Applied Environmental Microbiology
Dr. Gargi Singh
Department of Civil Engineering
Indian Institute of Technology, Roorkee

Lecture - 17
Microbial Ecosystem II

Dear students, until now we have studied about microbial energetics. So, we know how 1 individual cell will make sure it gets the electron acceptors, it requires the electron donors, it requires the energy, it needs to survive in the environment and thrive replicate and interact with the environment. Now, we are going to move on to microbial ecosystems like we did in the last lecture where we I introduced you to the basic concepts in ecology. So, today we are going to go little bit more in our advance and look into terrestrial ecosystems, which is the ecology of microbes in terrestrial ecosystems. So, let us start here.

So, microbes to live in an ecosystem they require 2 things, they should have all the resources that they need and they should have the right conditions to thrive.

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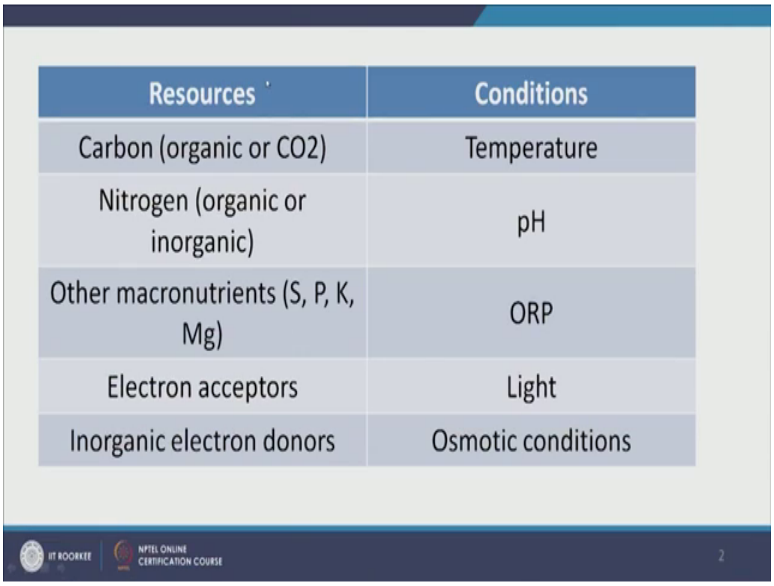

Resources	Conditions
Carbon (organic or CO2)	Temperature
Nitrogen (organic or inorganic)	pH
Other macronutrients (S, P, K, Mg)	ORP
Electron acceptors	Light
Inorganic electron donors	Osmotic conditions

So, some of the resources that microbes will require to thrive are carbon; some autotrophic microbes can utilize carbon dioxide as source of carbon others require organic carbon material. So, this is very important for life as we know that carbon must be available in the right form in the environment. The other thing we know is nitrogen is very essential part of a cell. So, if you remember there is DNA, the double helical structure that carries the information on how cell would live for proteins it would make how it would survive and it is activities.

So, nitrogen is very essential component of the genetic material. So, nitrogen should be available in it is environment either in organic form or inorganic form. Now, some microbes can actually fix inorganic form of nitrogen such as nitrogen gas and they referred to as nitrogen fixing bacteria others cannot. So, they would require other assailable forms of nitrogen such as nitrate, nitrite, ammonia or organic form of nitrogen; some cells also require other micronutrients.

So, remember the word here is macronutrients not microbe. So, these are nutrients that it requires in good quantities such as sulfur for phosphorus, potassium and magnesium. Then, there are micronutrients that I have not put in this table that are also required in trace amounts. So, we have talked about trace elements before how they are essential for making certain enzymes and amino acids, so we need them to got in very little amount.

Usually, microbial communities have a way of finding these micronutrients trapping them and recycling them over and over. So, the environment does not have to be rich in micronutrients, but definitely rich in carbon, nitrogen and other macronutrients. Also, then environment should have a good supply of electron acceptors and electron donors because all life processes are a redox reaction, they are a reduction in oxidation of electron acceptors and electron donors, so it is important to have both in the environment.

Now, when we talk of conditions the conditions should be just right for the microbe. Now, the temperature that is right for 1 microbe may not be correct for the other microbe for example, if we have a thermophilic microbe that loves hot temperatures and we put it in cold water, it will die it has to have just the right temperature that it requires; ranging from very cool like psychrophilic microbes for example, found in ice sheets of Antarctica and arctic and Himalayas or we can have thermophilic microbes that love to be in hot water lakes or undersea volcanic vents.

Then, the pH should be also right and in one of the first lectures I talked about different range of temperature and pH in which microbes survive. So, a microbe that grows in acidic lake, will not survive in a neutral or mays not survive in a neutral and alkaline lake, so the pH has to be correct too. Now, thinking of temperature and pH it is very important to note that human not only microbe, but even higher orders of life such as human beings also require just the right temperature and Ph; for example, I cannot survive in extremely cold environment such as minus 120 degree Celsius or hot environments such as 70 degree Celsius or 80 degree Celsius as we know it we cannot survive and same is true with pH. If pH is very low in our environment; in our air we will get burned and we will die of necrosis and other diseases; similarly, if pH is very high we will have corrosive burns.

Next is ORP, which stands for oxidation reduction potential. So, basically a methanogen which requires a very reduced environment to survive, will not survive in oxidized environment such as (Refer Time: 04:53). So, not only does methane methanogen, a methane producing bacteria it not require oxygen, but if it is exposed to oxygen it will die.

So, in this case we require just the right amount of ORP oxidation reduction potential of environment, the light should be correct too. If there are phototrophic bacteria and they are not getting oxygen they will time in the osmotic conditions, if you remember we have talked in 1 of the early lectures that cellular membrane is a bi lipid in bacteria and it has hydrophilic and hydrophobic end.

So, inside the cell there is some osmotic pressure relative to outside of the cell and if there is change in external conditions; the osmotic pressure in external condition the cell might either explode or implode. For example, if I take microbes that live in hypersaline environment like ocean and then put it in a freshwater bowl or freshwater lake, then they are likely to lose their integrity, same is true otherwise if we take water from or if we take microbe from a freshwater lake and put it into a saline environment, it will also lose it is integrity and not survive most probably.

Then, another thing we need to understand, so this is microbe in a individual level, we know what microbes require on an individual level? What resources? What conditions? Now, let us look at what microbes require?

