Geomorphology
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Lecture – 26
Aeolian Processes and Landforms - I.

So friends good morning and welcome to this lecture session of geomorphology. Today we are going to start a new topic which is called aeolian process and landforms. So what is aeolian process? See whenever we were talking about weathering erosion transportation something like that. so there are many agents of weathering and erosion we have discussed. the first and foremost thing was the fluvial process.

Then the fluvial process means the rivers, the streams the aeolian process that means the wind process the wind activity then the glacial process. then the gravity for mass wasting. So these are the agents of weathering and erosion. So out of which this aeolian process is an important domain within that weathering and aeolian process as it is involves the wind. So those areas we are prone to weathering by wind. that means that indicate the arid regions, the deserts, the coastal plains is not it?

So that means those area which are governed by this wind as a major agent of peneplanation landscape modification those areas we will deal with and how this wind is involved landscape modification. to what extent it will be modified the landscapes that will be discussed in this class. So here it is important to understand that that all other agents maybe the glacier maybe gravity maybe it is a fluvial or the river.

Those agents whatever the mass whatever the material they are transport they remove they remove down direction that means from upslope to downslope to direction. But wind is the unique agent of weathering which may transport the material upslope direction that means wind can blow material from low to high. So this is an exception is it not? So that is why in this class we will deal in detail how the aeolian process they are responsible for this landscape modification.

Now you see wind is always turbulent so that means if it is turbulent so that means whatever this equations we have designed for a turbulent flow that must satisfy here that may be utilized here to understand the air dynamics, the wind dynamics how the change in this turbulence the change in the wind blow characteristics that will affect the erosional processes that will affect the transportation process of this eroded material from one place to another place.

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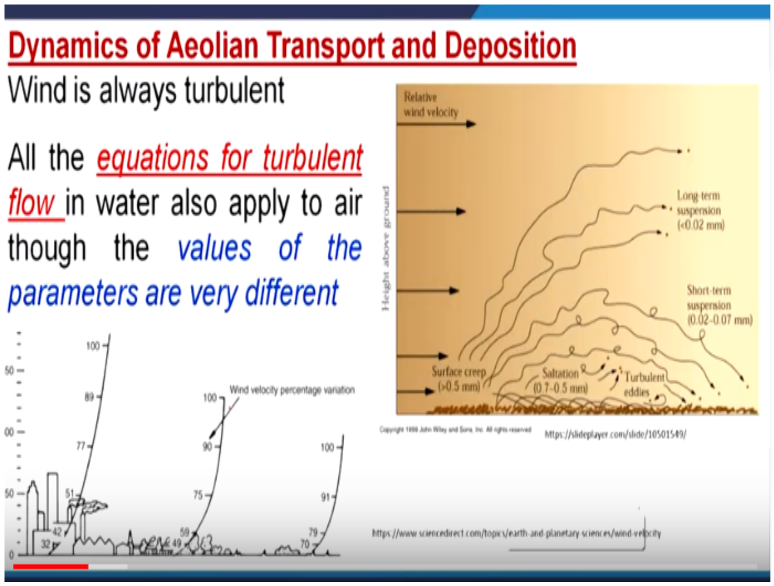

Now if you confine here in the figures below here you see this is these buildings are here these industries and some localities shown in this diagram here you see this is the percentage of wind velocity and you see below or close to this ground, we have 32%,42% 51%, 70 and 89 and 100%. and in this scale, we are increasing the height. In this scale we are increasing the velocity. Similarly now come to less industrial area or the local area or wherever where there are trees and whatever these other localities are there.

But that means less height infrastructures or less height objects. here this 100% of this wind velocity its achieved in this level. So come to barren rocks barren bare body bare rocks so there is no locality no vegetation like this. So here 100 % achieved at this level so that means i want to say wind velocity at this close to this surface is above to 70% here close to the surface is 49% here close to the surface is 32%.

So that means I want to say the velocity of wind it increases with less vegetation, less infrastructure , less object that means whenever that is a free area free land mass or free anything which is not for creating an obstacle to the wind moment here at lesser height wind gains its maximum velocity. But once more and more objects more and more heightened objects we are introducing the system we are gradually restricting the wind to blow and that is the why the maximum velocity of this wind its achieving at higher levels.

And in this figure if you see here this is relative wind velocity the scale in this direction here close to this surface, we have less velocity once we are increasing more and more height. This is the height scale once we are moving to more and more heights gradually you see the length of the arrow is increasing. that means the velocity is increasing. So that means if we draw a graph and it will look like this.

So once we are moving more and more heights that means we are increasing the wind velocity and in this particular photograph or particular figure here if you see these are the impressions of some sand particles and wind is allowed to blow on the surface. So here the surface creep greater than 0.5 mm 0.7 to 0.5 it is saltation then it turbulent edits then here suspension 0.02 to 0.07 and long term suspension 0.02 to less than 0.02 mm.

So that means I want to say once wind is blowing it is blowing and it is interacting with objects of different sizes. For example in this particular case if you say that we allow the wind to blow on a free sand surface because whenever why we are taking sand as an example because we are talking about this the wind activity in the arid region the deserts like this which is full of sand.

Suppose it is full of sand and wind is allowed to blow on it. So finer particles that will move off in the form of suspension then relatively coarser particle they will move in saltation. Saltation means it will move like this and this like this. So that like jumping so this is saltation and larger particles they will travel by rolling rubbing on the surface that is called creeping. So these are these characteristics movement of particles with increasing size and increasing wind velocity. So as we assume and as we know that the wind is a turbulent and every equations which is designed for a turbulent flow will be good here.

