Petroleum Reservoir Engineering

Dr. Pankaj Tiwari

Department of Chemical Engineering

Indian Institute of Technology, Guwahati

Lecture – 3

Petroleum Geology

Hello, welcome again to this MOOCs course on Petroleum Reservoir Engineering. In today's class or in this lecture of week 1, lecture number 3, we are going to continue our discussion about the petroleum reservoir engineering. Today's topic will be petroleum geology. So, we discuss briefly about the conventional petroleum system, then petroleum reserves across the world and in India. Today we will discuss about how this petroleum geology is important to identify the potential site where the petroleum hydrocarbon can be present. So, petroleum geology is actually a subclass of the geology.

Geology is defined as the science of earth. So, the earth science is actually the geology that deals with the origin, age and structure of the earth including its evolution, modification and extinction of surface and subsurface features. So, the petroleum geology is the study of origin, occurrence, movement, accumulation and exploration related to hydrocarbon fuels. So, how hydrocarbon fuels are getting originated, where they are found, how they are moving from one place to other place and how to explore them is the part of the petroleum geology.

It is a specific set of geology discipline that actually deals with the hydrocarbons, specifically oil extraction. Reservoir that comes under the petroleum geology is a porous and permeable lithological unit or set of the units that hold the hydrocarbon reserves. So, the job of petroleum geology is to identify the reservoir, understand its formation and actually quantify the amount of the hydrocarbon fluid those can be present in that geological formation. So, the theory of hydrocarbon sources formed underneath the surface divided into two parts. Inorganic theory that is having very less acceptance in today's world.

Other is organic theory that claims that the fossil fuels were formed from remains of plant and animals over the geological time scale under the influence of temperature and pressure underneath the surface through the chemical, biochemical and thermochemical processes. Radioactive bombardment is also considered one of the processes that converted this organic material into petroleum substance. When we look on the earth

entire spectrum from surface to center, the distance is around 6,300 kilometer that is divided from center of the earth to the surface into three major sections. At the center side, we call it core that is further divided into inner core and outer core followed by the mantle that is further divided in inner mantle and the outer mantle that span around 2,285 kilometers. On the top side of the earth surface from the center to surface distance, distance of around 100 kilometer is called the lithosphere where the organic crust and the continental crust are present.

So, this lithosphere is actually called the crust. The petroleum substance are found in this crust region only. So, if we look with respect to the temperature, the core is at very high temperature. The inner core is around 5,000 degrees Celsius and the outer core is around 4,500 degrees Celsius. The mantle temperature is also very high ranges from 870 degrees Celsius to 2,000 degrees Celsius and the crust temperature at the bottom of the crust around 100 kilometer down, the temperature is 870 degrees Celsius.

So, this temperature are very high at the temperature the entir organic matter will get converted into gas only. So, to get the oil and the gas or the suitable hydrocarbon formation from the organic matter, the upper part of the crust that is arsenic crust or the continental crust are very important for the petroleum reservoir. Actually, that is the place where the petroleum reserves are formed from these organic matters. So, the crust is most important for the petroleum geology. When we look classified the arsenic crust and the continental crust, some of the features like arsenic crust is under the ocean that is thin and ranges from 8 to 11 kilometer from the ocean surface made up primarily of heavy rocks that is formed when molten rocks or the magma cools down.

On the other side, the continental crust that is on the continental side, it is thick ranges from 16 kilometer to 48 kilometer composed of rock that is relatively light as compared to the arsenic crust. So, in the surface side, we are having the ocean and the land both the places the petroleum geology is important to identify the petroleum reserves. These are some of the features that I highlighted here. How this has happened? As I mentioned because of the temperature and pressure and some chemical biochemical reactions happening. So, the temperature gradient is there.

So, at the surface, we are having the temperature let us say average temperature is 25 degree Celsius at the STP condition as we go underneath the temperature increases and the temperature gradient is there that is also called the geothermal gradient. So, if we are going let us say 100 meter down, the temperature will vary from 1.5 degree Celsius on average that depends on the geological formation and other factor. Similarly, the pressure gradient is there because of the overburden pressure as wego down the overburden pressure put the pressure on the substance underneath the surface and the pressure

gradient is there that also depend on different geological formation, but on average, it is around 0.45 psi per feet depth we go down.