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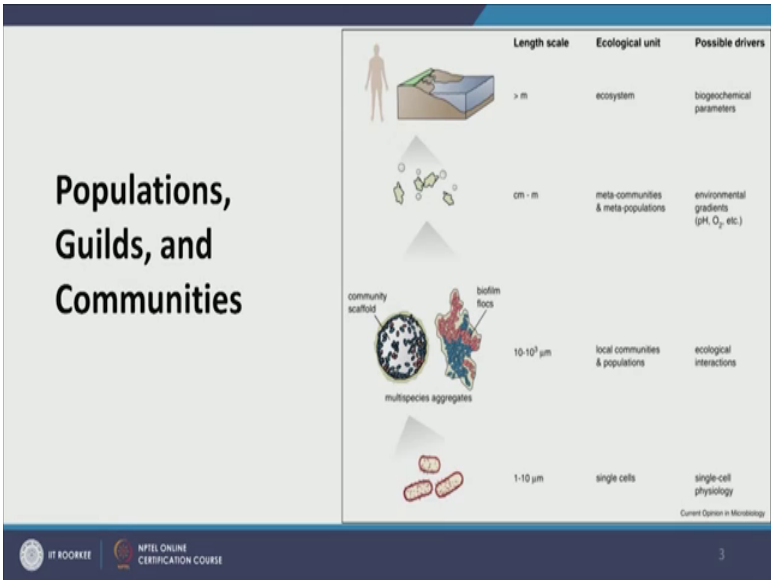

Then, they we are talking about many microbes present together in an environment because there is hardly any environment where there is just one microbe sitting and you are looking at just 1 microbes need, usually it is either a population Gildo community. So, now, is a good time to introduce you to the concept of population Gildan community, I have sort of mentioned this before, but let me be very clear, population is when many microbes belonging to same species are together.

So, we might have population of eco live, they all belong to same species. On the other hand, community is when different populations survive together. So, we might have ecoli, we might have pseudomonas aeruginosa, we have some other microbe acetobacterium (Refer Time: 07:00) pseudo bacterium coming there. So, we have multiple populations, so we have a lot of microbes from different species together they are interacting with each other, yeah this is community; microbial community and now the 3rd word is guild.

Now, guild is a group of microbes that are same in their function and this I have talked a lot about when I was talking about metabolism of microbes in previous lectures that because the ORP or oxidation reduction potential of an environment is bound to influence all the microbes that are present in the community, they are likely to have similar functional traits and we will go about this and I will show you right away what we mean when we talk about guilds.

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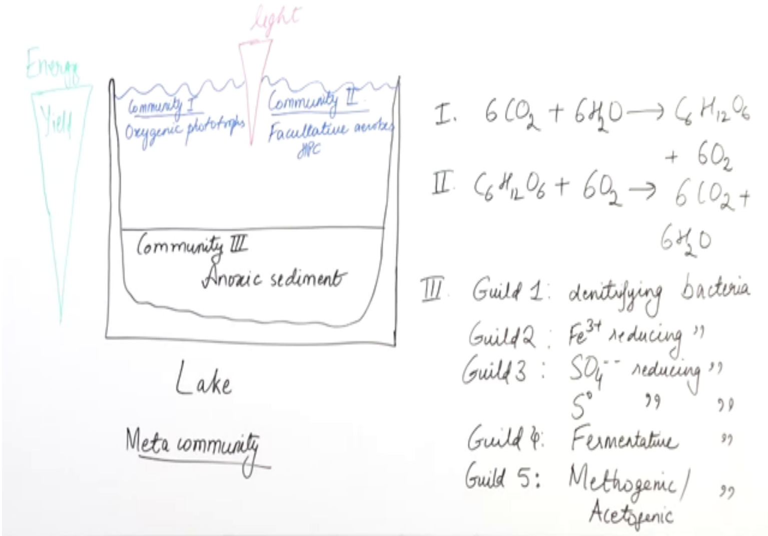

So students, now let us take a look at population guilds in communities within 1 particular environment. Here, we have a diagram of lake a very rough schematic and what is in blue and wavy is water and this is the sediment and this is the control volume boundary that I have drawn for the lake and this is the cross section by the way of the lake. So, let us look at the microbial community present in the lake. So, where, look here the red arrow is showing you the depth until which light can penetrate and it is width gives you an idea of the intensity of light that enters and reaches at this particular depth.

So, until where the light can reach we can have 2 kinds of microbes, where in the first microbial community we have oxygenic phototropes. So, remember because this is towards the surface of the lake we will have reaeration and aeration going on and thus oxygen will also oxygen will also be present in the top surface. So, microbes that can utilize the light, produce food by consuming carbon dioxide as the source of carbon they will be present here, the other kind of microbes that we will have here will be facultative or obligate aerobes that require oxygen as I mentioned oxygen will be present here.

So, the first kind of microbial community; now, remember I am calling this microbial community. So, it implies that there is not just one oxygenic phototropes, but there are multiple species of oxygenic phototropes that might be present or in certain unique environments you might only have one singular population of oxygenic a phototroph or facultative aerobes obligate aerobes.

Now, in community 1, the ones that is a phototroph they use light, they use carbon dioxide and water and produce glucose and oxygen. Now, facultative aerobe are in cooperation with them they are very happy to live next to the oxygenic phototrope because they are producing oxygen and they are producing glucose; facultative aerobes and aerobes in general can consume the glucose by using oxygen as a electron acceptor and get tremendous amount of energy from here. So, this is and produced carbon dioxide which can be consumed by oxygen in phototroph. So, this is an example of cooperation between 2 different microbial communities.

Now, in towards the sediment or towards the bottom of the lake we have anoxic zones and we might even have completely anaerobic zone. So, anoxic zone has like trace amount of oxygen present, anaerobic zone no oxygen present. So, in sediment for example, we might have 3rd kind of community that is lives in anoxic or anaerobic environment.

Now, in this part of the community if you might have at the top layer let us say there is some amount of nitrate present. Now, so the microbes that can utilize the nitrate, why did I say top layer because let us say initially when the lake was built, let us say it is a manmade lake there was nitrate present here. So, microbes started utilizing nitrate and as the nitrate depleted they moved on to different electron acceptors and they made a gradient of electron acceptors over time.

Why would they be a gradient because remember the oxygen is coming in from here and oxygen as it comes in, if nitrate has been denitrified it will oxidize it again so there is higher chances of nitrate to be present on the top of this sediment layer than on the bottom. So, one guild or one functional community of microbes could be nitrifying bacteria. So, bacteria or microbes they denitrify they are one functional group and they are likely to be found in the top layer.

Next, we have the 2nd guild which is ferric reducing bacteria. So, when let us say nitrate got depleted and now we have ferric ions present. So, microbes that can utilize that reduce them and get energy will be present here the 3rd guilt and most probably below it would be sulfate reducing bacteria followed by sulfur reducing bacteria and then fermentated microbes and then methanogenic and acidogenic microbes.