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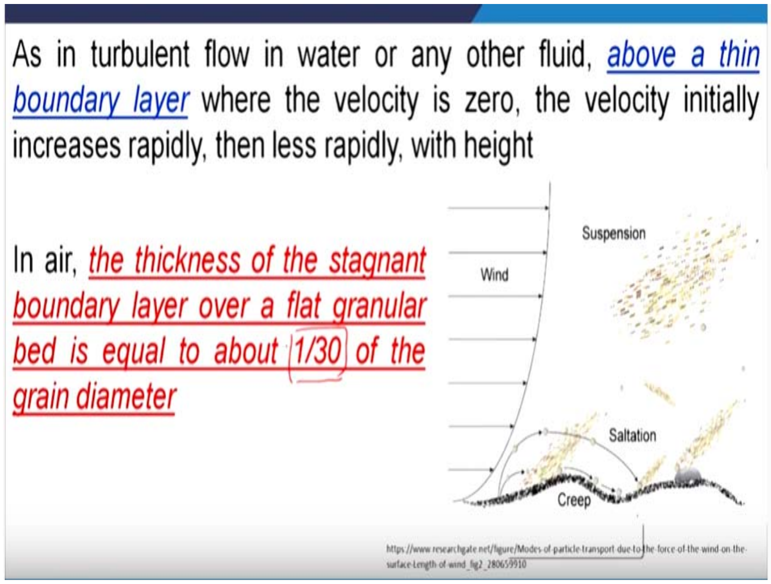

So turbulent flow in water or any other fluid above a thin turbulent layer where the velocity is 0 the velocity clearly increases rapidly then less rapidly with height. In air the thickness of the stagnant boundary layer over a flat granular bed is 1/30 of this grain diameter. So if you see here so once we say about this turbulent flow that means we know in turbulent flow there will be a boundary layer. The boundary layer where velocity is 0 and that means the system is stagnant. So above that the velocity increases very rapidly and then the rate of increase gradually decreases.

Similarly here he we say suppose we are allowing the winds to blow on the mixture of layers or mixture of rocks or simply for example for better understanding. you say the wind is blowing on this material having equal sizes diameter equal grain size diameter. So this boundary layer that means this 0 velocity that layer from the surface of the grain boundary its equal to 1/30 of this grain diameter.

So if we are allowing the wind to blow on sand that will be that means this boundary layer is very negligible very close to this surface on the sand 1/30 of the grain diameter. But if this much size boulders are there the wind is blowing so that the stagnant layer will be 1/30 of this boulder diameter. So that means larger and larger the size so larger is the distance is not it of that boundary layer.

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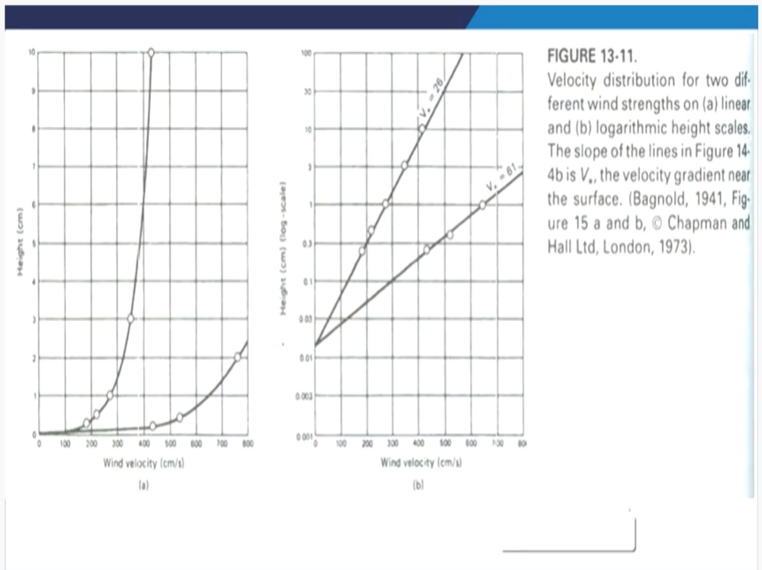

So here 2 figures are given one is on a logarithmic scale and another is a linear scale and this wind blow velocity of wind of different strength. For example if you see here for this particular graph here with less height it is height. this scale is the height. this side is the velocity here with the less height the velocity is maximum, or velocity is increasing with less increment of height.

So here wind is of high strength because if you feel it near to the surface close to the surface you see very that means 0 centimeter or this is 1 centimeter so that means it is 1 milli meter that means the wind is blowing close to this surface of the earth very close to the surface earth touching with the surface with a very high-speed. that means the wind strength is very active it will create more damage.

But here in this particular case here this wind velocity is increasing but here this rate of increment is different as compared to different. That means we are moving more height to achieve the more velocity. Here that means the wind strength is low. So that means similarly this is the same case it is logarithmic scale. So that means wind strength when we say we say very close to the surface or the surface of observations that what extent what height we are achieving maximum velocity.

So if it is close to the surface, we are achieving maximum velocity. That means we can say it is a strong wind strength of this wind is more or the reverse is true. So this boundary layers about which we are talking.

