Plate Tectonics
Prof. Pitambar Pati
Department of Earth Sciences
Indian Institute of Technology, Roorkee

Week - 10
Lecture – 49
Volcano

Okay Friends, good morning and welcome to this class of plate tectonics. So, if you remember we have completed different tectonics boundary their product and today we are going to discuss the exposed part of this volcanic product which is volcanoes. And volcanoes if you remember our earlier classes when we were talking about divergent plate margin that the volcanoes all along the divergent plate margin are existing and they are providing magma or lava and different types of gases along this mid-oceanic ridge system but it is underwater and one of the important mineralization by this volcano at that time if you remember we were talking about this VHMS or volcanic hosted massive sulphide deposit. Similarly, when we were talking about this convergent plate margin we were also talking about this volcanic system where these volcanoes are generated by this partial melting of this mantle and this partial melting was taking place due to infusion of H2O or water into this mantle wedge by the subducting plate. Similarly when we were talking about this transform plate margin, there were some volcanoes that are occasionally existing and all those volcanoes, their specific style of eruption their specific magmatic composition and that is why this geometry of this volcano, their magmatic composition as well as this product either it is of mineralized or will not be mineralized and whether it will be effusive or not, where it will be piled up magma at this site of volcano or it will move around 100s of kilometer like the Deccan-Basaltic flow. So that depends upon the magmatic composition and this volatile content with that and not only this mineralization, this magma or this rock formation, different rock formation, so these volcanoes they are also potential geological hazard.

When we talk about the geohazard or geological hazards, this volcano also one of them because volcanic eruptions in geological past and at the present day they change this climate. So, if you are talking about this P-T boundary, K-T boundaries, there are different types of stratigraphic boundaries and number of boundaries they are associated with this volcanic eruption and emission of a huge amount of volcanic ash to this atmosphere which was forming this artificial cloud and this sunlight was cut up from this earth and for the long time it was happening. So, the ecosystem imbalance was there and that was also one of these major this extinction of many of these species on the earth. At

present day there are number of volcano, you can say hundreds of volcano that are existing in this earth and few of them are also surrounding to Indian subcontinent and there are number of volcano in the quaternary period they are active and due to their activity huge amount of volcanic ash that was emitted or it is in the atmosphere and due to this wind activities so this volcanic ash that was travelled thousands of kilometer and now they are found in the different stratigraphic horizons in the quaternary.

Particularly in this Narmada valley and surrounding Indian and nearby countries the volcano which was at this Philippines, this Toba volcano that was erupted thousands years back and this volcanic ash bed nowadays is found all over this Indian subcontinent as well as the surrounding countries. So this question now arises how these volcanoes formed, what is the internal mechanism that is responsible for volcanic formation and what were the factors for which these different volcanoes that take different shape. Somewhere this magma is flowing, however in contrast somewhere this magma is piling up. So, somewhere this volcano of high height, somewhere it is flat so what was the reason behind it and is there any compositional change in this magma properties and which type of magma is responsible for mineralization that is who is the money maker for us. So let us talk about what is a volcano and how these volcanoes are classified, what is their product and what is their utility and how they are used or how they are responsible for climate change events.

So a volcano it is a vent in the earth's crust from which the eruption occurs. So now you see this is the animated image, this is the volcanoes and this magma is coming up that is lava when it is on the surface it is called lava, when it is in the subsurface it is called magma. So the lava it is flowing here as lava river you can you can see different branches and this volcano in this figure if you see this is the magma chamber which is existing few kilometers below from this surface and this magma is coming through this feeder channel or you can say it is a feeder dike in the cross section you see just a line but actually it is a plane which is dikes. If you remember when we were talking about the about the divergent plate margin we are talking about this sheeted dike complex. So these are the dikes through which the magma is coming and these are the product this is the volcanic ash which is spreading throughout this atmosphere and this larger blocks that is called block and bomb that we will that we will talk in next class when we will talk about this classification of this volcanic products and this is the lava flow.