So, you notice here, that as the electron acceptor gradient; so, we notice here that the microbial community gradient follows the electron acceptor gradient. So, here we have oxygen, then we have nitrate, we have ferric, sulfate, sulfur, then we have fermentative condition and then methanogenic and acidogenic conditions. So, again is our microbes that have same function. So, all microbes that are iron reducing microbes they form one guild, all microbes that are iron oxidizing microbe their other guild. Now, they might have different populations within them, yeah. So, within guild too there might be many different kinds of iron reducing bacteria, wherein sulfate reducing bacteria they might be very different kinds of sulfate reducing bacteria.

So, a guild might have singular population or it might have a community, but the unifying factor for a guild is that their functional characteristics are same. Now, as I mentioned before population you should remember is one species only, over all this together. So, a community would be here, you know the environment is similar, right; their functions are sort of similar, multiple populations living and interacting with each other.

So, this is 1 community, community 2, community 3, within each community there are multiple populations; together they make a Meta community, clear. All right, now note here from top to bottom we have a gradient of oxidation potential; oxidation reduction potential, we have a gradient of electron acceptors therefore, and we also have a gradient of the kind of microbial communities we will have, no now because oxygen is energetically most advantageous we also have a gradient of energy yield.

So, if the microbes growing on the top of the lake, would have would get the highest energy in yield and the ones on the bottom that are methanogenic or acidogenic will have minimum energy yield all right. So, to revise we have single cell physiology, so we have single cells and then we have local communities and population, remember population is microbe of same species, communities are different populations existing together for example, in this microbial frock we have microbe stained red and microbe strained blue, all together this is a community.

Then, we have Meta communities and Meta population. So, a Meta community and a Meta population the example would be the lake that we just saw and then we have ecosystem. So, we have the entire region that includes aquatic components, terrestrial components and air components.

So, the range in size also varies, our single cell can be anywhere from 1 to 10 micrometer, the communities and population can be anywhere up to 1000 micrometer, the meta community is meta population and we will see some of them today in lecture can be up to meter and ecosystem more than meters many meters.

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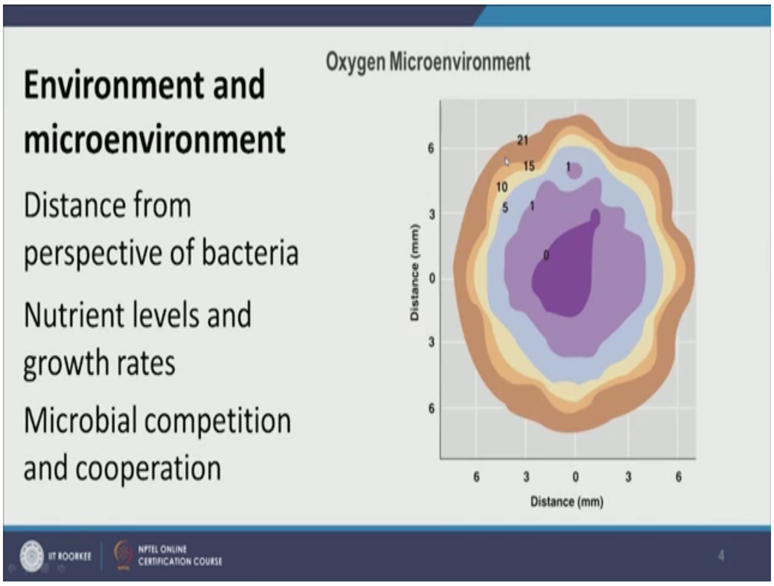

So, now let us look at environment in micro environment of microbes, their populations and their communities. So, when we talk of environment and microenvironment let us try to get an perspective of the area or a microbe on distance.

So, for a human being a 10 centimeter is not a long distance, yeah. So, 10 centimeter we can just approach it very easily, but now think from the perspective of a microbe that is only a few micrometer in length, for that microbe 3 millimeter can be as long as it is as 2 kilometers is for human being.

So, within 2 kilometer radii, we can have different as we know we have different populations of higher order of life, we can have monkeys, dogs, cats and rats and human beings again human beings all following different practices here, different food habits; similarly, in for microbes within 3 millimeter space it is a very small space from humans perspective, but it is plenty from bacterial perspective that we can have by microbes bacteria of very different functions of very different populations.

So, if within 3 millimeter space we can have very, very diverse community, as diverse community and even more diverse community than we have when we talk about higher order of life like birds and animals and humans and etcetera, insects and etcetera within 2 kilometer radius. The other thing is within 3 millimeter radius you might say well it is just 3 millimeter; the environment would not change a lot. So, the microbes within 3 millimeters should not be very diverse, but the beauty here is that, in the micro scale we notice that the environment changes, the gradient of rate of change of environment is very high.

Now, on the right panel here, I have a picture and this is a cartoon a schematic showing you the oxygen levels in a soil micro pore. So, you know soil has pores where through which the air and water are transported, now this is a micro pores. So, even among pores it is really small and we notice that this is some 12 millimeter in a diameter and now what you are seeing in different colors is oxygen gradient. So, in the brown you have the highest amount of oxygen and it reduces that it goes to orange and then lighter yellow and then blue, then a little bit slight purple and then dark purple there is no oxygen left.

So, within this 6 into 6 milli, so we have 12 millimeter range, we can go from aerobic microbes to fermentative methanogenic and acidogenic bacteria. So, think about it this way and so if you look at even this is too big a micro pool by the way, even in pools as small as 3 millimeter we have seen similar characteristics, similar behavior. So, in the dark purple region we might have methanogens, acidogens, we might have sulfur reduction, sulfate reduction, nitrite reduction, nitrate reduction and then, obviously, oxygen reduction. Now, all this diversity in the ORP, oxidation reduction potential of this micro environment will result into diverse function diversity of microbes, which will allow a very diverse community to grow in this 12 millimeter by 12 millimeter micro pore.

Now, all these microbes of different kinds they will compete for resources; for example, in the aerobic region denoted here by dark brown, we not only have one singular kind of aerobic bacteria or archaea or eukaryote, but we have different kinds of microbes and all of them are competing for oxygen. So, the one that can grasp oxygen fastest, the one that can degrade it is electron donor fastest and grow fastest is likely to out compete other microbes, but then there are other factors also that influence microbial growth, microbial competition. So, now, about microbial complete competition because of this, we notice that over time the microbial communities undergo succession.

So, initially we might have 10 different aerobic microbes here and after some time we notice we have 8 because 2 have been wiped out and let us say microbe population number 4 was the most abundant initially, but now that might have been out competed by microbial population number 6. So, we notice that microbial communities undergo succession over time because of competition and in the other end of spectrum we have cooperation.

So, microbes cooperate with each other for example, someone’s waste product could be someone’s input and in next few slides we will see how microbes not only cooperate with each other, but they also cooperate with higher order of life such as plants and such as humans and if you remember, this is 1 of the first things I talked about in introductory lectures that we have more non human cells in our body than we have human cells, begging the question how human we are.