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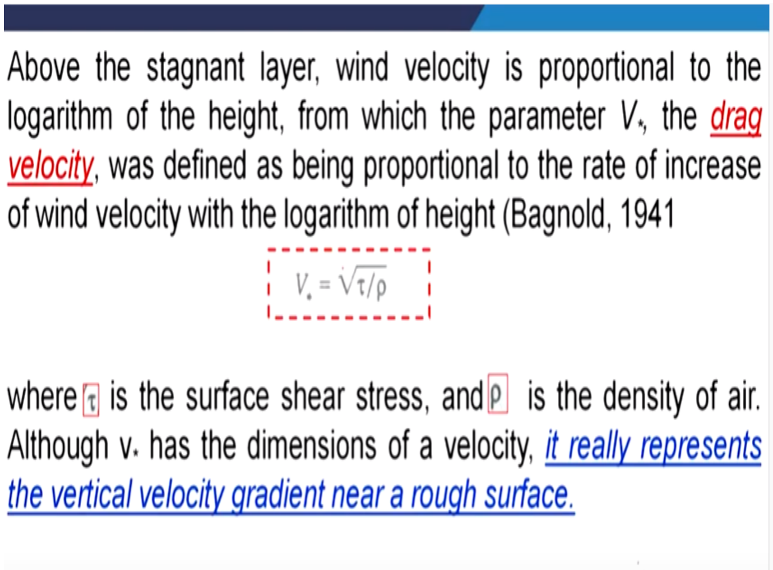

Above the stagnant or the boundary layer wind velocity is proportional to the logarithm of the height from which the parameter V or the drag velocity was defined as being proportional to the rate of increase of wind velocity in the logarithm of the height. So what is this velocity or the drag velocity, drag velocity means the velocity at which a particular size of grain will drag down. So that means drag out from this stagnant system from which I suppose there are number of grains at such time a particular velocity at particular grain size that will be dragged out. it will be lifted up.

So that is the drag velocity so that velocity is equal to this it is represented by this formula root over of tau by rho ($V=\sqrt{\tau}/\rho$) this tau τ is the surface shear stress and rho ρ is the density of air. So although this velocity V has the dimensions of a velocity, but it is really represent the vertical velocity gradient near to the rough surface. Why vertical velocity because whenever we talk about this wind-blown material that means at a particular velocity this metal will lift near about the vertical that is why it is called the vertical velocity.

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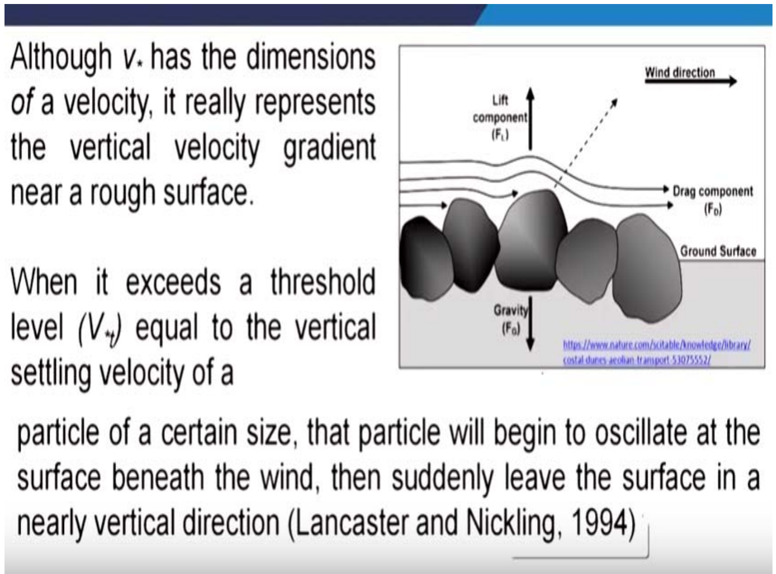

Although V has the dimensions of these velocity it really represents the vertical velocity gradient near to the rough surface. when it exceeds the threshold level that threshold level is Vt is equal to the vertical settling velocity of a particle that means this sand grain or any grain that will lift near about vertical. So once it moves up once it moves to the system it will try to move and remain in this air. But that depends upon this wind-blown velocity as well as this density as well as this grain size diameter of the system.

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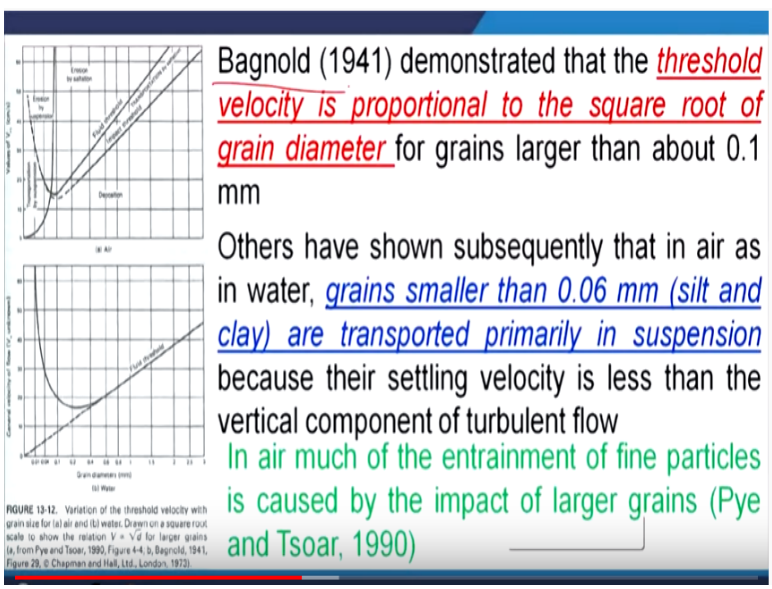

So here the pioneering work by this gentleman Bagnold 1941 it demonstrated that the threshold velocity is proportional to the square root of the grain diameter of grains larger than about 0.1 mm. So this formula or this assumption is right, and it validates for those grains having diameter more than this 0.1 mm. But those grains which are less than that it is not holding good. why? because we know if you analyze you can recollect when there is a grain size variation in fluid system also the larger grains can be transported with relatively less velocity and it can be lift off with from this riverbed with lift less velocity.