The lava is flowing on the surface and this part of this volcano if I describe so this is the magma chamber or this magma reservoir which is below this surface and these are this feeder channels or the feeder dikes and they are the branch dikes from the feeder dikes and when this is parallel to this stratum that is called sill and when it is perpendicular or at an angle to this stratum that is called dike. Then this called conduit that is this

connection between the subsurface and surface then this is the throat of a volcano and this is the lava flow and this is the crater that is the depression at the crest of this volcano and you can say it is a magma pool it is there if there is a lava pool sometimes it happens sometimes it becomes empty depending upon the magma supply and depending upon the composition whether there will be lava pool will be there or it will be empty that depends upon. So, it is called crater and this is the summit the highest point of this volcano that is called summit and this is the vent that means through which the magma is erupting this is the main and this is the subsidiary vent or the secondary vent. Similarly this is the main cone and this is the secondary cone. So, volcano on volcano the secondary cone and these are the ash beds whenever there is volcanic eruption there will be gaseous material that will be very tiny particles like clay size particle that is called ash that can travel to thousands of kilometer and huge amount they are settled down on this volcano itself.

So, we have alternative sequence of lava flow and ash so based on that there is a classification also stratovolcano we will talk when we will talk about the classification system. So, that means I want to say this is the different part of this volcano and this geometry either it will be conical shape or it will be flat, ash and lava amount that is proportionate that depends upon the composition of this magma at this eruption site. So, when the volcanoes erupt they can spew hot dangerous gases as lava and rock that cause a disastrous loss life and properties especially in the heavily populated areas. Volcanic activities and wildfire affect around 6.2 million people and caused nearly about 2400 deaths between 1998 to 2017.

It is the WHO report or the World Meteorological Organization it is part of this UN so its report, it says, so this much loss have been occurred from this 1998 to 2017 and there are about 1500 potentially active volcano worldwide. If you see this world map or world geographic map these red spots they are the spots of volcanoes. So, you can remember our earlier classes when we were talking about the mid-oceanic system and this convergent system this is called circum Pacific Ring of fire because it is the ring like appearance it is surrounding the Pacific Ocean you can say 90 percent of this volcanoes they are lying all around this Pacific ocean and in India we have number of active volcanoes at the Andaman and Nicobar Island this is the group of volcanic chain. So because the Indian plate it is subducting at the Indo-Burmese arc so the subduction related volcanic system so it is one of them.

Similarly at the circum pacific ring of fire in all direction the pacific plate is subducting this is the mid-oceanic ridge system it is the formation of this pacific plate and it is subducting here at the Peru-Chile Trench here is the Japan arc and all around this pacific

this plate is subducting. So as it is surrounded by the subduction zone in all directions most of these volcanoes in the world they are lying here. And this part is another hotspot of volcanic formation this is the active rift zone that is East African rift valley we have the Gulf of Aden and we have the Red Sea. So this zone is another set of volcanoes are there and that is why mostly the plate boundary zones we are getting the volcanoes. So wherever it is a divergent system or it is a convergent system we are getting the volcanoes but this difference is that in divergent system the volcanic eruption is subaqueous system in the subaqueous environment below the water and that is why this shape of this rock product that is called pillow lavas.

The pillow lava it is the product of subaqueous volcanism that is found along this mid Oceanic Ridge system. However, at the continental system when there are hundreds of volcanoes are existing this is not the pillow lava which is forming there. So this lava which are forming either it is giving it is a lava flow or it is giving a conical volcanic shape. So that depends upon the magmatic composition. So here there are different numbers are given and this numbers it is described here.

So here the island arc system that is saying this I and C is the continental arc whenever there is C that is a continental arc then it is R that is rift you see number of R is there that is rift the East African rift valley rift system. Then H is hotspots we have Yellowstone hotspots. So we have this is this Cameroon hotspot. Similarly M stands for the mid oceanic system. So wherever this M is written that is replying this mid-oceanic system is there.