So, for example, in our gut we require certain microbes to give us a healthy functioning of gut and then that microbial balance gets upset, we have diseases such as diarrhea and irritable bowel syndrome. So, microbes are very important in terms of both competition and cooperation and by the way this diagram should remind you of what we just studied in the lake how different kinds of functional gradient can be found in environment. So, now, let us look at surface in biofilms, until now we have not talked about how microbes interact with the environment. We know they are there, are they just sitting there? Are they attached to where they are sitting? Or are they floating in water? Yeah or flying in the air?

So, let us start with understanding all microbes interact with surface, we know that many microbes love to attach to a surface and there are many advantages why they would love to attach to a surface for example, let us say we have a stream with relatively low amount of organic material, low amount of electron donors and electron acceptor, it has good electron acceptor oxygen, so it is a very healthy stream and it is flowing down.

Now, as it flows down it interacts with rocks and other surfaces where microbes can attach. So, the microbes in water itself do not have a lot of food to eat, but once a microbe attaches to the rock it now has a perspective from which it can stay stationary and capture all the nutrients from the flowing water. So, attachment has an additional advantage that microbe can capture nutrients in flowing water instead of just flowing with, in an oligotrophic environment, which means in a nutrient deficient environment.

So, it is advantageous for microbes to attach, there is another reason why microbes would love to attach to a surface. When they attach to a surface and they replicate, they produce daughter cells and the daughter cells also attach to replicate over time, what we might have is accumulation of material. So, initially we have just a plain surface with one microbe attached, microbe replicates produces 2 daughter cells and so on and so forth the application continues, over time we have a heap of microbes and now they are talking about a singular population, but then we can also have communities, complex communities of microbes.

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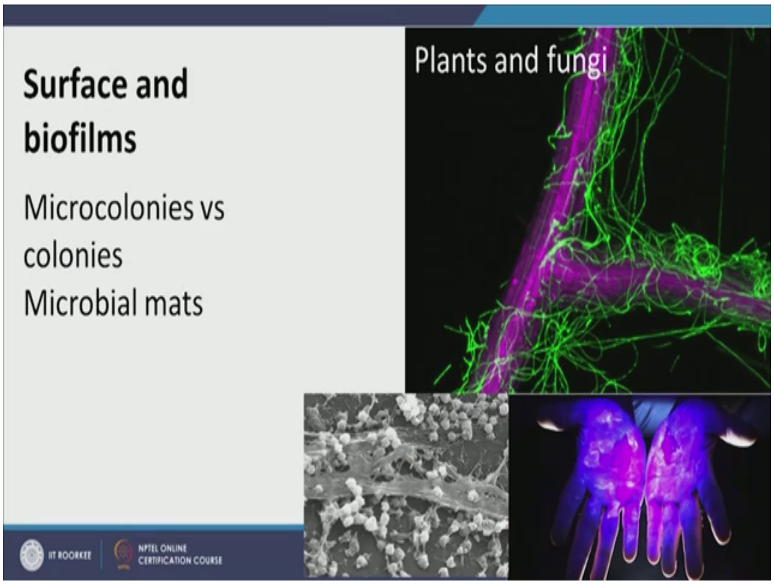

Now, if microbes are faced with some problem like a disinfectant, then only the ones only the microbes on the boundary would be affected and the microbes closer, in this accumulation this heap of microbes will not be affected, thus surface attachment and growing this films on a surface actually ensures longevity of microbes.

The other advantage of attaching to a surface and growing these films they are referred to as biofilms by the way. So, we have here the second term biofilm is that these biofilms, microbes and biofilms they secrete what is called as EPS. So, these are extracellular polymeric substances that create a mesh in which those cells can trap not only themselves, but can also trap nutrient. So, if there is any glucose molecule floating in the water, it will be trapped in this matrix and then the cells can devour it.

So, thus we see that biofilms can give a protection to microbes and it can create a nutrient rich environment in otherwise neutral deficit environment. So, biofilms are very, very beneficial for microbes. Now, if you remember in 1 of the first few lectures I talked about plating of microbes and culturing so, in plating what we have is we spread the inoculum over a plate and we spread it in such diluted amount that we expect that when they grow from a singular microbe from a single bacterium for example, one colony will sprout up which we can see the next day or the day after or after some days.

So, what the important take home message is that the colony emerged from singular microbe, singular micro bacteria or some other microbe and it is visible to eye, so we can actually count them right; however, sometimes in oligotrophic environments such as very clean streams, in drinking water systems the microbes do not grow into colonies, in sense that even though they are source from a single microbe they grow make micro colonies, so the only thing is we cannot see them.

So, for example, let us look at this picture on the right panel; right bottom panel. So, this is a hand of a person and we are noticing this under dark light. So, this is a special technique where we can ask microbes to, we can make microscopes microbes to fluoresce to give fluorescent signal under a particular (Refer Time: 24:45) when lit by a particular light.

So, whatever you are seeing here giving a fluorescent signal shining is actually microbial micro colonies. So, on hand like mine which I believe is pretty clean right now, I cannot see micro colonies because they are too tiny and only when I put my hand on a dark light then I can see oh how this tiny colonies growing, that are otherwise invisible to naked eye. So, structurally they are too small to be seen, but the signal can be seen by the eye. Now, microbes not only make micro colonies in our body; on our body and in our body, but also in other surfaces for example, in the top right panel we have a plate titled plants and fungi.

So, in the purple you have root; the root of a plant and in the green you have fungal sheath. So, the fungus it has attached to the root has entwined with it and is enjoying the nutrient rich environment of the roots and hopefully the root is also benefiting from the fungal attachment to it. So, remember it is not just bacteria, but fungus also attaches; other microbes also attached to surfaces. Here, we have another example where we have these microbes who have attached to this surface and this is actually a picture from a microbial mat. So, micro colonies are very small we cannot see them, colonies we can see there, both are their source is singular microbe.

The microbial mats are very interesting, they are microbes have populated so much, they have grown so much, the biofilms that they are centimeters thick and even meter thick maybe and we can see them, well I don not know if me to think exists, but definitely many centimeter thick we can see them and we can see the gradation, so let us take a look at that. All right, before we take a look at that let us go back to our root microbe interaction.