But those smaller grains like clay, silts we need more velocity of water to lift it up. the same thing is here applied. So that means those we are talking about this turbulence flow, this wind velocity the threshold velocity. they all are valid for those grains which are more than of 0.1 mm diameter but those grains which are silt and clay size particles this equation will be different and different means in the sense I say that means we need more velocity to lift a grain of large smaller size from the system as compared to the larger size.

So that means see subsequently other workers of Bagnold 1941 says that the air or in water grains smaller than 0.06 mm that means silt and clay particles are transported primarily in suspension because this settling velocity is less than the vertical component of turbulence flow here it is an important thing to understand. Settling velocity that means a grain will settling either it is air or in water if we are considering water. then we will consider the water system if were considering air that the freefall in the air that is talking about the wind system.

So that means larger grain fragments larger grain size like silt and clay are transported primarily by suspension. Why they are moving in suspension and that means maximum time they remain within this air. why? Because their settling velocity is less than the vertical component of the turbulent flow. So the vertical component of the turbulent flow is more as compared to the vertical settling velocity. That is why this component is able to make in suspension.

So in air much of this entrainment of a fine particles is caused by impact of larger grains because we know when there were when there is a wind moment there are different types of movement as we have discussed in a few minutes backs there will be something creeping that means rolling and something in this saltation and something in suspension. So here whatever during saltation that means by jumping of grains. Suppose one grain is here and do allow the wind to pass through it.

So it will move here and will hit the system and will again. So once 1 grain is coming and hitting the system here the free sand grains are there. So that means it impacts on larger grains. So these larger grains wants its impact here. that means its entrance number of particles. So those number of particles if they are smaller their sizes. So they come to in the suspense mode because their vertical settling velocity is less than that the turbulent component or the turbulent that the vertical component of the turbulent flow.

So that means that is why more and more number of grains we are putting in suspension mode so that means gradually we are increasing the density of the system or the layers.

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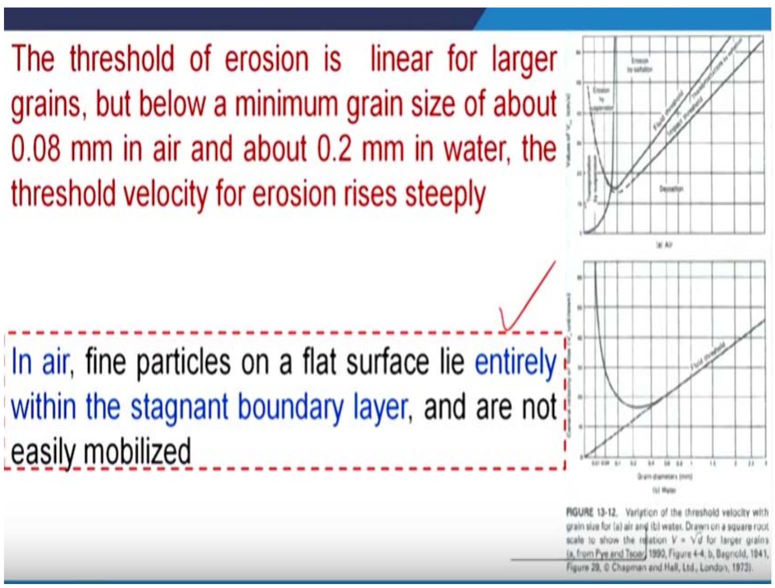

The threshold of erosion is linear for larger grains but once it comes to this minimum grain sizes minimum grain size of about 0.08mm in air and about 0.2 mm in water. The threshold velocity for erosion rises steeply. So in air the fine particles on a flat surface lie entirely within that stagnant boundary layer and are not easily mobilized very interesting here to discuss.

Suppose we have a flat surface we are putting a number of grains on different sizes and we are allowing wind to blow. So once were increasing and increasing the wind velocity at the particular threshold velocity comes when the larger grains will be picked up because that large grains which is about that is larger than that a threshold the minimum that means 0.1 mm. Those grains which has more than 0.1 mm that will try to move however those grains which are of less than of about this they will not move.

Why? because they are that means the in this air particle the flat surface entirely within this stagnant boundary layer because we know that stagnant boundary layer its 1/30 of this diameter is it not 1/30 of the grain diameter here we say this is boundary layer and are not easily mobilized. So those grains those fine grains they comes within that boundary layer and it is not easily picked up by this wind velocity. So that remain there that means coarser grain relatively coarser grain will remove but finer grains for lifting a finer grain we have to increase the wind velocity there.