So, we are going like several 1000 feet depth, the pressure will be almost half of the order in psi unit. The temperature required for thisorganic matter to convert into petroleum substance ranges in the 70 degree Celsius to 175 degree Celsius and the pressure that depends on the depth, it may vary from 3000 psi to several 1000 psi or roughly like we can say around 10,000 to 15,000 psi. So, the geology of this crust is also important because this crust is continuously changing and moving because of the two forces of the nature. One is origami another is weather and erosion processes. So, the origami or mountain building is a process where the movement is happening because of the tectonic plate movements or because of the volcanism.

While the weather and erosion process these are the forces, they break down the sediments and transport them from one location to the other location. So, what these two-weathering process are physical process and the chemical process. In the physical process solid rock is fragmented by the physical processes that do not alter the composition of the rock. For example, the wind, water and heat and even the glacial movement shifted the sediment from one location to the other location and example could be the frost wheezing where the water is going through the solid and the liquid phase and continuously changing the structure or the rock formation. Chemical weathering process that changes the chemical composition of the rock because of the minerals in the rocks they go through the chemical reactions.

For example, the potassium feldespar convert to calonite over the geological time. How this transportation happens? As I mentioned the land transportation is possible because the sediment is moving by the rivers, wind and ice form because the sediment is moving by river, wind and other form. Oscenic transportation because of the current and precipitation. So, the movement is continuously happening but that happens over a very large time scale. This movement followed the burial and lithification process into sedimentary rocks.

In this diagram we can say from the mountain or other region the land transportation is happening from the ocean because of the current and precipitation movement of the rock is happening they are going through this process where the burial and lithification process is happening. So, what is lithification? It is a process of porosity destruction through compaction and the cementation. So, the movement is happening because of the pressure and the cementation it is forming a more compact rock formation. How the subsurface geological formation happens? Primarily because of weathering and erosion they are the closely interrelated geological process. As rock weathers it becomes susceptible to

erosion.

Erosion is the process of removing this weathered debris. So, the rock gone through the weathering process erosion just erase those weathered debris. These forces and the other forces or processes have resulted in the creation of the sub geological formation where the petroleum substance are formed. So, how many types of the rocks are there in our earth surface? Broadly they are classified into three types. Ignatius, metamorphic and the sedimentation.

So, what is ignatius rock? They are formed from the crystallization of the molten rock within the earth's mantle. So, at very high temperature the crystallization of the molten rock happen and the ignatius rocks are formed. The example could be granite, vassalt and the gabbro. The pictures areshown there for each of them. Metamorphic rocks they are formed pre-existing rock by mineralogical, chemical or structural changes.

They happen deep within the earth crus and the example could be slate, marble and cyst. You might have seen some of them in your life where we are having the marbles, cyst and the slate in the granite for different applications. Third category is the sedimentary rocks. These are the rocks those gone through the lithification process by the compaction and the cementation deposited in the horizontal layer or the strata, one above the other at the bottom of river, ocean or in the delta. The examples are limestone, sandstone and the clay.

So, which rock is the petroleum bearing rock where the petroleum reserves may be found? These are the sedimentary rocks. So, among these three the petroleum reserves are found in the sedimentary rock. In fact, all the petroleum source rocks are the sedimentary types of the rock. Ignatius and metamorphic rocks rarely contain oil and gas substance. So, the sedimentary rock could be of sandstone type, carbonate, shell, evaporite.

These rocks are not fixed like they over the long time period they get converted from one form to the other form through a rock cyclic process. So, each rock is formed from the others through the circular process. What that circular process is there? So, let us say deposition is there. The deposition is gone through the weathering and erosion process, went to the sedimentation, gone through the burial and lithification process and from the sedimentary rock. The sedimentary rocks over the heat and pressure got converted into metamorphic rock and at high temperature, the melting of this metamorphic rock happens and that gets converted into ignatius rock.