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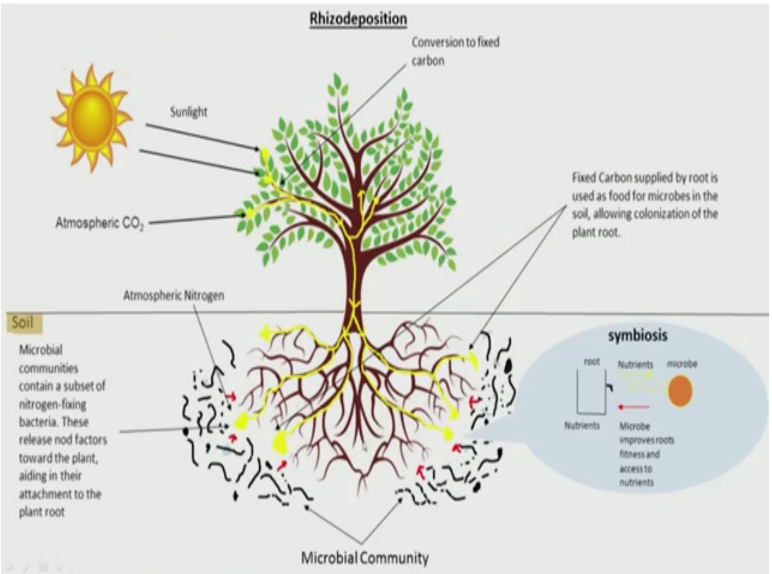

And here, we have a plant, a tree and it is making food from sunlight, carbon dioxide, water and in it is root it is using roots to get water and other resources that it requires and you will notice that the roots provide a fixed supply of carbon, the yellow line or nutrients to these microbes here and these microbes in other on the other hand fix the nitrogen and they provide nitrogen source to tree.

So, this is a very good example of symbiosis. All right, so now, let us take a look at microbe, microbial growth on surfaces.

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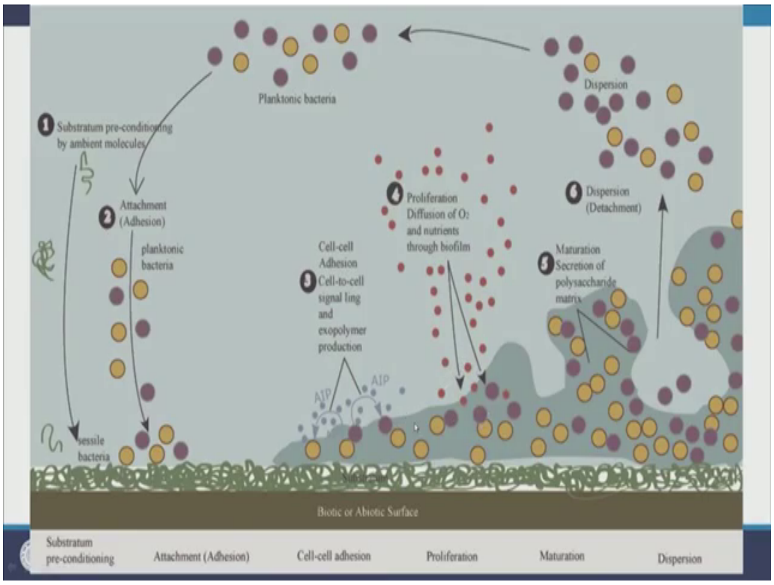

So, the first 1 we have here we want to understand how biofilms grow and how microbes probably freight in them, later on we will be talking about drinking water system and drinking water treatment, it is very important to understand how biofilms will grow in our drinking water system and this is a big challenge by the way, so let us get our fundamentals right here.

So, in this picture we have 6 different stages of biofilm formation, the first stage is substratum preconditioning. So, initially this is our biotic or abiotic surface. So, a biotic surface would be like root or like a teeth or like my hand or hand; abiotic could be like a pipe material or a wall right, now or like a catheter when we are talking about medical devices.

So, we have the (Refer Time: 27:59) bacteria, they will grow and they will attach to the surface and then prepare the surface for better attachment by like microbes. So, this is how bacteria have attached and they have conditioned the substratum. The substratum is now ready to be sticky to allow things to stick to it and now we have this packed microbes in our yellow and purple color, there planktonic bacteria; what means they are free freely floating bacteria.

So, here we are imagining this blue environment to be water. So, they are freely flowing bacteria and they are coming in all the surface ready for attachment and then they get attached, when they get attached not only do they get attached to the surface, but they also get attached to each other.

So, what we notice in the 3rd step is cell to cell adhesion. So, these microbes they start talking to each other using chemicals. So, they do bio signaling, cell to cell signaling and they tell I am here who else is here, how many of us are here, are you are the other microbes present here or the enemies or their friends are they going to compete are we going to cooperate are we going to have predation. So, they communicate with each other and then they stick to each other according to whatever serves them the best. So, they will stick to the ones, when sticking is beneficial. So, they have cell to cell adhesion, cell to surface adhesion and they have a very nice communication network.

Now, at this stage they also start producing the exo polymer. So, this is EPS, which they produce, so this is a net that they cost. So, if you see here dark blue, darker shade of blue here this background environment is the eps that they have made. So, initially there was no EPS just the surface was ready to accept microbe, but now we have EPS layer that will trap both nutrients and trap the microbes.

Now, in the next stage we have proliferation, so in proliferation this biofilm that has grown and this EPS structure that has grown here. So, it has some microbes and lot of EPS structure, they will start trapping food, so nutrient. So, diffusion of oxygen and nutrient through biofilm because this is a pipe cut schematic showing how biofilms grow in pipes.

So, we are talking about oxygen, but if not it does not have to be necessary oxygen as we see later, but the nutrients electron acceptor, electro donor and everything others else required will start diffusing into these biofilms and the microbes will start proliferating which means they will start growing in population and then when they start growing in population they produce more and more EPS and they make more complicated structures and this is maturation. So, they are now secreting polysaccharide matrix EPS and now they are having more complex structures and very diverse microbial community by normally by this time.

Now, note here they allow diffusion of oxygen and nutrients, let us say we have a disinfectant in the environment. Now, this disinfectant will also diffuse, but will only affect microbes who are at the boundary and some microbes here will survive and once the microbial community in the biofilm becomes more and the biofilm becomes more mature, then the population surviving microbes in face of disinfectant would be much higher than microbes that don not survive, after a while when the biofilm grows too much, that it is structurally unstable and the microbes are too populated they are ready to find new avenues for attaching and for growing then they would have dispersion.

So, this is where the biofilm releases itself, breaks how open and the microbes are released back and they become planktonic bacteria. Now, this is where the problem is, let us say there was a pathogen hiding and proliferating here, some pathogens can proliferate in biofilms many cannot, but some can or let us say just someone was surviving here, saving itself from the disinfectant and getting the minimum nutrients it requires to survive in such an oligotrophic environment. Now, in this stage when they are released back into the water, then this water can be drunk by a human being or by some other being.

So, when we open the tap and we get this planktonic bacteria, some of them could be pathogenic and next thing we know we are falling sick or the other fate of planktonic bacteria is there nobody drinks them, but they find more attachment surface and they attach. So, you can see this is a cycle and they induce each other, so more biofilms produce, more biofilms one big it is the other and next thing we know that our drinking water system is afflicted and with lot of biofilms. So, biofilms are rampant in our water distribution system.