So that means you see all these components they are the part of this tectonic system. So that means you see all these volcanoes in the world they are associated with plate tectonics. So either it is a subduction or it is a divergent environment. So the volcanoes are forming there. So these are the specific places where volcanic eruption takes place.

So volcanoes are associated with different tectonic environment. So without tectonics no volcanoes and many volcanic hazard factors such as the likelihood and the duration of the eruption and the eruption style and this probability of its triggering large landslide or caldera collapse are related to this depth of this magma source. So this volcanic hazard that depends upon the depth of the magma source from which depth it is coming because if you remember our earlier classes we were talking about this partial melting taking place in a range of depth starting from near surface or few kilometers from surface to a depth of about 670 kilometer or so. So that means yet the magma source depth are commonly poorly known though we say this magma source depth is potential for this volcanic hazard factors but still the depth from which the magma is generating it is

poorly understood yet. And even frequently erupting volcanoes such as Hekla in Iceland and Etna in Italy.

So though they are frequently erupting and number of research are being carried out but still it is not 100% sure that what is the depth of this magma. But sometimes when we are talking about the seismicity and this depth of magma sometimes they are coinciding and we believe that probably this magma source is at this depth where the seismic wave is coming out. But still there are some disagreement that we do not know what depth the magma is coming out of different eruptions because there is likely that that means when is magma is coming for a particular depth when it is erupting at the surface it is contaminating when it is coming through different depth rock types. So that is my pinpoint says that yes this is the depth of magma which is coming out it is quite impossible till yet. And the length and thickness ratio of these feeder dikes sometimes people have used it to estimate the depth of source of magma and mostly the volcanic eruptions are supplied with magma through dikes.

That is why suppose a dike is coming out so its length and width this ratio because when it is coming to this near-surface environment and to a compressional environment to near-surface environment that means it is that means coming from high-pressure environment to a low-pressure environment. So there is a change in its width. So people have used this width and depth ratio to decide so what is the depth of magma source. And here you see different environment how the dikes are emplaced and the different 2009 dikes then it is 30 to 0 million years old dike, 30 to 0 million years old sill and they are the normal faults. So this is African plate, this is Arabian plate so the divergent system or East African Rift Valley in the rift system this different dikes of different generations that means from million years old to very recent.

So these dikes people are using this to study this magma source but still they are not able to say pinpointly yes this is the magma source. So most feeder dikes in turn are injected from magma chambers. So now the question arises what is a magma chamber? So if you see this figure this is the magma chamber and this is the magma reservoir. So now you see there are two sets of dike one set it is supplying magma from this magma reservoir to this magma chamber and another set of dike they are supplying magma from this magma chamber to volcanoes and some of them they are dying out within this system. So here the dikes and inclined sheets and here this is the composite volcano and these are these fissures and these dikes are emplaced here and here this as a magma eruption and we say it is a volcano.

So a magma chamber may be defined as a partially or totally molten body located at the crust and capable of supplying magma to volcanic eruptions. So here this is at the base of this crust it is a temporary unit you can say where magma is supplied from this magma reservoir and it is a partially molten or it is totally molten. So this magma when it is rising from this magma reservoir and it is placed here so temperature at the surrounding is increasing. So once its temperature is surrounding increasing part of this rock from the surrounding it is melting here and it is incorporated within that magma system. So a composition from here and here will be totally different and once this such magma is erupting from this magma chamber to the surface there are many rock types through which it is passing through.

So there is very possibility that it is getting contaminated from the surrounding. So that is why talking a magma composition and deciding its depth of origin it is quite impossible and this magma chamber act as a source for magma injection. So once magma is injecting it is injecting in terms of dikes, in terms of sheets, in terms of sills into this surrounding crust and to the surface of this associated volcano. Active magma chamber act as a sink of magma from a deeper reservoir which is commonly located at the lower crust or this upper mantle. So here this is the magma reservoir either the base of this crust or at the mantle you can say the upper mantle mostly and this magma reservoir is supplying temporarily to this magma chamber and from the magma chamber the magma is supplied to this volcanic system.