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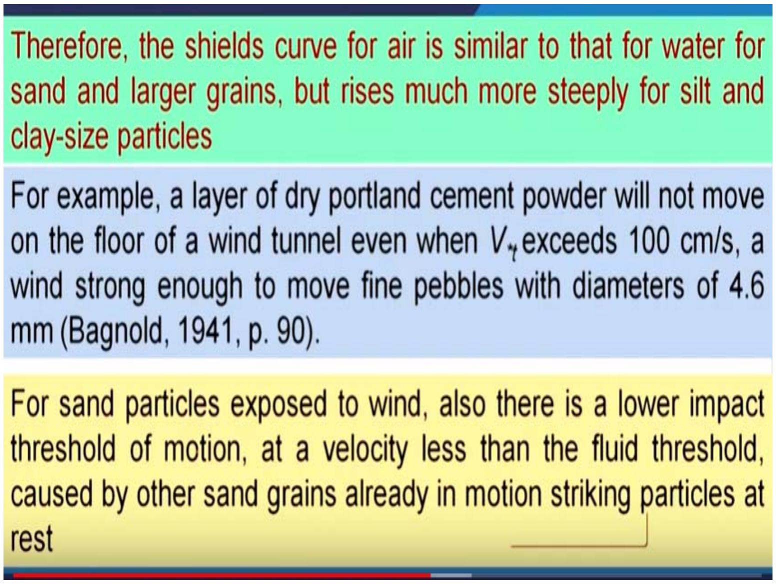

Therefore the silts curve for air is similar to that for water for sand and larger grains but rises more steeply for silt and clay-size particles. So that means we have to increase more and more that wind velocity to lift finer grains as compared to coarser grains. For example suppose a dry Portland cement powder is lying in the floor of a wind tunnel even when this threshold velocity Vt threshold velocity exceeds 100 centimeter per second as wind strong enough to move fine pebbles with the diameter 4.6 mm.

So that velocity that can move this 4.6 mm diameter grains. However this same velocity is not able to pick up a Portland cement grain why? because that grain remains within that stagnant layer. So that means that velocity is not able to pick this Portland cement particles. For sand particles exposed to wind also there is a lower impact threshold of motion at a velocity less than the fluid threshold caused by other sand grains already in motion striking particles at the rest.

So that means whenever there is sands are in motion that sands are putting an impact on this other sand grains. But once this velocity that means this impacted grains, they also some velocity is added to it, but that velocity is not enough. So that means still it remains within that boundary layer that is why it is not picked up.

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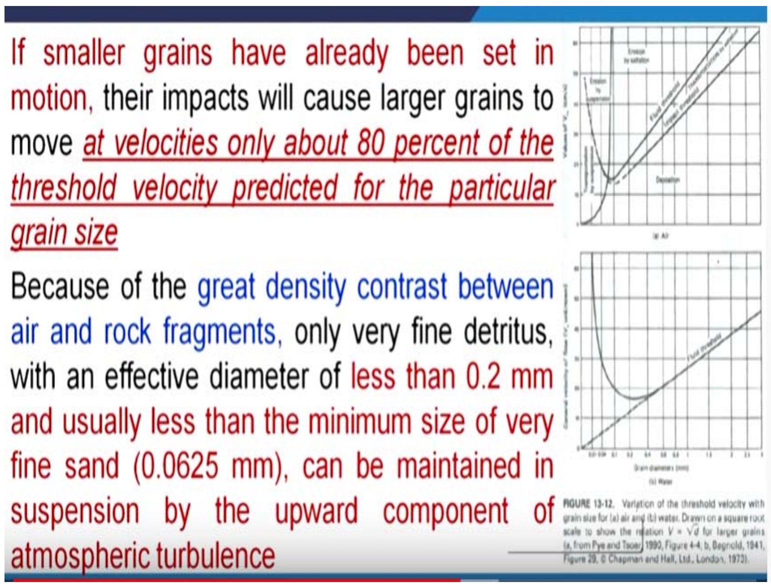

If smaller grains have already been set in motion, their impacts will cause larger grains to move also but at velocities only about 80 percent of the threshold velocity predicted for the particular grain size. Here that means either larger grains they are impacting smaller grains and smaller grains they are impacting larger grains .

So larger grains impacting on smaller grains that means it will life it up Once they lift it up they remain in the suspension and sometimes whatever this larger grains impact on smaller gains on the clay and finer size particle but still it did not able to lift it up because that remains within that threshold velocity they impact velocity which is guaranteed by these smaller grains but still it is less than that threshold. So that it will remain within that layer but smaller grains once it is impacting on larger grains , larger grains attain some velocity, but that velocity is about 80% less than or 80% of the threshold velocity it is required to lift again.

That is why that remain stagnant because of the great density contrast between the air and rock fragment only very fine detritus within an effective diameter of less than 0.2 mm and is usually less than the minimum size of very fine sand. That means 0.0625 mm can be maintained in suspension by the upper component of the atmospheric turbulence. So that means whenever then in the atmospheric turbulence the wind is blowing a mixture of metal is there only the fine fragments of this much size or so they will remain on the suspension.

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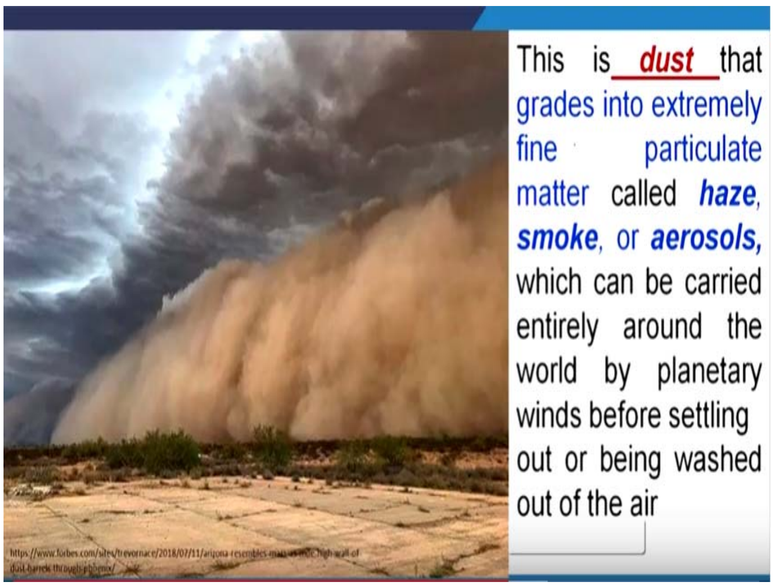