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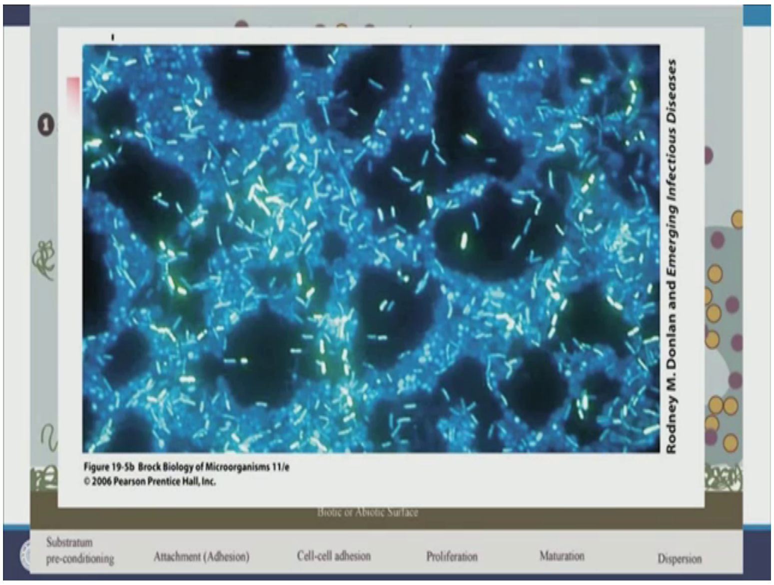

Now, this is a picture you might think how will, microbes attach to something like a metal surface. This is a picture showing microbial attachment to stainless steel surface. So, we have stainless steel surface in the background and all these forces that you see here is from microbes all right and this is a picture of different pipe material.

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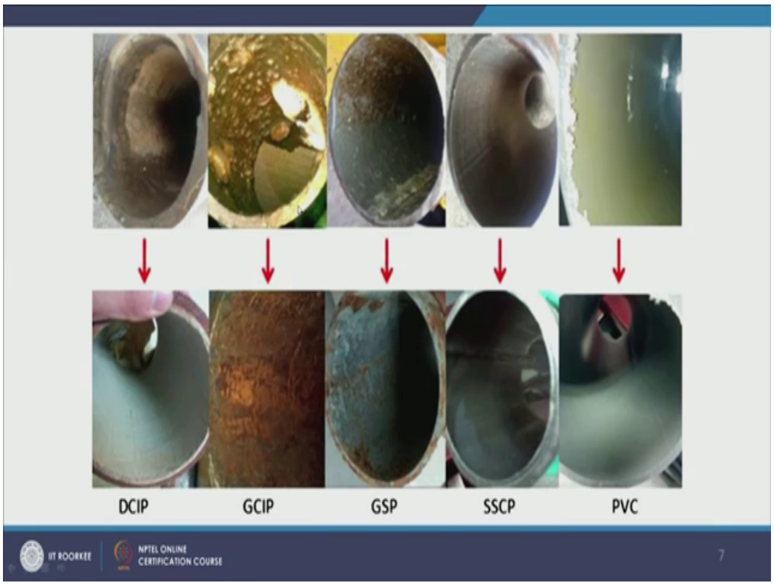

So, in the right here PVC here, we have different kinds of metallic pipes and we notice how biofilms develop and how they aid in corrosion, we would not get into depth here, but later on when we talk about drinking water treatment, I will talk more about this. The other example of biofilms would be our teeth. So, remember this is not just all plaque that forms in a teeth, but now we have bio from shining unity. Now, let us talk about microbial mats.

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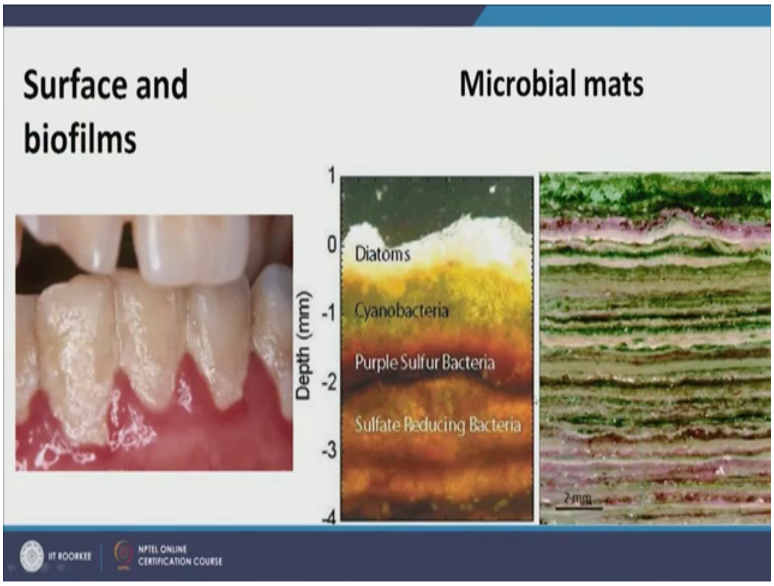

So, as I said microbial mats can be multiple centimeters. So, here we have nearly 2 centimeter long deep microbial mat. So, we have different layers and the beauty of microbial mat is that they have different layers. So, here we have 4 millimeter depth of microbial mat, let us look on the top we have diatoms, then we had their kind of special kind of algae who are very highly sophisticated and I might say microscopically very beautiful cell wall kind of structure and then we have cyanobacteria, then we have purple sulphur bacteria and they are sulfate reducing bacteria.

So, you can see not only do we have layer of microbe, but we also have a layer of functions and if you remember what is a guild? A guild is microbes of similar functional nature. So, this, these are guild, these are layer of guilds, surface reducing bacteria and you know they can be different they can belong to different phylum. So, they can be very different, but they are all same function, so this is a guild.

Now, let us look at some very exciting microbial mat, usually found in the coastal regions of Chile and Peru in South America and this is a sulfur oxidizing chemolithotroph thioplaca.