Now all these rocks because of the natural forces, because of the tectonic plate

movements or other activity, they may get to the deposition directly or over the time they may get converted into one form to the other form in the cyclic manner. The rock characterization is important to understand the rock is having the petroleum substance or not. So, the petrophysicist and geologists they study the rock. The common thing among both petrophysicist and geologist is the rock, both study the rock. So, what petrophysics is, it is the study of the physical and chemical properties of the rock and their content fluid that include the properties of the rock, its storage capacity, means how much porous it is and how much permeable it is.

So, it is allowing the fluid to transport from one location to other location and the saturation, how the fluid distributed within that formation. In petrophysics, the same rock type is not based on the history rather than based on the pore geometry itself. So, in petrophysics, the same rock type is not based on the history, how the deposition is happened like the geologist are interested in that, but it is the properties of the rock, for example, the pore geometry that is how one rock is similar to the other rock. So, the pictures on here the distribution of the different size of the grain in the rock formation or in the sedimentary rock formation where the petroleum substance are also present along with the rock and in that when the petrophysist are studying, they are studying about its physical and chemical properties. While the geoscience also known as earth science or the geology, they study the structure, evolution and dynamic of earth and its natural mineral and energy resources.

So, how deposition happens, how deposition evolved from a different rock type are investigated by the geologist. They investigate the processes that actually have shaped the earth. When it comes to the petroleum reservoir, certain physical properties are important like the depth, how the reservoir is located and at what depth it is located. The area and the thickness of the reservoir, how big the reservoir is which is carrying the petroleum reservoir fluid, porosity, permeability, fluid saturation and the page on. These are some of the features those are important for the petroleum reservoir engineer and they get this information with the help of the petrophysicist and the geologist.

Some of the nomenclature of the petroleum reservoir is included in this diagram. So, this is one of the examples how the formation is carrying the petroleum fluid. Because of the density difference, the fluid are stored like the water at the bottom followed by the oil and the gas on the top. Some of the nomenclature that says the highest point here is called the crest. The highest point of the formation up to that point the hydrocarbon fluids are present.

The lowest point up to that point the hydrocarbon fluid could be present is the spill point. The distance between these two is called the closure and the zone immediately beneath

the petroleum is called the water water. So, this section is called the water water and this is the ages of the water and the pay that is very important. So, the fluid that is trapped underneath the surface in the petroleum reservoir it is having certain reason through which it is producing that is we call the pay zone or the vertical distance from the top of the reservoir to the point where the oil water are in contact. So, from here to here this is petroleum fluid in the form of oil and gas this called the gross pay.

Among this gross pay the section that is actually contributing for the production is called the pay. Other than this nomenclature the seal and the cap rock is important to hold this reservoir fluid at the place. The trap it is a stratigraphic or structural feature that ensure the hydrocarbon remains trapped in the subsurface rather than escaping due to their natural buoyancy and being lost. So, the trap is required in the reservoir formation to keep the reservoir fluid intact within the trap. Otherwise, the fluid will get migrated to the surface or spill out to the surface or move from one place to the other place.

The movement of the fluid within the reservoir is understood by the migration and the accumulation principle. So, migration is the natural movement of oil from source rock to reservoir rock. This happens because of the buoyancy, hydrodynamics and the capillary action. So, the density of the fluid will decide like it should move to the upside, downside for example gas will move to the upside because it is lighter. Hydrodynamics how the fluids are saturated in the reservoir how they are having the preference to move one over another and third one is the capillary action.

So, the oil substance within the reservoir is also trapped in a small, small pores those are present in the reservoir formation and the capillary action hold those fluid within those small pores. So, this capillary action is also responsible to allow or migrate the fluid. Reservoir rock must have a cap rock or a trap or a seal on the top to keep this reservoir fluid within the reservoir rock domain. The basic mechanism involved in the migration of hydrocarbons are important. As I mentioned because of the lighter nature oil settle on the top of the water and the gas above all, capillary action is the tendency of a fluid to rise in a small tube.