Many and perhaps most of Volcanoes are preferred by double magma chamber. So one magma chamber is here and another is here that is called the magma reservoir. One is at the shallow depth that is called magma chamber and it is considerable crustal depth and the lower chamber refers to the reservoir. So this is the lower chamber that is the magma reservoir and this is the upper one that is the shallow depth one which is called magma chamber. And the shallow chamber acts as a magma collector for the deeper source.

So here this is it is collecting magma from the deeper source and it is supplying to this volcano. So some facts about this magma chamber. So magma chambers in the major stratovolcanoes, calderas and basaltic edifices are commonly active for hundreds of thousands of years. So you can say this magma chamber it is not just only it is temporarily against that temporarily that means we are talking about geological temporary even if they can exist for thousands of years and active chambers may be partly or totally destroyed through large collapse of caldera eruptions.

So here you can say you see in this figure or this animated image. So this is the caldera that means a depression which is formed by this subsidence of this top of this volcano you see here they are getting subsiding and this subsidence is due to this loss of magma from this magma chamber. That means once this magma is here it is providing support to this overlying roof. So once magma is erupted so this becomes empty so if the same magma is not compensated from this low-lying reservoir so that means the empty space is created and to compensate that empty space this caldera collapse occurring so this part is subsiding down. So following the destruction of a chamber a new chamber sometimes forms to the side of this destroyed one either deeper or shallower level of this reservoir.

So maybe a new chamber formed or may not be formed and if a new chamber formed at the same place that means this likelihood of caldera collapse is less and if it is a different place so there will be new volcano to the side that means you can say a secondary volcano will be formed and this caldera collapse will take place. And this geometries of this magma chambers vary. So this geometry varies maybe from ellipsoid shape to a circular shape or maybe of different shape that depends upon this temperature and pressure, the composition and the surrounding rock and this magma supply. So many chambers are sill like and is similar to flat oblate ellipse. So now you see if you make it more flat so it will look like this.

So that means it is a sill like and most of this magma chambers in the world they are also this silll like they are showing so that means a succession of sills there that will be replaced one after another. So others however develop geometries that are closer to being approximately spherical and occasionally prolate ellipsoidal that it is shown here in this figure and some chambers in particular young chambers with sill-like geometries may be totally molten. So once this is totally molten that means they become an active source for this magma supply to these volcanoes. And many magma chambers not only this molten material are lying there. If you remember earlier class when we were talking about magma chamber properties at this divergent plate margin you can remember we are talking about the crystal mush there is a transition zone, there is a crystal mush, there is a melt lens so those components that we discussed there.

So here similar things once we have a magma chamber so we have a system which is crystallized. So this crystallized that means these different crystals a bunch of crystals are lying at this periphery because the magma cooling starts from the periphery of this magma chamber and inside we have different lenses of magma and from which frequently magmatic supply is taking place to this volcano. At high strain rate such as during earthquake and parts of the matrix may fail into the brittle manner. So that means

whatever the crystal mesh or crystal mush we are creating here once they are solidifying but still they are floating within that magma. So during earthquake or any reason when there is some disturbances they are settling down and brittle failure may occur in the system.

So that can be seen in this fossilized magma chamber wherever you get a fossil magma chamber that means magma chamber which is fossilized which is totally solidified. This type of structure that means this seismic related shaking and this destruction of this crystal mush, this destruction of this layer sequence which is formed at the magma chamber that is very well seen within that. And each volcanic eruption is unique and different in size, style and composition of this eruption material. So, one of these key factors that makes this eruption unique is that this chemical composition of the magma that fits the volcano. So this chemical composition decides which type of eruption is going to take place.

So the eruption style, the type of volcanic cone either it will be flat cone or that it will be very sharp cone and the composition of the rocks that found at the volcano all these that decides by the chemical composition of this magma. An eruption that involves a steady non-violent flow of magma is called effusive. So that means sometimes there is a violent volcanic eruption, sometimes there is no violence at all, just magma is flowing like water, so like the Deccan traps. So hundreds of kilometers there is magma is travelled before solidifying. So that is called effusive eruption, no disturbances, no seismicity, just magma is flowing down.