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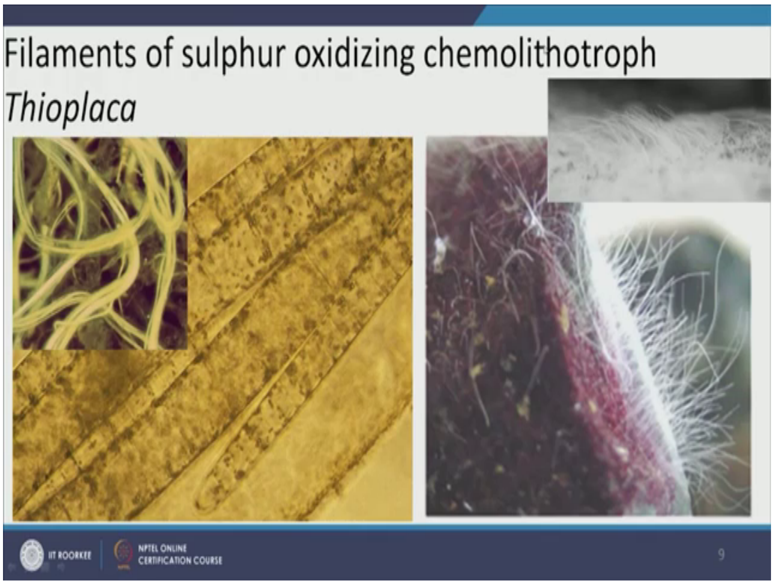

Now, thioplaca oxidizes sulfur and it is a chemolithotroph and it forms filamentous microbial mat that can go up to 5 to 10 centimeter below the sediment. So, we are not just talking about 2 centimeter here as we were talking here, but here we are talking 5 to 10 centimeter below the sediment and then they have these hair like filaments that they have outside these are sheath that actually allow that whole thioplaca together. So, this is a microscopic picture and these are indeed some other beautiful pictures from Chile and Peru.

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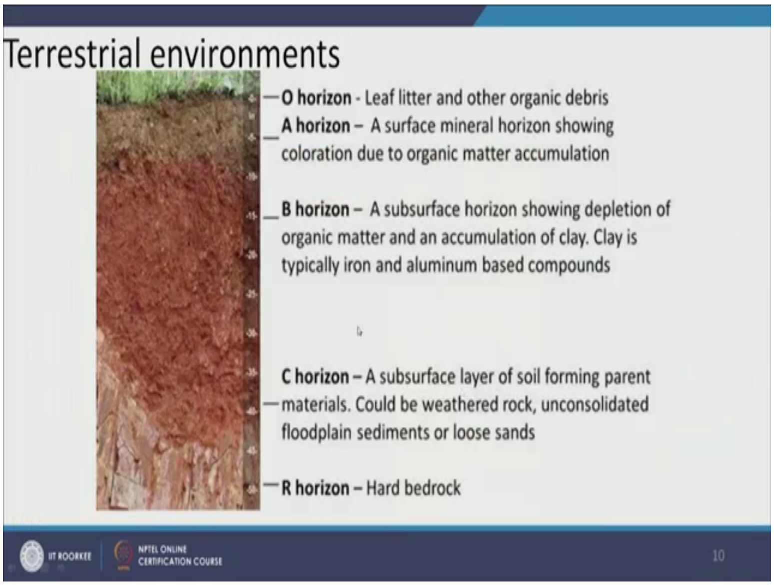

Now, let us look at terrestrial environment as promised. Now, this is a well mature soil. So, not just why would microbes form a gradient? Why will they go from diatom or to all the way to sulfate reducing bacteria as we saw in this microbial mat? Because the environment is changing this is oxygen rich and then oxygen gets depleted, as oxygen gets more and more depleted and let us say for some reason the reaeration is stopped, then the sulfate reducing bacteria will occupy more volume than the other and when sulfate is gone then we have fermentation or another of the electron acceptor being reduced. So, it is not just microbes that form gradient, but in nature too we noticed that the environment is has a gradient.

So, this is a fully mature soil and at the bottom we have our zone; our horizon which is a hard bedrock, then we have C horizon which is a subsurface layer or soil forming parent material, this could be bearing material for the soil, this could be weathered rock, unconsolidated floodplain sediment or just loose and then we have the B horizon here, which is a subsurface horizon which is showing depletion of organic matter.

So, we have rich organic matter dark, so rich organic matter gives soil dark color, but here the color has been lost we have a lot of clay and we have depleted organic matter. In A, we have dark coloration because organic matter has accumulated; in the O we have leaf litter, so we have lot of biomass waiting to degrade and waiting to make the soil darker in color and make it rich.

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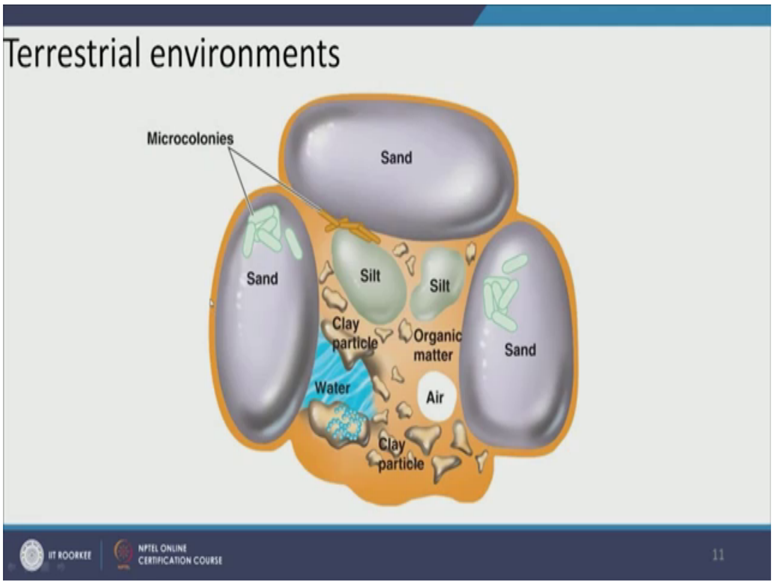

As I talked earlier about micro environments, terrestrial environments are very complex for many reasons because think of it this way each pore in the soil and even in a small handful or spoonful of soil you will have so many pores, each pore is a micro environment and within this micro environment we have gradient of nutrients, we have gradient of electron acceptors and even we have some pockets within micro environment that will have waters and will not have water as illustrated by this schematic, thus we can expect very diverse microbial communities in each pore and you know 2 pores adjacent to each other might have very different microbial communities flourishing one might be anaerobic, the other might be water loving aerobic.

So, let us look at this little micro pole, we have sand particles, we have some silt, we have some clay, small clay particles here it is air trapped. So, oxygen in this air would be utilized until there is no oxygen left and then because they might be nitrogen and other things we might have a nitrogen fixing bacteria or the kind of microbes. Now, in each of these zones we have micro niches that are perfect for a particular kind of microbe to grow. So, microbes that love binding to sand will probably stick to sand and grow there, the ones that would love to grow between silt and sand or stick on silt grow sticking on silt; the ones that love to grow in water will grow wherever they find little trace amount of water within the microbe pore and we are talking really small environment here, yeah.

So, we notice that there are a lot of m nutrient diversity and even you know as our air gets consumed here, initially we will have aerobic microbes here, then when air gets oxygen gets consumed it will move on to non oxygen electron acceptor zones such as microbes that use nitrate microbes that reduce sulfate or sulfur and eventually to methanogen and fermentation, fermentation and methanogenesis. So, we will see both electron acceptor gradient, we will see nutrient gradient and water gradient some love water some like to like water, but they like to keep a distance. So, they would grow in this region instead of going in this region.

