**Creep Deformation of Materials**
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**Mechanisms of Creep Part V**

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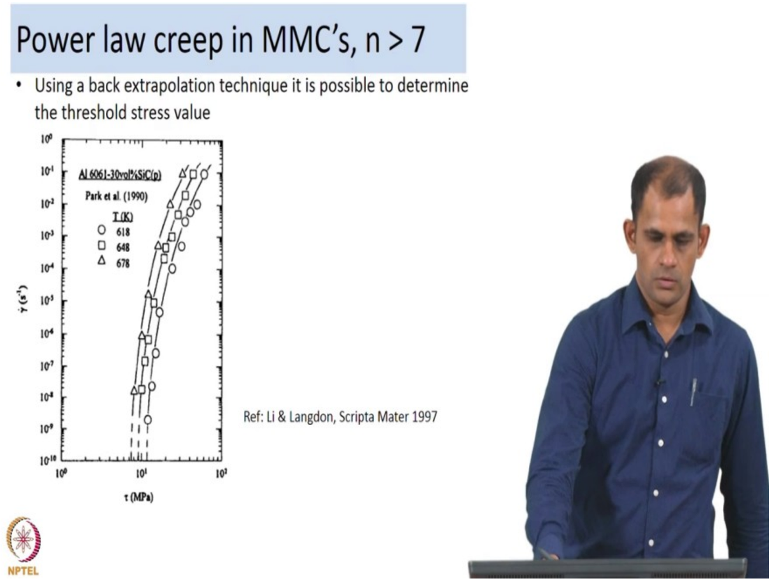


So till the last portion we were talking about Power law creep and we were looking at the Power law creep behavior of metal matrix composites where one might get a stress exponent value larger than 7 and what we said was this larger than 7 value of n is actually due to the presence of a threshold stress.

So if you invoke a threshold stress into your deformation equation then after that you would see that the stress exponent value would come in the range of 4 to 7 which we normally associate with Power law creep. So that was about metal matrix composites.

And we also said how by using a simple back extrapolation technique, it is possible to find out the magnitude of the threshold stress and like I said, I am going to give you an example on how to determine the threshold stress for a material, for metal matrix composites, this is something that I will cover in the coming portion.

Now talking of stress exponent values greater than 7,

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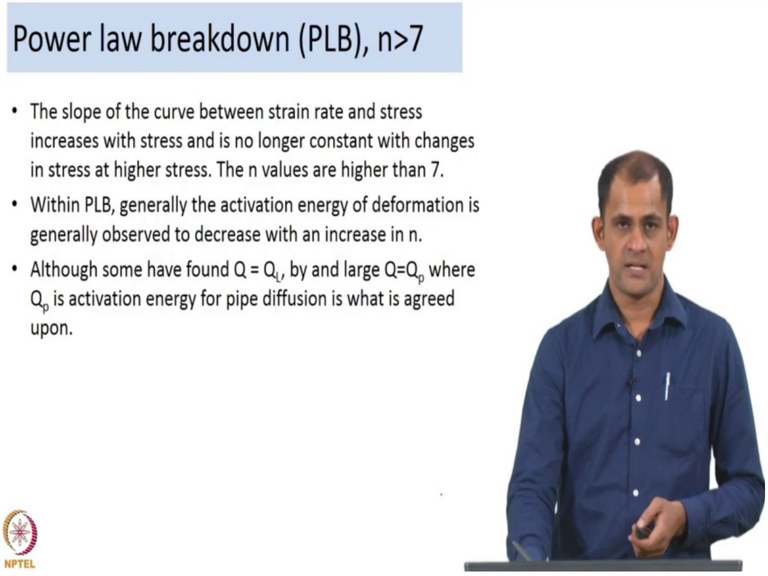


typically when you see n value greater than 7, then the mechanism of creep is, or the regime in which the creep deformation is happening is known as Power law breakdown.

So Power

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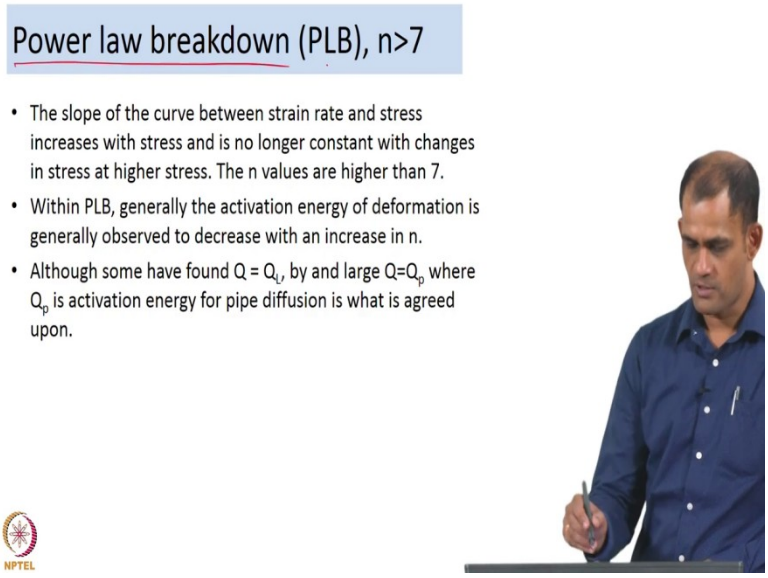


law breakdown is the creep regime where you will see very high stress exponent values and generally these are greater than 7.

So what has been observed in the Power law breakdown regime or basically the characteristic of the Power law breakdown regime is that the slope of the curve between strain rate and stress continues to increase with stress and is no longer constant with changes in stress at higher stress.

So basically what the statement means is, so if you have epsilon dot versus sigma in the power law creep regime, so you will have n is equal to 4 to 7 or let us say in this case, let us take an example of n is equal to 5.

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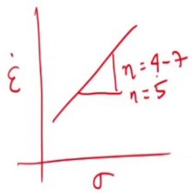
## Power law breakdown (PLB), n>7

- The slope of the curve between strain rate and stress increases with stress and is no longer constant with changes in stress at higher stress. The n values are higher than 7.
- Within PLB, generally the activation energy of deformation is generally observed to decrease with an increase in n.
- Although some have found $Q = Q_L$, by and large $Q=Q_p$ where $Q_p$ is activation energy for pipe diffusion is what is agreed upon.