So that is called runny lava that means the lava is running on the surface like flowing at the river. So this is allowing gas and volatile to escape very easily because the magma viscosity is very less, so that these gases and volatiles they can escape very easily. But in the contrast if this magma viscosity is very high, so it is not allowing the gas to escape. So in that case violent type of eruption is expected and that is in terms of felsic magma. If we have felsic magma system that is high viscous and magma eruption is violent, so we have different type of volcanoes in the world existing.

Some of the volcanoes they are erupting very violently and some of them very silently, so that depends upon the magma composition. If it is basaltic lava, so very cleanly or you can say without any violence this magma is flowing out, but if it is felsic, so this magmatic that means eruption is very violent. So here there is different types of magmatic composition that has been shown in this diagram. If it is mafic, what should be the SiO_2 content and if intermediate what should be the SiO_2 content and if it is felsic

what should be the SiO2 content. So now you see this felsic, mafic and intermediate, all this magmatic compositional classification is based on SiO2 that is silica content.

If silica content is this much we have mafic magma, if it is slight more than that we have intermediate and it is far more than that you can say 3 quarter is occupying by silica, so that is called felsic. And that also here that depends upon the gas content. For example, this mafic to felsic magma has been classified based on this weight content of the weight percent of silica and weight percent of gas and the gas mostly of water. And this water if you remember when we were talking about the subduction system and the divergent system, the plate which is down going it is taking water in its pore space in the sediment as well as it is greenschist metamorphism taking place the subducting slab. So it is chlorite, actinolite whatever this minerals that was there serpentine, so they are containing water in their crystal structure and clay minerals they are taking water in their crystal structure.

So those water which is reflected here and that water and this silica content that decides whether there is a mafic magma or that is an intermediate magma or that is a felsic magma. So if it is mafic magma, so here the viscosity is very less. So that is why whatever the crystals are there they can easily settle down at the bottom of this magma chamber. So you remember when we are talking about the layered gabbro and this isotropic gabbro. In the layer gabbro time when we are talking about this magmatic composition was this basaltic but this olivine the pyroxene crystals which are forming they are heavy in nature.

So they are settling down because the magma viscosity was less as compared to this specific gravity of this crystal. However with time with the differentiation when this mafic part is settled down that is within that crystal, so remaining magma becomes felsic so its viscosity increased. So whatever these crystals they are formed, so they are floating down floating within that magma. So that means from mafic to felsic if it is converting by differentiation, so it can be reflected through their crystal settlement and the crystal composition from this bottom of this magma chamber to the top of this magma chamber. And Mantle plumes and spreading ridge magmas tend to be consistently of mafic and so effusive eruptions are normal.

Effusive that means without any violence. So this mantle plume which is coming from D double prime layer if you are talking about this hotspots magma, this oceanic hotspots, this mantle plumes, so the oceanic hotspots that is coming from this core-mantle boundary. So there is very high mafic content is there, so that means it is effusive

eruption. Similarly the mantle plume it is coming from this mantle directly it is of mafic composition, but that is why we have magma viscosity is less, so effusive eruption is expected. At the subduction zone the average magma compositions likely to close to intermediate, but we have seen that magma chamber can become zone as when composition ranging from felsic to mafic are possible. So eruption style can be correspondingly variable if it is mafic magma or it is a felsic magma.

It is volatile rich magma, volatile poor magma. So all that decides which type of eruption is going to happen and that also to decide which type of volcanic characteristic, so that means geometry of this volcano is likely to happen. So here you can see there are number of eruption styles somewhere this magma is just flowing without any that means without any violence. So this is the magma which is flowing and this is underwater magmatic eruption like this pillow basalt when it is forming at the mid-ocenic ridge system and here you can see both these magma as well as gases both are erupting and here you see most of this gas that means the ash is erupting and this is the volcanic material how it is hazardous to mankind or the society the huge amount of lava and material it is just washing out all this which is coming in its front. So these are the different hazards associated with the magmatic eruptions and these are the different styles of magmatic eruption and mostly it is governed by this magmatic composition. While the lava and ashes are typical characteristics of almost every volcano they differ in their formation and eruption.