So, we understand with the capillary principles like the small tube the capillary of the small tube the fluid will rise more similar things happens that smaller capillary within the reservoir the fluid will try to tense or the fluid will move to the smaller pore region. The migration is a critical process and we are trying to understand this underneath the surface as several thousand feet depth it is not well understood but it is very important to understand how the petroleum migration is happening. The migration happens into three steps the primary migration. So, the source rock that is having the capability to produce a hydrocarbon fluid it produces the oil and gas. These oil and gas migrate from source

rock to the reservoir rock this called the primary migration.

In the secondary migration these reservoir fluid those reached to reservoir rock through the primary migration they may move to some nearby reservoir or some coarse grain carrier bed or some faulty reservoir because of the secondary migration. In tertiary migration when the petroleum moves from one trap to another trap or to a sheep. So, primary migration is the expulsion of the petroleum from the source rock to the reservoir rock. Secondary migration when the petroleum moved from a coarse grain carrier bed or fault to a reservoir. So, from one reservoir region to the another reservoir region it may move because of the secondary migration.

In tertiary migration when petroleum moves from one trap to another trap or it just sheep out to the surface if there is not a proper seal or cap it will keep moving from one domain to another domain or even to the surface through the tertiary migration process. So, these reservoir those are sedimentary rock reservoir actually contain the reservoir fluid or the hydrocarbon fluid. So, almost all reservoir rocks are sedimentary in the nature. Sedimentary rocks could be sand those are loose or uncomacted nature of the rock for example quartz and the feldespar. Sandstone they are the compact for conglomerate a cemented clastic rock containing rounded rock fragments like the pebbles or the gravels.

Limestone they are primarily formed by the accumulation of the shell and the coral they consist mainly of calcium carbonate and along with this water is always present as a dissolving agent in the sedimentary rock. If we look around the sedimentary formation mostly this is the carbonate reservoir around 45 percent followed by the sandstone 35 percent and remaining 20 percent are of the shell nature. So, most of the world's oil lies in the sedimentary rock formed from marine sediment deposit on the edge of the continent. For example, there are many large deposit that lies along the Gulf of Mexico and the Persian Gulf. Another important feature is most of the oil is found in the carbonate reservoir around 60 percent of the total world crude oil reserves are found in the carbonate reservoir.

For example, the Gulf country contains 62 percent of the total oil reserve that is proven oil reserve out of which 70 percent reserves are carbonate reserves. So, the carbonate reserves carrying the more amount of the oil than the sandstone reservoir. However, in India our mostly reservoir are the sandstone reservoir. So, the reservoir are having the trap because of that the fluid are stored at the reservoir rock formation. The traps are classified as the structural trap that is the result from rock layer deformation.

Second classification of the trap is stratigraphic trap where reservoir bed is sealed by

other beds. So, the one bed is sealed by the another bed and the porosity of permeability changes within the reservoir bed. More detail about those reservoir traps we can discuss about like the structural trap could be anticlinic, fault, fold or dome shape. So, there could be the structural deposition in such a manner where the different shape of the petroleum reservoir rocks are taking place underneath the surface. For example, when the rock layers are folded and taken the shape of dome it is called the anticline like this one where they are taking the shape of dome and the deposition is happening.

Reverse of it is the sink line. A fault is a break in the earth strata. So, there are several fault happen within the deposition that is we call this fault trap that could be upward, downward or in any direction. The fault naturally may occur in any direction. A fold is a bend of flex in the layer or layers of the rock. So, there are certain folds those are present in the reservoir rocks.

Those are also arranged in such a manner and falls under the structural traps. Another is salt dome is an anticlinic uplift form where the salt dome is formed like this and the oil and gas are trapped somewhere in between. And this is caused by pushing up of the body of the salt. So, the salt body is pushing up underneath the surface the formation water is having high salt and the deposition of salt may result such kind of the salt dome formation underneath the surface. Second classification is the stratigraphic traps where the reservoir bed is sealed by another bed.