So here n is equal to 5, this value does not change irrespective of the increase in stress. So you have stress increasing but the slope continues to remain constant at n is equal to 5.

But

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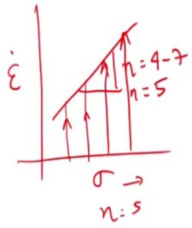


in Power law breakdown regime when you have epsilon dot versus sigma, so what you have is, you have something like that so the slope continues to change and with increase in stress. So as the stress increases if you will see the slope is increasing

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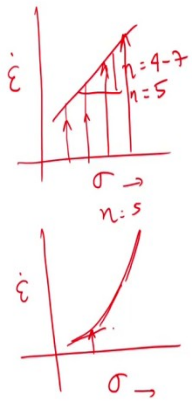


as stress is increasing. So that is the characteristic of Power law breakdown.

So if you get your creep data and if you plot the minimum creep rate, that is the secondary stage creep rate against the applied stress and if you see something like that where the slope seems to change as a function of stress then that means you are most probably in the Power law breakdown regime.

And in addition to n so which is increasing what people have also observed is, within the Power law breakdown regime generally the activation energy of deformation is also observed to decrease with an increase in n. So what it basically means is, as your n increases there is concomitant decrease in the activation energy of deformation.

So Q seems to decrease as n increases. Now if you

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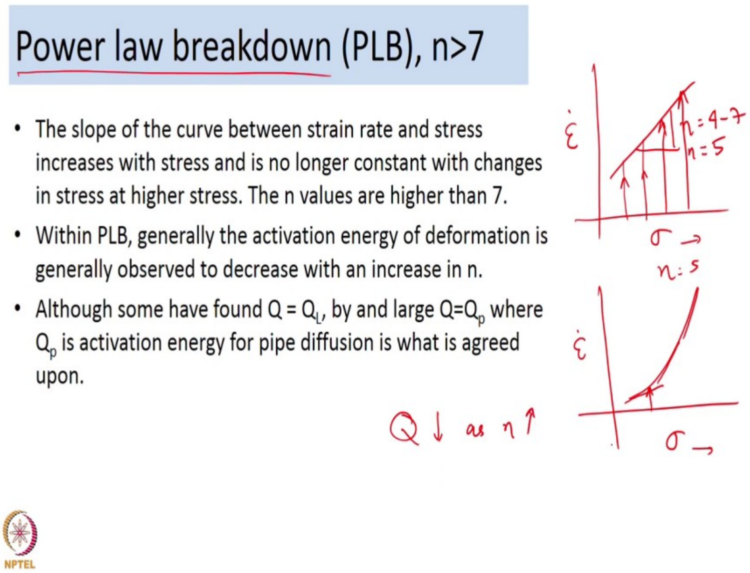


notice we are saying n increases when stress increases.

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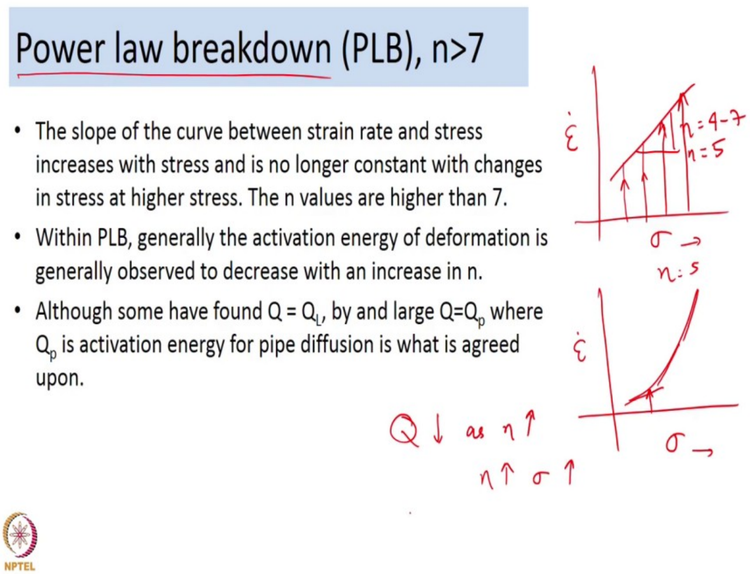


So this also means that Q seems to decrease when stress, applied stress is higher. And that is the behavior of Power law breakdown

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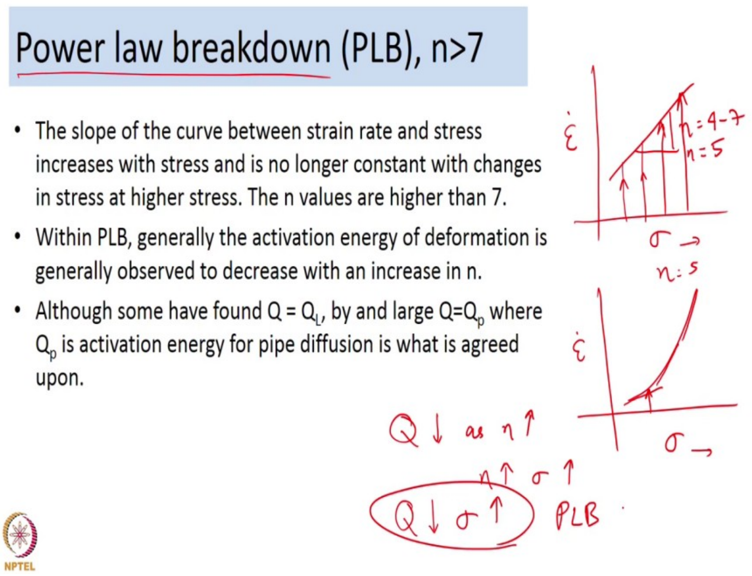


regime.

So the activation energy of deformation also seems to come down in the Power law breakdown regime. Now generally we look at activation energy of deformation as either equal to lattice self-diffusion, so you have Q is equal to Q L, or which is basically the lattice diffusion activation energy.