On other things that is larger than that that will be in a saltation mode and larger than that that will be in the creep mode. So now this is called dust that means the finer particle these silt and clay particles which is remain on the suspension mode this is totally collectively that is called dust. So this is dust that gets into extremely fine particulate matter called haze, smoke or aerosols which can be carried entirely around the world by planetary winds before settling out or being washed out of the air.

So here those particles by any means either due to increase of velocity or by impact of grains any means it comes to a suspension mode. If this wind velocity remain as it is, they will remain in the suspension mode and those particles the remain in the traveling conditions so that can go up to thousands of kilometer distance. For example in Narmada valley when we are talking about this weathering and erosion and mass transport, we might remember it.

So in Narmada valley we have some that is what is called that volcanic ash beds. So those volcanic ash beds was dated back to several thousands of years and the origin was traced in the volcano of Toba. So that means you see from here to Toba or the Indian subcontinent not only on Indian subcontinent most part of these South east Asia this area this volcano from this Toba the volcanic ash from Toba was distributed. Why it is thousands of kilometers apart? So this is because particles this composed of this silt, the clay even if not silt it is clay particle very minute size.

So once they come in suspension mode that can travel large distance thousands of kilometer remain in the suspension mode because to settle down the wind has to be calm for a long time. That means the threshold limit the threshold of the settling velocity. Wind velocity less than the threshold velocity then it will settle down. But most part of this if the wind velocity remains above then this even if slightly above then the threshold velocity but still this particle will be in the suspension mode.

That is why those suspended materials that clay size particles that is called haze, smoke or aerosol which can be carried entirely around the world by planetary wind before settling down and being washed out by air and water.

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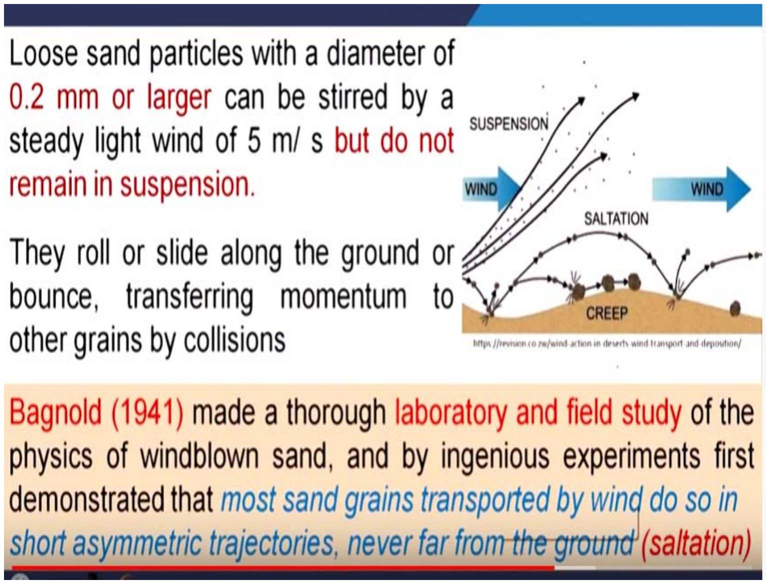

Loose sand particles with a diameter of 0.2 mm or larger can be stirred by a steady light wind of 5 meter per second but do not remain in suspension here. So for suspension we need very fine particles. Suppose a mixture of grains are there mixture of particle size different size of particles are there we allow to blow this wind about 5 meter per second velocity. That velocity is able to steer these sand grains but do not remain in suspension.

So that means it will not come to in the suspense mode. However it will pick up this sand particle and it is gradually decrease and it will fall somewhere else. It will transport from one place to another for short distance of migration this is called saltation. For example in this figure you see these are the sand grain it is taking a trajectory motion and it is coming here. This type of motion this type of motion jumping from one place to another place this is called saltation motion.

So the role or a slide along the ground are bounce transferring momentum to other grains by collisions. Here some of them are over rolling the larger particles that rolling that means with the touching within the ground they remain within the ground but some of them they are moving here by jumping. So this way once this moment starts sand grain moment start, they transfer momentum to other grains.

Here it is going and suppose it is moving from here to here or here to here that means it is transferring momentum. Similarly here introduce jumping from here once it impact from here it is transferring momentum. So that means momentum transfer takes place. So this gentleman Bagnold 1941 made a thorough laboratory and field study of this physics of wind-blown sand and by ingenious experiments first demonstrated that most sand grain transported by wind do so in short asymmetric trajectories never far from the ground which is called saltation.

So this height it is not very high so how much height it will be that depends upon the size of this grain and depends upon the wind velocity. So these experiment laboratory experiment and field observation says that those trajectory motions those sands they are lifted to very less distance from this ground. and finally takes a trajectory motion and impacts on the ground itself. So these type of jumping type of motion of the sand grains it is called saltation.