The example could be the lens or anticular trap where the reserves or hydrocarbon fluids are trapped in the form of the lens. They may be unconformity trap could be formed and this happens under the situation when the sedimentary sequence lying over a tilted sequence of the earlier rock. So, these are the tilted rocks here and the deposition is just lying above of it. Pinch out is the natural ending of the sedimentary rock. So, the deposition may be where the sedimentary rocks is just ending at a particular end.

Another trap is porosity trap is created because of the variation in porosity within the rocks. So, the rock is having different porosity so some section is having like high volume to accommodate the hydrocarbon reserve other is having the less but entire reason is trapping the hydrocarbon fluid within the geological formation. Now it becomes important to understand how this geological formation happened and at what time scale those happened. And the time scale for this reservoir rock formation is geological time scale or their geological age. Geological age of reservoir is very important because it is actually used to characterize the petroleum substance and the productivity of the rock formation.

How much fluid hydrocarbon fluid are present there and at what rate those can be

produced are understood if we understood the geological age of that rock at what era they got formed. Organic and sedimentary materials they take millions of years to form the hydrocarbon fluid or recoverable hydrocarbon fluid. To understand the reservoir rock depositions certain principles are there and one of the principle is principle of uniformity tyrannization where it is assumed the geological process and forces happens underneath the surface they operate to modify the earth crust they acted in the same manner and with essentially the same intensity throughout the geological time. It means this principle says whatever the processes are happening underneath the surface to modify the earth crust or the movement of the fluid or the deposition of different rocks they happens in the same manner or essentially with the same intensity in different time scale and the past processes those happened can be explained by understanding the present situations. So, the forces those are observable today they can be correlated to the past and understood the geological formation.

E-stating relative age of the sedimentary rocks layers by the principle of this force understanding at the current situation can be correlated to the past and the age of the reservoir can be established. That is how old they are in relation to another. So, this is the relative age that says the reservoir which reservoir formation is older than the other one they did not tell about the absolute age. Based on that the geological formation are classified in different ages like some of them we are familiar the name some of the name we are familiar is Jurassic and some others are there where the depositions is happening. So, the on average the deposition of the oil and gas in the world is classified based on the geological age and the percent of the field those are having the oil and gas are estimated.

So, we can see mostly this happens during this cretaceous geological age followed by the Jurassic and this Paleocene age. So, when it comes to age dating as mentioned this principle of uniformity that gives us the relative age not the absolute age does not tell us how long ago said something took place in that formation. It only allows us to correlate one event to the other event and the deposition of the different formation or different types of the rock within the reservoir formation can be established or within the earth crust can be established and relative age tell us which one is the youngest and which one is the eldest. The deposition may happen or deposition in general happens in the layer formation over the geological time scale it may happens like not just one type of the rock is deposited than the other. So, for example shell followed by the limestone then another layer of the shell got deposited followed by the sandstone and they can be in the any sequence.

To estimate the absolute age physics of radioactive decay can be utilized that can pinpoint the absolute age of the rock but knowing the absolute age does not mean relative age is not important actually absolute age just supplement the knowledge of the relative

age. To calculate the absolute age there are several radioactive maerial those can be used depending on the formations we are having. So, for example the carbon 14 technique can be used for the organic material deposition age potassium thorium and uranium they are identified or are getting utilized to calculate the absolute age of the rock formation. So, some more basic of age dating principle like the stratigraphy the study of the origin composition and distribution as well as the sequence of layer in the sedimentary rock or astrata are studied through these two principles like the principle of horizontal horizontally.

Like most layers of sediment are deposit in a nearly horizontal layer. So, the depositions is happening in the horizontal layer over the particular geological time scale. Second principle is principle of superposition. So, each layer of sedimentary rock in a sequence that has not been tectonically disturbed is younger than the layer beneath it and older than the layer above it. So, with these two principles it is understood like the deposition is happening in the horizontal principle. So, at a particular time the horizontal depositions is happen of a particular rock formation and at a different location those can be met properly and they can be correlated like this particular deposition is happened in region A, B, C and the amount of the deposition may vary but deposition will be there in the same manner like the A type means this X type of the rock followed by the Y, Z similar deposition will happen at the different locations also.