Or you could have Q is equal to Q g b which is activation energy helped by the presence of the grain boundaries which is grain boundary diffusion activation energy.

In addition to that we also talked about viscous glide creep mechanisms where the activation energy of diffusion was dependent on the solute diffusivity. So we said Q is probably or Q is equal to Q s which depends upon how fast the solutes diffuse along with the dislocations.

Now in Power law breakdown while some people have noticed that the activation energy of deformation is close to that of lattice diffusion, but by and large people claim that the activation energy of diffusion in this material

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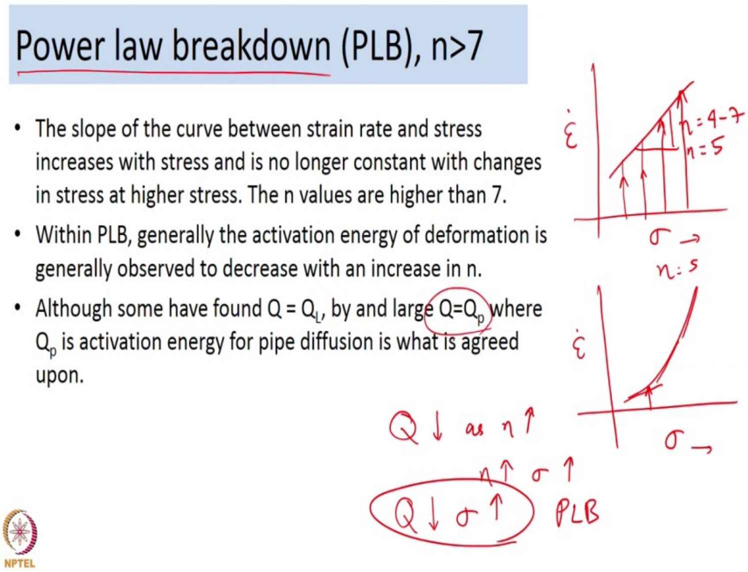


is in the range of Q is equal to Q p where Q p is defined as the activation energy

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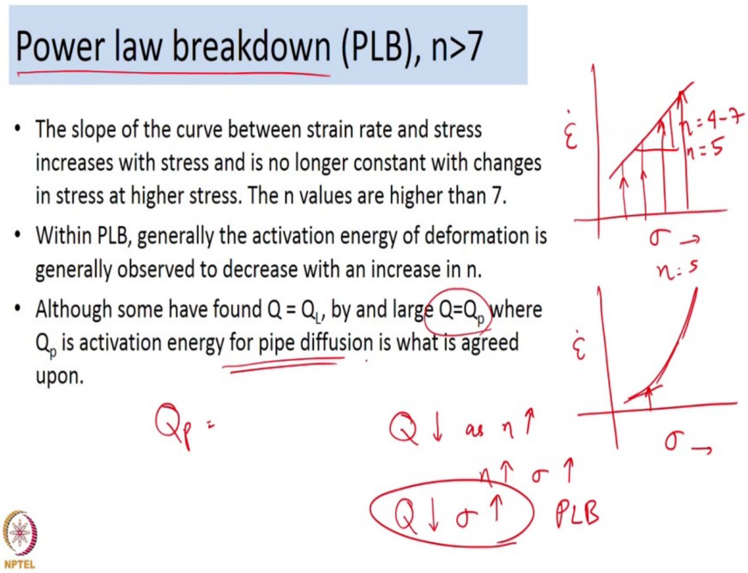


for pipe diffusion.

So this is what people have agreed upon. So pipe diffusion we will talk about this, so people say that in the Power law breakdown regime the activation energy for deformation is equal to that required, is equal to that of pipe diffusion.

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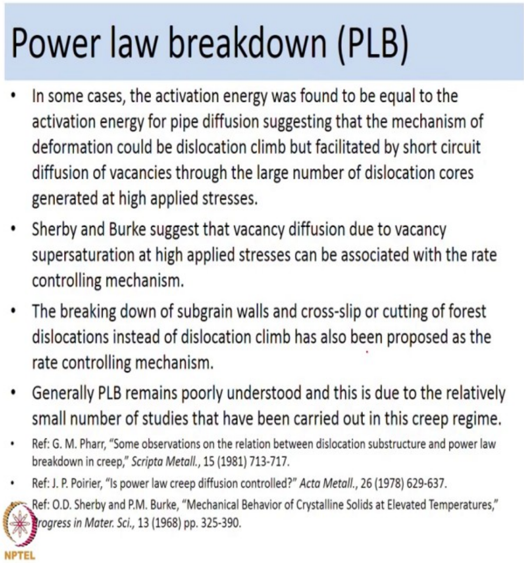


So pipe diffusion, the mechanism of, so basically what happens is in pipe diffusion, you have a short circuit diffusion of vacancies through a large number of dislocation cores generated by the high applied stress. So you have short circuit

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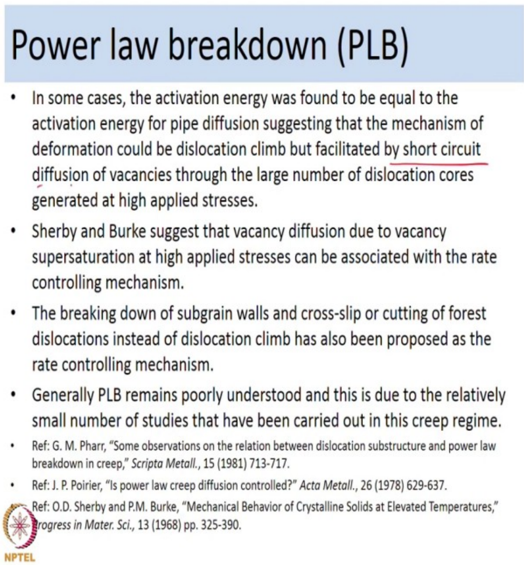


diffusion of vacancies through a large number of

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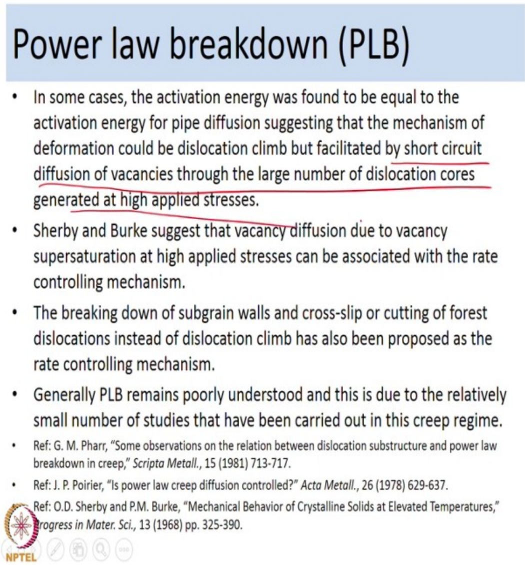


dislocation cores.