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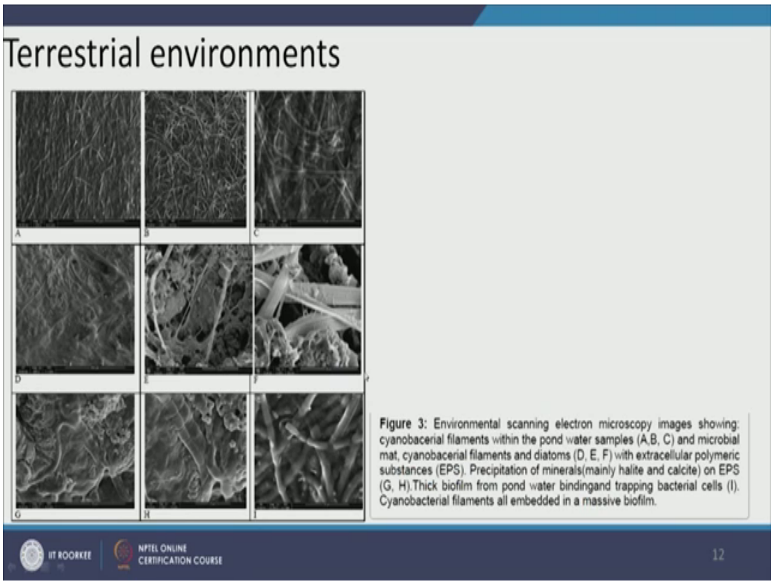

Now, for example, I here I showed you microbes that love to stick to sand. Now, there are microbes that what they do is and this is electron scanning this is a scanning electron microscopy image that is showing you cyanobacteria by the way and these are filaments and what they are doing is in this they the filaments and the sand traps the microbes. So, the sand is what is trapping the microbe here, like how this picture shows here; the sand is what these asking microbes come and stick to me. So, this is what this picture is showing.

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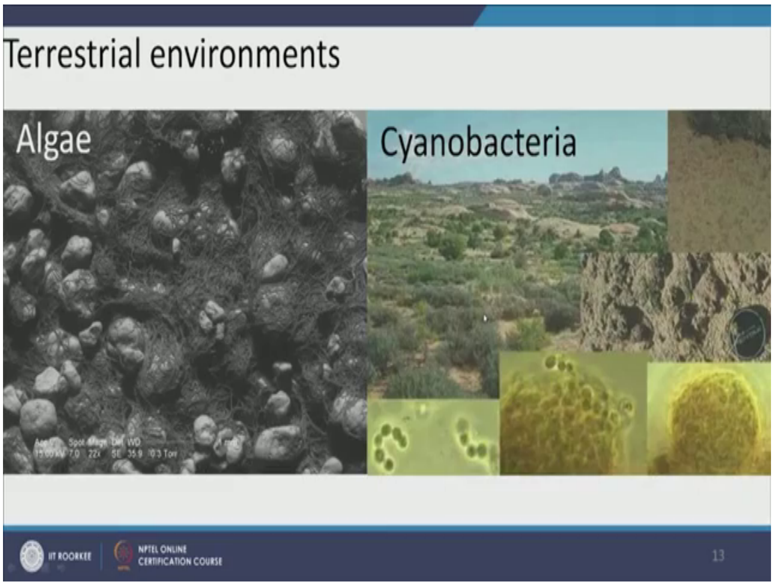

But, here we have a very different phenomena happening, we have no sand particles in desert and in this particular example we have cyanobacteria again like here and here we have algae and they are binding the soil.

So, both the microbes can be trapped by the soil, can be trapped by the sand and then they will proliferate they will grow they are or undergo succession or they can actually change their environment by binding the so here, all these sand particles are very they are not attached to each other, they can disperse very easily, but the algae has grown in and around them and bound them together.

So, next thing we know the soil is very compact, it is not loose you, would not have sand blowing on your face and similarly here is a desert in USA, where they conducted investigations; intensive comprehensive investigation and they found that it was cyanobacteria that was actually the binding the sand particles together and thus changing the characteristics of soil and changing the characteristic of vegetation.

Now, within soil as you now notice that there are different micro environments, there are different functional guilds and thus we notice a very, very diverse microbial communities in our soil and this is just a snapshot of some very basic eukaryotes, archaea and bacteria there have been known to found in soil, each of these kingdoms whether we go to eukaryotes or bacteria or archaea, each of them are very, very diverse.

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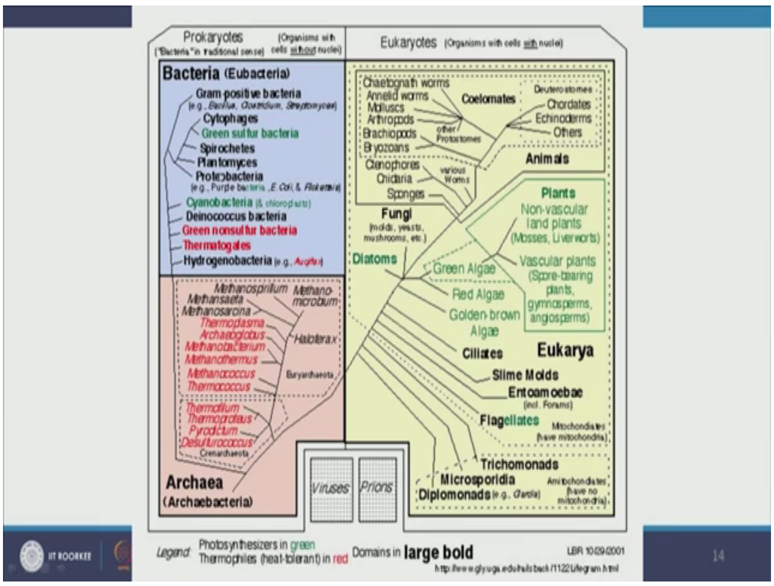

So, we cannot say that soil you have gram positive bacteria, spirochetes, plantomyce, plantomyces or proteobacteria you will have a lot of microbes and within each of them for example, proteobacteria is a very, very broad phylum within proteobacteria we have alpha, beta, gamma, delta and epsilon proteobacteria and within each of them we have very different kinds of microbes for example, some delta, delta proteobacteria are sulfate reducers, some are sulfur oxidizers, some are aerobic and they do not care about sulfate reduction or sulfer oxidation. So, as you notice microbial communities in soil interest terra are very, very diverse.

So, my dear students this is all for today, in next class we will move on to aquatic environments and we see the ecology of aquatic environments.

Thank you.