And in that the previous rock is older than the new rock and this is older than the Z. So, the layer that is below is the oldest. So, the rock that is below that is the older and followed by the other layers those are younger than that rock. So, the layer rock sequence illustrated the relative is and deposition of the strata in the horizontal layer. Another is paleontology that study the life in past geological time based on the fossil plant and animal.

This becomes an important consideration in the stratigraphic record and is significant in assessing age of rock unit. In 1793, William Smith he recognized that fossil could be used to date the relative age of the sedimentary rocks. So, the fossil those are present in the sedimentary rocks they can be utilized to understand how old they are or the rock formation are. So, in 1793, William Smith he recognized that the fossil could be used to date the relative age of the sedimentary rocks. So, the presence of the fossil in different rocks they belong to different geological time scale those can be used as a substance to correlate the relative age of the formation.

So, the layer are characterized by their lithology and the fossil content. Then geologists can correlate the formation in a local area or around the world how these kinds of the fossils are present around the world. The petroleum industry relies on such kind of the

data for the exploration and the production of these hydrocarbon fluid. So, the mapping of the geological formations are done by the geologist and then they do it over the time and for the entire world. So, the geologist actually they build a worldwide rock column on relative time scale. What is geological time scale? It is a system of chronologically dating that relate geological strata to time.

So, when we see this picture, we can see like the entire time scale from earth formation to current can be divided in different era or in different periods. For example, like the earth is evolved around 4500 millions years ago and the human are evolved so like 1.6 million years ago only and between this lot of the things happens and the geological time scale just classified that entire period into different time zone. So, for example, the Jurassic is was around 138 millions years ago in that period. So, geological time scale becomes very important for the earth scientists to describe the timing and relationship of the event that occurred during the earth history and they are able to correlate lot of the information about what happened in a particular part of the world and how this reservoir rock formation or the strata got deposited over the time.

So, when this time scale is done, when we understood the reservoir formations and other part, it comes to the rock and organic matter that is contained the petroleum substance. So, the maturation is one of the technique or the analysis that is actually assess how thermally mature the rock is and how much amount of the hydrocarbons are stored or the rock that is subjected to the maturation study tells us the amount and timing of the hydrocarbon generated and exposed from the source rock. So, the rock sample is taken out and subjected to maturation study. The thermal maturity is the extent of heat driven reaction that alter the composition of the organic matter. So, the conversion of the sedimentary organic matter to the corrosion happens during this thermal maturity and further the petroleum substance produced.

So, the oil goes to the cracking process and produce the gas and this happens under the thermal maturity. So, the important part for the petroleum reservoir is the rock that is having the organic matter that is in the crust part from a different geological time scale. It is subjected for a certain analysis to understand the amount of the hydrocarbon those can be produced from that reservoir formation. One of the analysis is the maturation that involves assessing the thermal history of the source rock in order to understand the amount and timing of the hydrocarbon generation and expulsion happened in the source rock.

In thermal maturity, the heat driven reactions happened. Corrosion formed from the organic matter that corrosion converted into petroleum substance and in further processes the oil crack down to form the gases. The reaction involved are complex and not fully

understood but the process required parameter which are temperature in the range of 50 to 120 degree Celsius or in principle the petroleum bearing reservoir are found in the temperature range of 70 to 175 degree Celsius. These reactions happen over suitable geological time scale generally require burial to a depth of 2 kilometer or more. So, this kind of the petroleum substance over the geological time scales happens underneath the surface more than 2-kilometer depth in the temperature range of 70 to 175 degree Celsius. It does not mean like less than 2 kilometer we are not able to find the hydrocarbon fluid they are there but these are in general concept where the possibility of getting the hydrocarbon reserves are more.