So again coming back to the concept of a dislocation so you have an extra half plane of atoms which means there is space available

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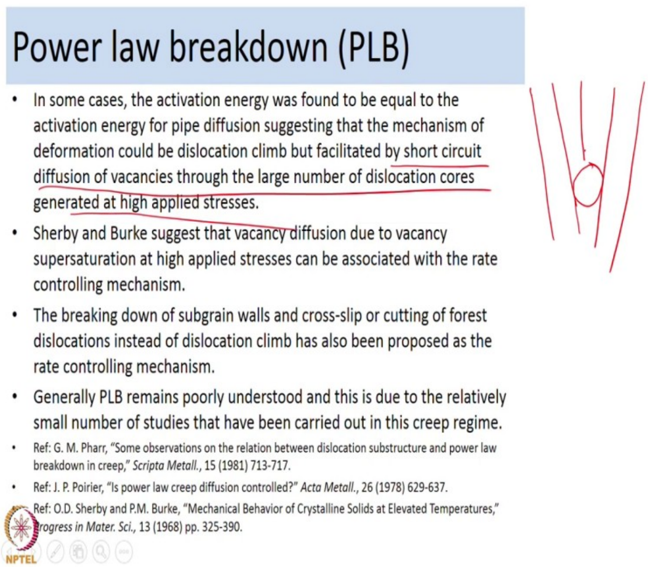


below the extra half plane of atoms. So when you have space available, you can assume that the vacancies or atoms will find it easy to migrate through this

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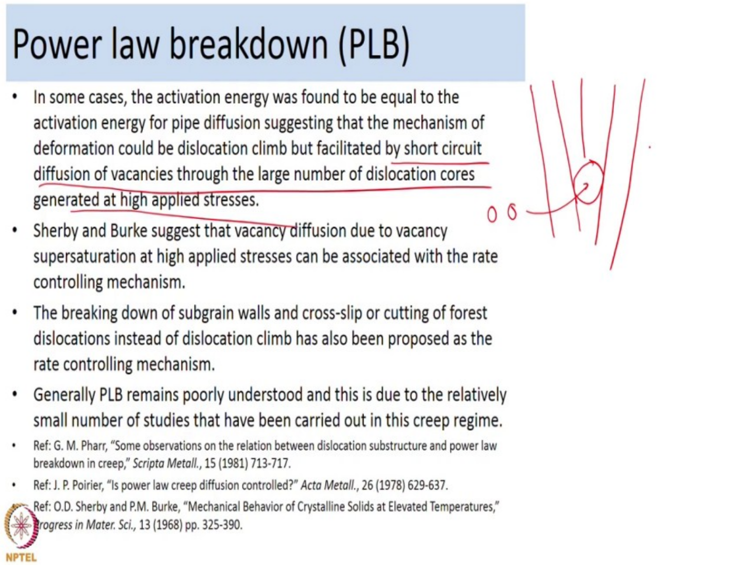


vacant space. So it is basically like a pipe, because you have a dislocation line and then there is a vacant space below it.

So

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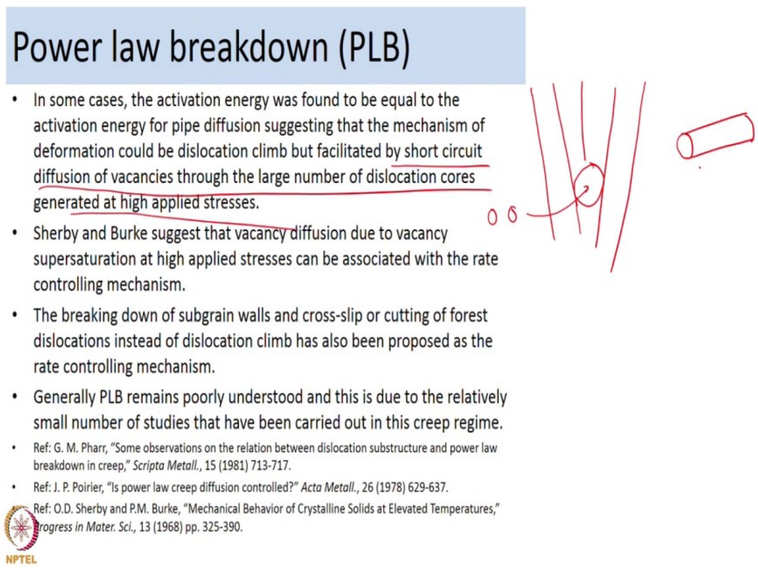


as long as the dislocation line stretches, so you have a vacant space below that dislocation, so what people are saying is there is short circuit of diffusion of vacancies, so the vacancies find it easy to diffuse through a large number of dislocation cores and the number of dislocations increase as we increase the applied stress.