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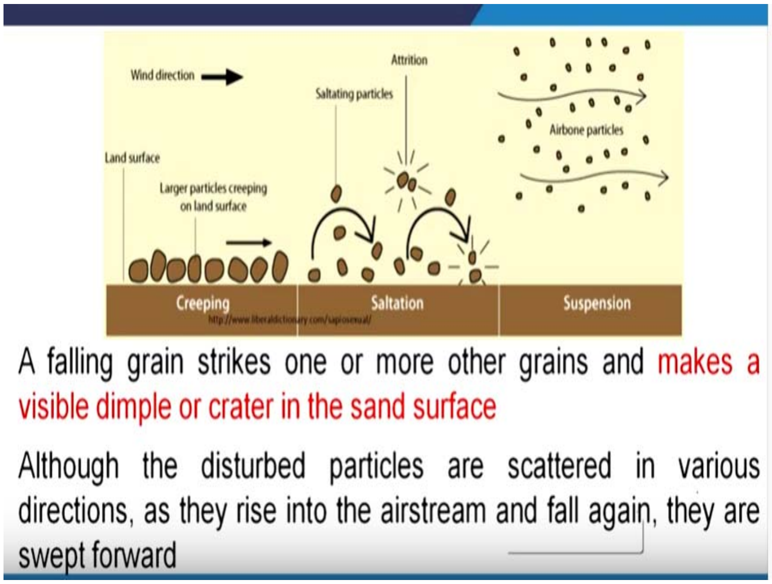

So a falling grain strikes one or more other grains and makes a visible dimple or crater in the sand surface. For example if you see here this grain is going and coming here so once it impacts here for example here it is creating an impact and it is disturbing number of grains from the site. Although the disturbed particles are scattered in various direction as they rise into the airstream and fall again, they are swept forward.

Because momentum is gained so once the momentum is gained it will carry forward. but the distance at what distance it will move that depends upon the wind velocity. So it may distance up to this it may distance up to this or maybe very small distance it will migrate depends up on the wind velocity the sizes the density of those grains.

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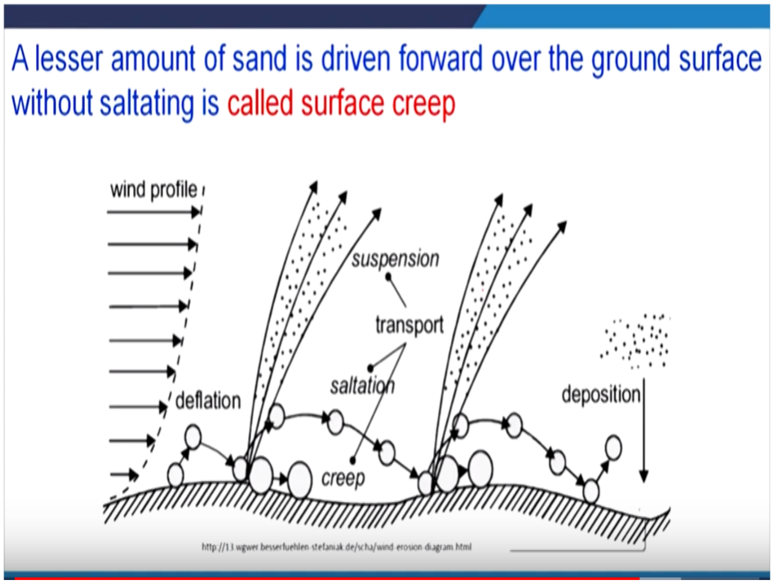

So the lesser amount of sand is driven forward over the ground surface without saltating called surface creep. So if we see here there are 3 types of movement one is saltation movement is jumping one is your suspension movement here suspending material that is very fine it is dust or aerosols whatever may be. Now very less amount of sand is driven forward over a ground surface without saltating is called surface creep.

These are the surface creep that means they move along this ground they do not leave this ground at all. So on the surface the role the slide or different type of movement. So these type of movement it is called creep movement.

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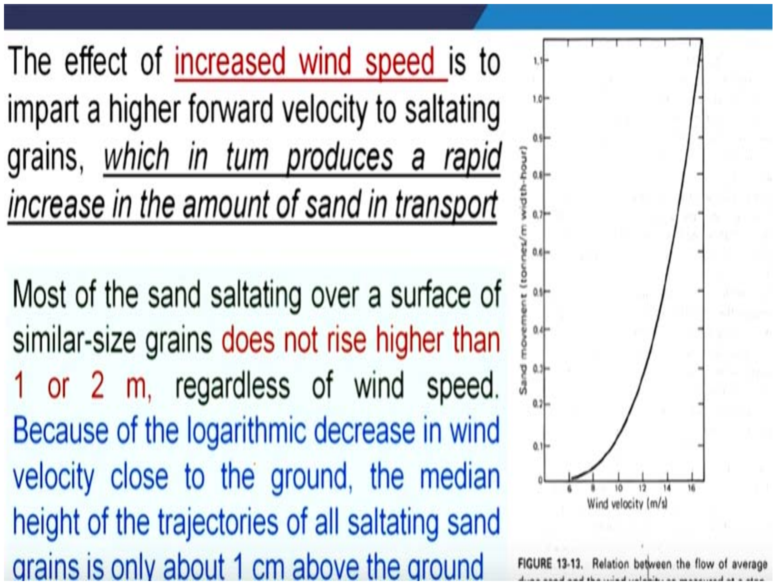

The effect of increased wind speed is to impart a higher forward velocity to saltating grains which in turn produces a rapid increase in amount of sand in transport. So that means more and more velocity we are adding to the wind. So that means more and more transportation capacity we are increasing which in turn produces a rapid increase in amount of sand in transport. So more amount of sand is transport so more amount of sand in transporting that means the landforms which are going to form it will be more it will be larger landforms.