Different geological formation were produced different grade of the fuels different geo chemical scales are used to indicate the label of thermal maturity of the organic matter and the types of the fluid it can produced. Some of them are betrenite reflectance pyrolysis Tmax temperature followed by the rock evil analysis and the biomarker maturity ratio. So, what these are betrenite reflectance is a measure of the percentage of the incident light reflected from the surface of the betrenite particle in a sedimentary rock. It means the rock substance is taken out the light is passed through it the light reflects because of the betrenite substance present in the rock and the measure betrenite reflectance is termed as R0 percent. So, the betrenite reflectance is a process to characterize the rock betrenite is a substance that is coaly organic masteral derived from the connective tissue of vascular plants.

So, it is a substance that is actually present in almost all the rocks. So, when the light is passed through this rock formation which is having the betrenite substance light reflect because of the betrenite and it is recorded and the parameter R_0 percent is used to assess the quality of the rock or the quality of the rock in terms of hydrogen bearing capacity. So, if the value of the reflectance is in the range of 0.5 to 0.6 percent it means the rock formation or the geological formation from where the sample is taken is at the onset of the oil generation it is about to produce the oil when the value is between 0.

85 to 1.1 percent it is the termination of the oil generation means almost all the oil has been generated from that formation or from that source rock. The onset of the gas generation happens when the reflectance value is between 1 to 1.3 percent and termination of the gas generation when the value is 3.0 percent means when the value is 3.0 percent the all the organic matter present in the source rock has been generated and the expelled out.

Pyrolysis Tmax temperature process to characterize the rock it is the temperature at which the maximum rate of hydrocarbon generation happens and that we can relate with this reflectance value using this formula where the temperature is measured in the degree

Celsius. So, what is Tmax temperature is for example the organic matter that got converted into corrosion that corrosion further goes converted into heat because of the heat and pressure into petroleum substance like the hydrocarbon fluid oil and gas. This corrosion that is present in the rock sample can be classified based on the ultimate and proximate analysis into different grade. So, based on the elemental analysis this can be classified as the type 1 corrosion, type 2 corrosion and type 3 corrosion.

So, when this rock that is having the corrosion is subjected to the pyrolysis. Pyrolysis is a process when we heat the substance under the inert condition at a specified temperature program or within a temperature history. So, for example the source rock is taken it is crushed make a powder and then it is subjected for the temperature history and this substance is heated at a specific heating rate let us say 10 degree C per minute to a higher temperature we will get the material that is coming out in the derivative form like this. So, the weight loss happens because of the temperature and the derivative of weight loss is in the form of DTG derivative of the thermogravimetric data and the temperature at which the maximum amount of the hydrocarbon generation is happened is the T_{max} temperature and these corrosion type 1, type 2 and type 3 they behave differently and they produce the maximum hydrocarbon at different temperature. So, this can be classified as hydrocarbon generation zone if the rock is immature then the maximum temperature will be reached before 435 degrees Celsius. If the corrosion is of type 2 nature the oil-bearing rock will give the maximum temperature in the range of 435 to 455 degree Celsius.

Corrosion 3 types will give the same value at a little bit higher temperature on the other side like 465 and the gas will get generated around 455 and 465 from the same source rock. So, the rock is taken to understand under what conditions the organic matter or the corrosion in the source rock and when we heat it what temperature the maximum hydrocarbon is coming out from this corrosion that can be characterized as one of the parameters to assess the quality of the rock. In rock-evil pyrolysis similar thing is done the sample is placed in the furnace or in a heated chamber under the inert condition heated at a specific heating rate let us say 10 degre C per minute to a high temperature 550 to 600 degree Celsius and during that time the evolution of the product from this source rock are characterized. So, when we heat with respect to time the temperature will increase because of the heating rate so either the time or the temperature can be considered on the x scale and y scale we will get the derivative. So, when we are heating let us say from ambient temperature at a certain specific heating rate reaching to 300 degree Celsius holding there for some time some weight loss will happen and that will reflected in the DTG curve as a peak that is can be characterized at S1 when we go further at a higher temperature a bigger peak will be appeared that is because of the hydrocarbon produced from the source rock and then when we reach to a very high

temperature another peak S3 will happen that is because of the decomposition of the minerals and releasing the CO2 to the product side and whatever the amount remaining in the crucible or in the sample holder we can measure that and record as S4.

