direction of movement of entrained petroleum caused by force of buoyancy