So that means the landforms is proportional to deposition. So whenever more and more sand we are introducing in a system that means we are creating a deposition of landforms of larger size. Most of the sand saltating over a surface of similar size grain does not rise higher than 1 to 2 meter regardless of wind speed because of this logarithmic decrease in wind velocity close to ground this median height of this trajectories of all saltating sand is only about 1 centimeter above the ground.

So that means it is not much distance it is going this height does not rise 1 to 2 meter and similarly it is if you see here the median height of this trajectories of saltating sand grain is only about 1centimeter above the ground. It is not going very high from this ground and it is within 1 centimeter this trajectory height is very well there and the distance is about 1 to 2 meters.

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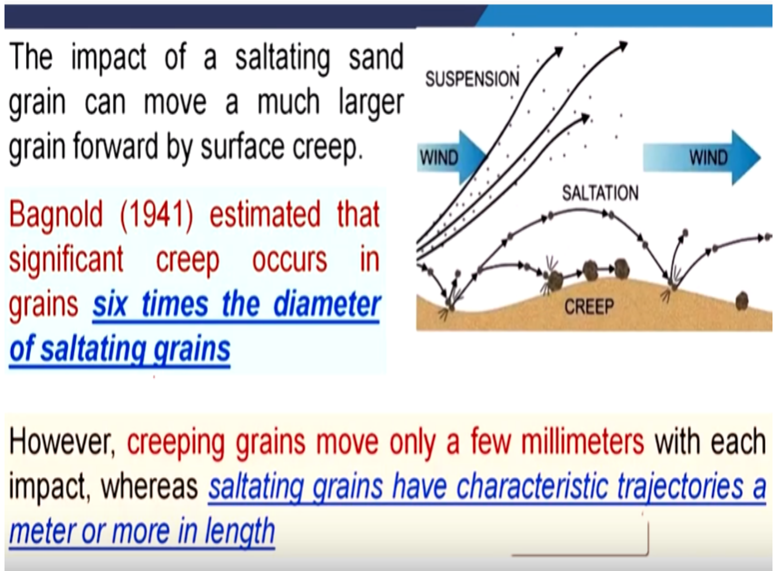

The impact of a saltating sand grains can move a much larger grain forward by surface creep. This is important. the impact of a salting sand grain can move a much larger grain forward by surface creep . You see surface creep suppose a surface creep for a particular wind velocity. This grain is under surface creep and it is moving from here to here and but if it is impacting here suppose a saltating grain is impacting here this may move to a larger distance.

So here it is said the impact of a saltating sand grain can move a much larger grain forwarded by the surface creep. So that means a larger grain more than this can be moved through surface creep. But the distance of movement may be less so that means the effect of saltation is more as compared to the effect of creeping. So that is why these landforms are readily modified in the arid region mostly due to this saltation process.

So Bagnold estimated that significant creep occurs in grains 6 times the diameter of saltating grains. However creeping grains move only a few millimeters with its impact whereas saltating grains have characteristic trajectories a meter or more in length. So creeping though it is effective, but it is up to very few millimeters. But saltating grains it is moving up to meters and there in the advance form in the landscape modifications.

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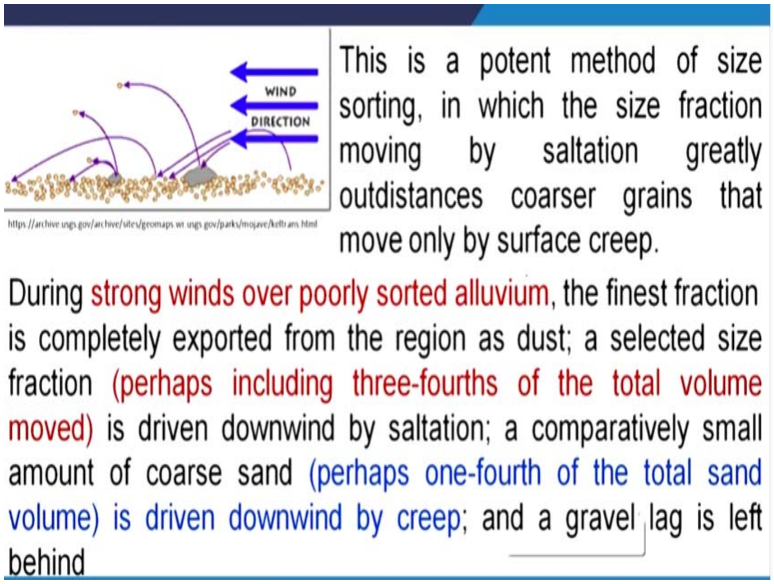

So this is a potent method of size sorting in which the size fraction is differentiated. So for example suppose we have sand grains we have mixture of grains and we are allowing wind to move. So in that case sand grains are coming and hitting the system that is why once they are hitting with larger grains, they impacting on that but themselves they are separated from the system.

So that means at one part of this area that will be enriched with larger grains at one part of this area they will enriched in the smaller relatively smaller grains. So that is why there will be sorting differences there is a natural sorting occurs within that. That is why this windblown materials they are highly sorted as compared to this fluvial systems. So I think we should stop here and in the next class we will continue with the discussion. Thank you very much. Thank you for your attention.