So as we increase the applied stress, the density of dislocation increases so vacancies find easier paths for traveling through the dislocation core. That is why the activation energy is going to come down as

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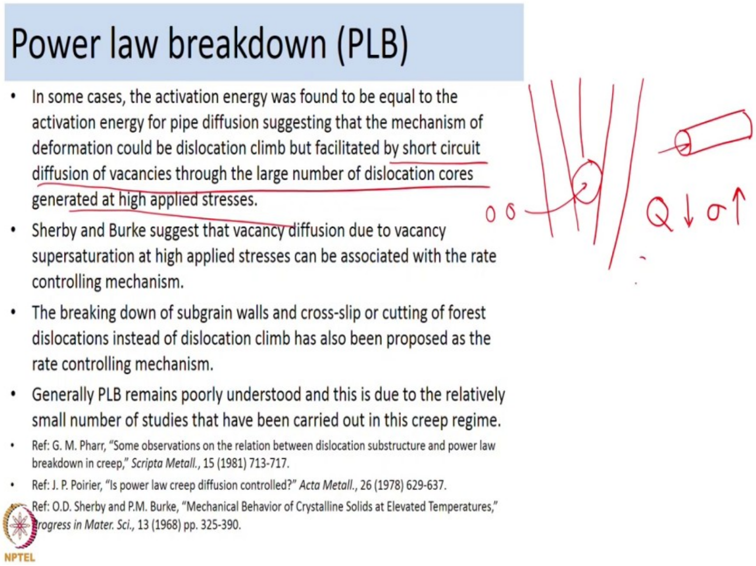


the stress increases and so Q is equal to Q p which is lower than that

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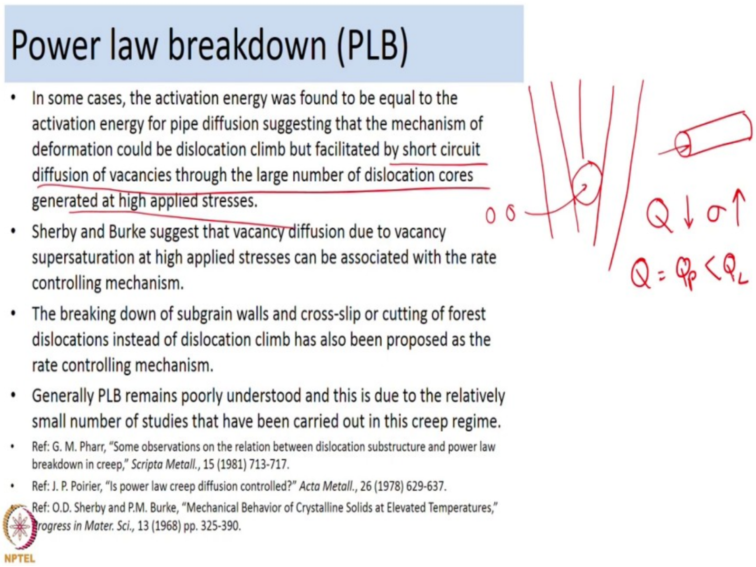


of Q L.

Now Sherby and Burke, so based on this observation Sherby and Burke suggested that vacancy diffusion due to vacancy supersaturation at high applied stresses can be the rate controlling mechanism in Power law breakdown regime.

So although in Power law creep we generally talk of dislocation climb as the rate controlling mechanism, in

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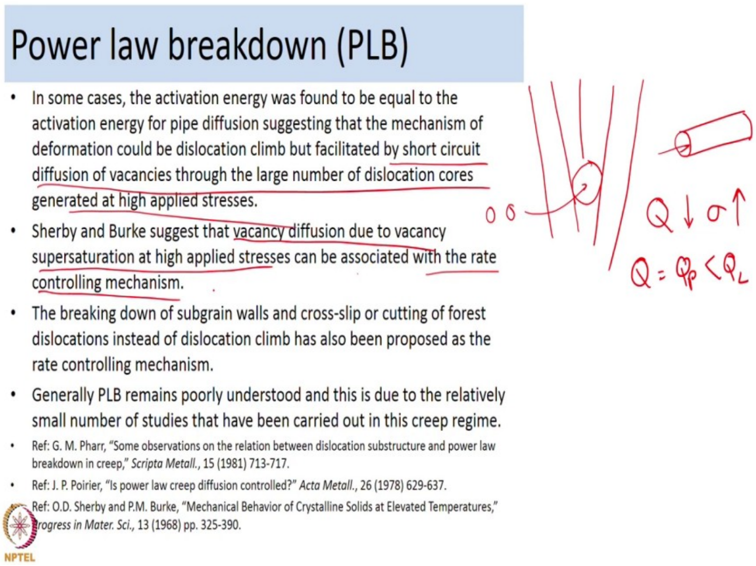


Power law breakdown regime one could say that vacancy supersaturation and vacancy diffusion due to vacancy supersaturation at high applied stresses can be the rate controlling mechanism.

Another mechanism that people have suggested is the breaking down of sub grain walls

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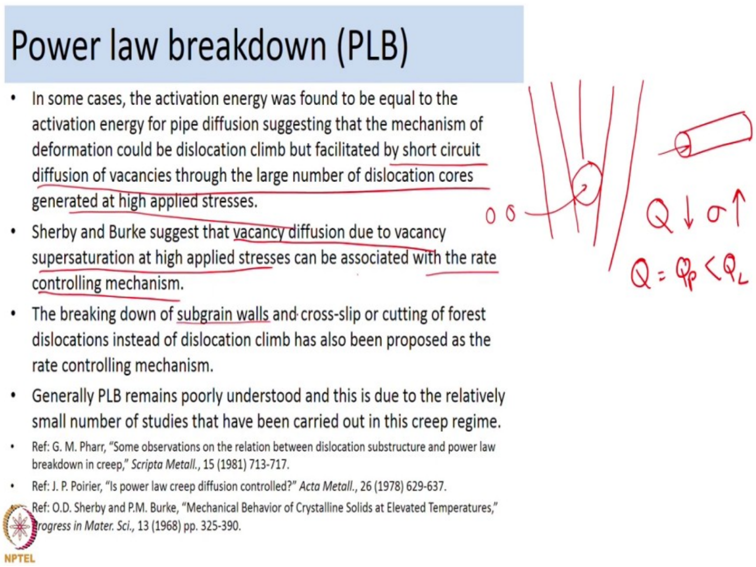


and cross-slip or cutting of forest dislocations. So other mechanisms that people have suggested is you could have sub grain walls breaking down.

So in Power law creep we are talking of the formation of sub grains within the material so, so one mechanism that has been proposed is that these walls tend to break down in the Power law creep regime.