So, the area under the curve here is S1 here it is S2 here it is S3 and the remaining after the experiment is S4. So, these kinds of the data can be used to understand or estimate the total organic carbon present in the sample and that can be done using this formula percent of the total organic carbon contained in the sample is equal to 0.082 multiplied by the area of peak S1 and S2 plus S4 divided by 10 and that will give us the TOC value. So, this S1 that measure milligram of hydrocarbon per gram of the rock that is actually S1 is appearing because of the free hydrocarbon present in the sample during the analysis. S2 happens that characterize the rock in terms of the volume of hydrocarbon that formed during the pyrolysis process of the sample and actually this is used to estimate the remaining hydrocarbon generation potential of the sample.

The source rock that is taken it might already expelled out some of the hydrocarbon fluid at the time it is taken, but when it is subjected for the analysis how much potential it is having to produce the hydrocarbon fluid is characterized by the S2 peak. S3 is corresponding to the CO2 yield during the thermal breakdown of the corrosion and the S4 is the residual carbon content of the sample. The residual carbon content of the sample has little or no potential to generate the hydrocarbon due to the lack of the hydrogen and the chemical structure of the molecule. So, this is actually kind of the char substance that remains after the experiment.

So, another technique is biomarker. These biomarkers are present along with the organic matter. The analysis of this biomarker can be done using the GC or GCMS that can be done by extracting these biomarkers from the source rock or performing the pyrolysis collecting the product and analyzing those things or in the petroleum product those are getting produced. These biomarkers are a good indicator about at what geological time scale the samples are collected because the systematic changes took place in the biomarker composition with increasing the depth of burial. So, the biomarkers are a good indication of the rock quality. Certain biomarkers ratio were compared with the thermal maturation of the organic matter like the emacs or a reflectance of butyrinite reflectance data and generation of the petroleum and consequently have been utilized as the thermal maturity indicator of the petroleum and source rock in the sedimentary basin. So, biomarker are kind of the substance those allows us to correlate lot of the information with the other data to understand the petroleum bearing rocks capacity and the sedimentary basin.

So, certain biomarker ratio were compared with the other data like the thermal

maturation of the organic matter that is change in the coal rank, butyrinite reflectance, generation of the petrol and consequently all these data set help us to understand the thermal maturity of the petroleum and the source rock present in the sedimentary rocks and all these data are actually utilized to establish the relationship that is allow to understand the reservoir rock in a more better way as thermal maturity indicators for petroleum and source rock in the sedimentary basin. Some advanced techniques are getting utilized to characterize the rock for different purposes. Actually, the understanding of the geological formation start from the drilling process itself where the log data are collected. So, at the well site analysis generally concern the evaluation of two types of the log data electrical or resistivity log data and the porosity data. So, the porosity logs actually the percentage of the voids in the reservoir which is filled with the fluid are measured with the porosity log data.

Resistivity data help us to understand the material to flow of electric current calculated by the Ohms law. This law porosity and resistivity they help us to understand the water saturation present in the geological formation. Advanced technique along with this log data those are getting utilized to understand the rock formation better. So, like X-ray, FESEM, XPS, FTIR, BET, CT scan, vibrating sample magnetometer, VSM, porosity and permeability to completely characterize the rock and understand its porosity, permeability, types of the mineral present, the pore structure, the pore volume level and allthese analyses give us the fair good idea about the rock samples, its petroleum bearing capacity and the amount of the petroleum substance that can be expected from a particular sedimentary formation. In today's class we discuss about petroleum bearing rocks, migration of the petroleum, maturation techniques and the rock characterization using different analytical techniques.

With this I would like to thank you for this lecture. In the next lecture we will discuss about the well drilling methods that is how to drill the well, what are the important component of the well drilling process. With this I would like to end today's lecture. Thank you very much.