So here depending upon this composition, so this different geometry of these volcanoes has been decided. So this volcano type that is also classified based on this type of eruption, the type of material, this type of magma composition that is deciding the geometry of this volcanoes. So first is the Fissure volcano that means Fissure type one main Fissure is there. So from this Fissure the volcanoes that means lava is erupting and it is flowing around hundreds of kilometer like the Deccan basalt. So Deccan basalt you can say the most of this part it is on the Arabian Sea and you are coming to the central India that is Jabalpur or even beyond.

So here the whole total area it is covered by flood basalt. So eruption of different times and times in terms of thousands of years millions of years apart. So this magma which was or the lava which was erupting at the western coast it is coming to central India as volcanic that means flows that is basaltic flows is called traps because it is a step like appearance so that is called traps. So they differ from other volcanoes due to their lack of central structure and form around this crater. No crater is formed because it is Fissure type eruption no vent type eruption. Vent-type eruption means there is a cone so there is

a vent so this is the vent type of eruption and this is a Fissure type of eruption because this is a just a Fissure it is a fracture through fracture the magma is flowing.

So this is lava it is escaping this volcano is of low viscosity and therefore lateral development of Fissure volcano is more pronounced than the vertical development. So East African rift that is that is Cordon Caulle and this Holuhraun and our Indian context is the Deccan trap they are also very much exemplified with this type of volcanoes. So another is the shield volcano so here you see we have a vent so through vent magmatic eruption is there. So the height of a shield volcano is much less than its width and hence have low slopes and the lava flow is effusive and it is slow moving due to less viscosity and being less viscous lava flows to a greater distance before its cooling and accumulation of such type of lava flow over a long period series give rise shield volcano.

So this is the characteristics of shield volcano. Then dome volcano the name itself such is a dome it is very thick lava that could not move too far because it is of felsic nature. So it is piling up there too viscous so moving sluggishly cool down and piles around the vent giving rise characteristics of domal shape. So lava domes are typically low height similar to composite volcano they can catch violent eruptions. Then ash cinder volcano that means volcanic ash is falling there and this volcanic product whatever this debris and ash they are piling up at their places and giving this external geometry of this volcano. So typically about 300 to 500 meter and fragmented erupted ash that falls near the chimney of this vent.

So cinder cones volcanoes that is lack of horizontal layers instead they form rather steep that is conical hills or tephra or pyroclast. So what is tephra and pyroclast we will talk in the next classes. The loose volcanic debris escape from this vent and collect around it giving rise to ash cinder volcanoes. Then composite volcano that means we have lava flow and we have this volcanic ash. So that means one layer of lava flow so here you can say one layer of lava flow another layer of volcanic tephra that is this ash and whatever this debris has there.

So compositely they are stratified that is called stratovolcanoes or other word it is called stratovolcanoes. Then caldera volcanoes that means we have a caldera we have one depression and this caldera collapse may occur that we have already discussed. And volcanoes are classified depending of activities such as active volcano, dormant volcano or extinct volcano. Active volcano that means it is active recently and most active volcano has erupted in the recent past and a very high chance to erupt again. And

dormant volcano that means it is not erupted in recent past and extinct volcano there is no chance that that means it can erupt in future.

But strictly speaking no volcano is extinct so that means whatever this activity we have noticed or recorded that is within that recorded time scale. But if you talk about the geological time scale we cannot say whether this extinct volcano will be totally extinct forever it may extend in geological future. So strictly saying it is an extinct volcano it is somehow we are wrong. So this is all about the volcanic system. So thank you very much we will meet in the next class.