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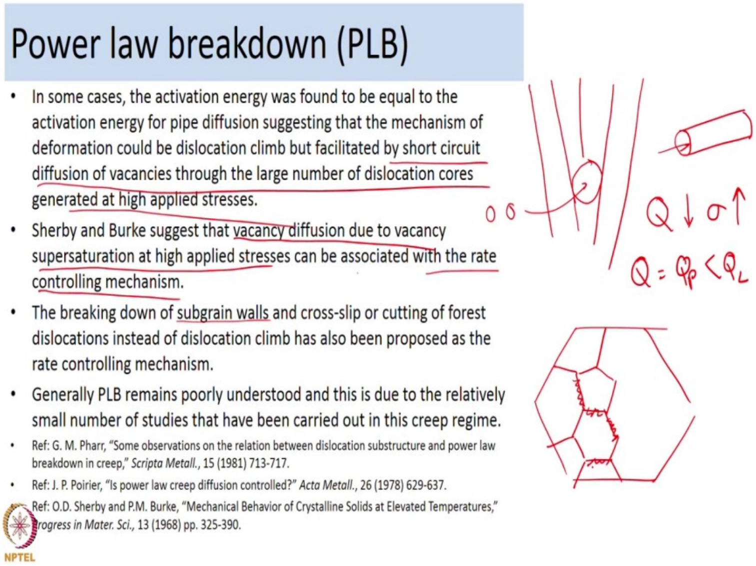


And another mechanism that has been proposed is cross-slip of forest dislocation. So since we are going to have a large number of dislocations and in the presence of high stresses these dislocations move, there can be a significant of, amount of cross-slip or cutting of forest dislocations happening and this could also be the rate controlling mechanism

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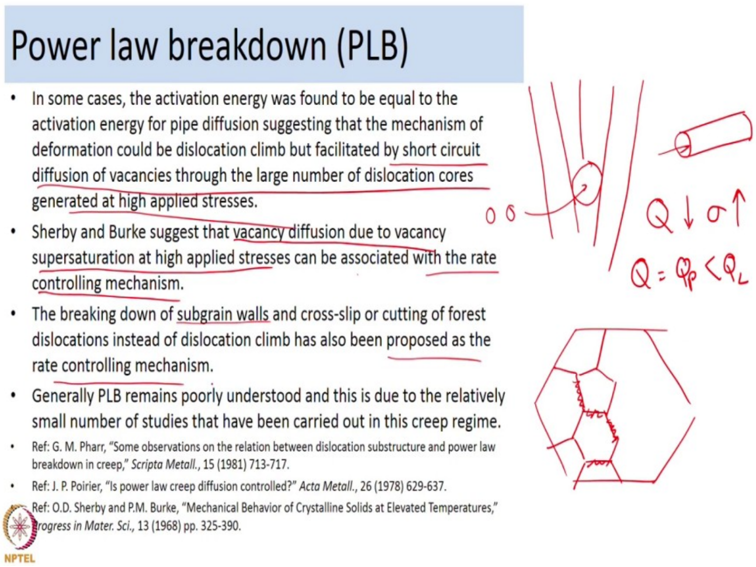


in Power law creep regime.

However having said this that people have said dislocation climb could be one of the rate controlling mechanisms, people said diffusion of vacancies through dislocation cores leading to Q is equal to Q p could be the rate controlling mechanism and in some other cases people have said the breaking down of sub grain walls and cross-slip or cutting of forest dislocations is the rate controlling mechanism.

However by and large you can say the mechanism of Power law breakdown regime is poorly understood and this is due to the relatively small number of studies that have been carried out in this creep regime. So in a way, still there is some amount of work that can be carried out to understand what exactly is the mechanism of deformation in the Power law breakdown regime.

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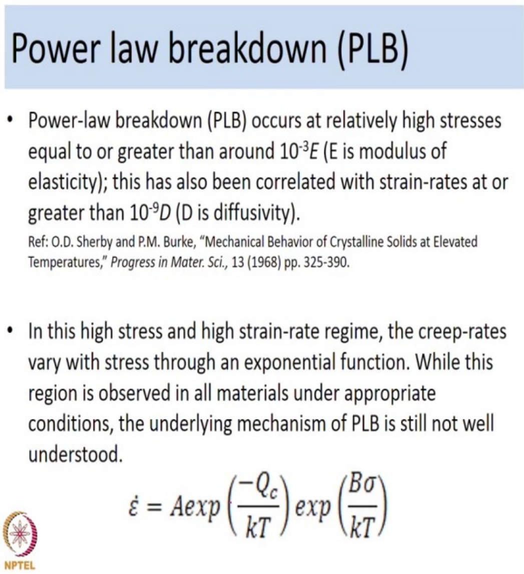


Now one thing that people have noticed is Power law breakdown generally occurs at high stresses, something that I already mentioned. So you go from epsilon dot, you have say n is equal to 5 and when you go to higher stresses

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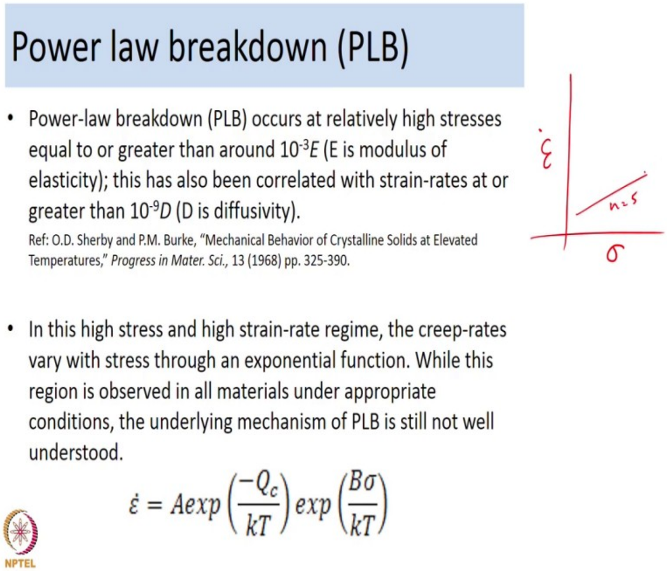


you see something like that so basically

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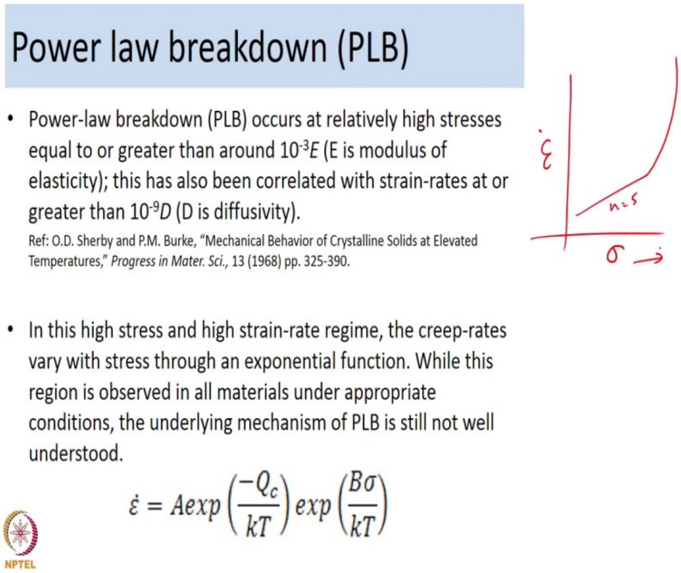


the Power law breakdown is the result of high applied stresses.

And what people have noticed is if the stress is normalized with elastic modulus then typically Power law breakdown is observed around sigma by E is equal to 10 to the power minus 3.

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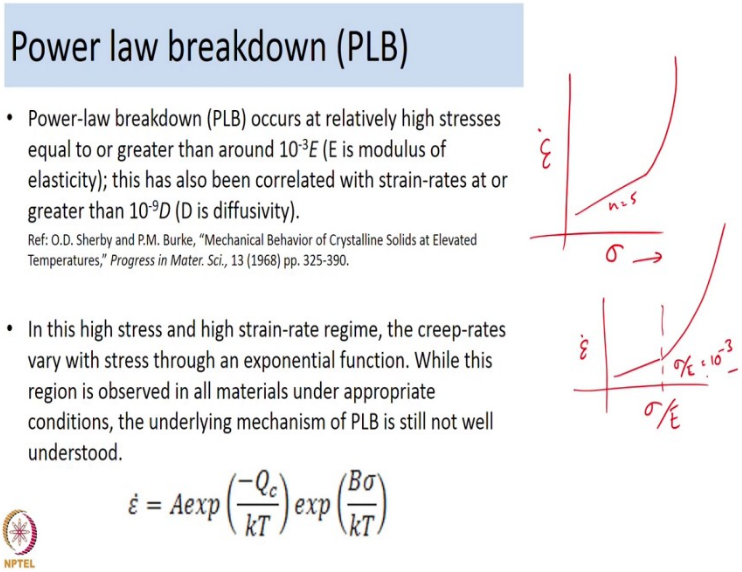


In that range is where Power law breakdown has been observed. In other cases people have said Power law breakdown also corresponds to strain rates greater than 10 to the power minus 9 D.

So if D is the diffusivity people have also noticed

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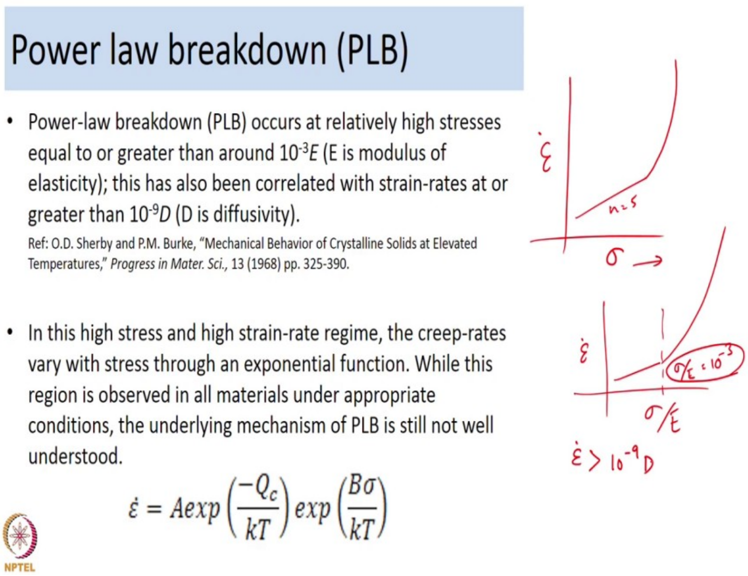


that if the creep deformation is proceeding at strain rates greater than 10 to the power minus 9 D, then also one could say that Power law, Power law breakdown creep regime could ensue.

Now in this high stress and high strain rate regime, in Power law breakdown regime creep rates vary with stress through an exponential function. So the governing equation of

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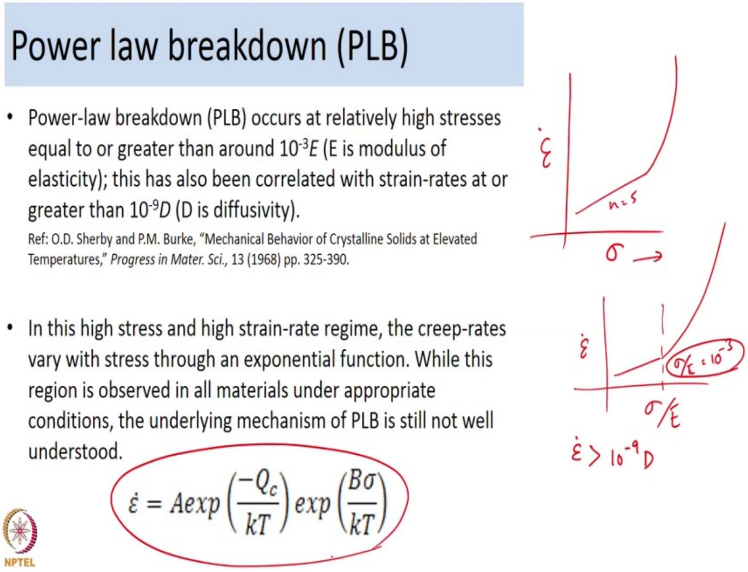


creep in the Power law breakdown regime is described here. So you see an exponential dependence on the applied stress.

So while this regime is observed in all details and therefore the underlying mechanism of creep like I mentioned earlier is not well-understood, but one thing is clear. The strain rate

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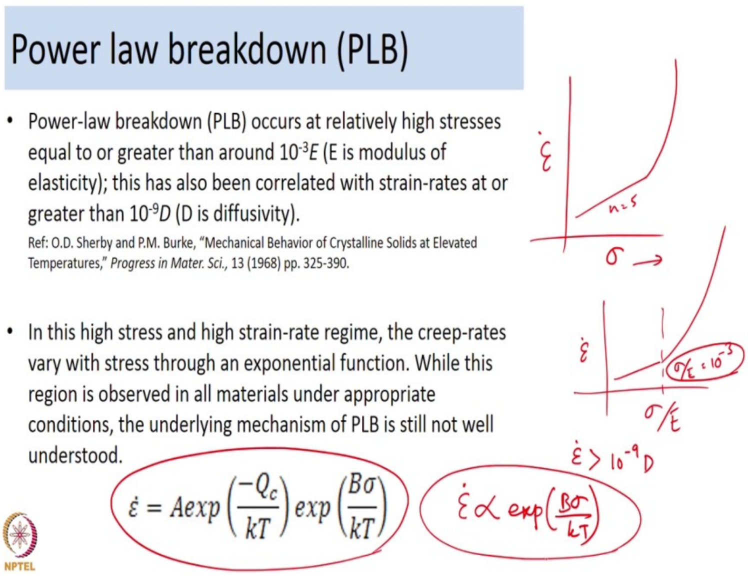


of deformation is dependent, has an exponential dependence on the applied stress. So that is the equation of Power law breakdown.

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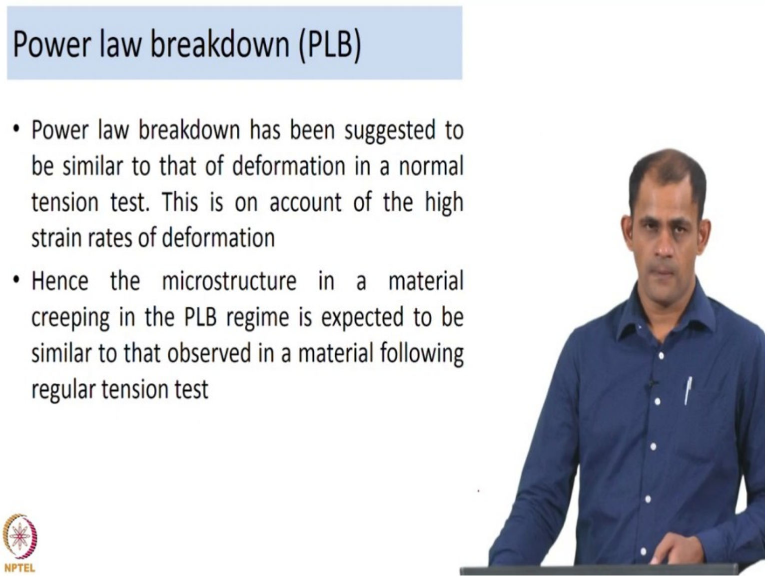


Now on account of the fact that you need high stresses for this deformation to happen, Power law breakdown has also been suggested to be similar to that of deformation that the material experiences in a normal tension test. So if you are carrying out a normal tension test, typically the strain rates of deformation are of the range of 10 to the power minus 4 or 10 to the power minus 3.

And in Power law breakdown similar range of strain rates are observed. So people have come to conclude that Power law breakdown could also be considered like that of a normal tension test.

Now in account, on account of that, so since you are calling that Power law breakdown could be like a normal tension test then what also could be said is that the type of microstructure that the material would develop after deforming in the Power law breakdown regime should be similar to that of a material deforming in a regular tension test.

So the strain rates of deformation are similar. So the microstructure that one would generate in a tension test following plastic deformation in a tension test, a similar type of microstructure is expected to form in a material that has deformed by creep in the Power law breakdown regime.

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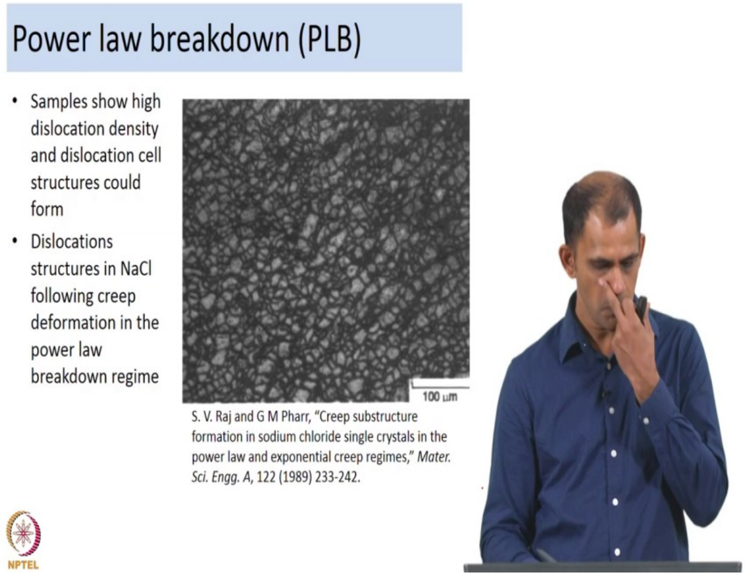


So the kind of microstructure that people have observed is shown in this slide. So this is a microstructure taken from sodium chloride single crystals which were deformed in the Power law breakdown regime.

So what has been noticed by the researchers is that the samples showed a high amount of dislocations. So the samples following the creep in P L B regime had high dislocation density and dislocation cell structures, so these are dislocation cell structures that would form

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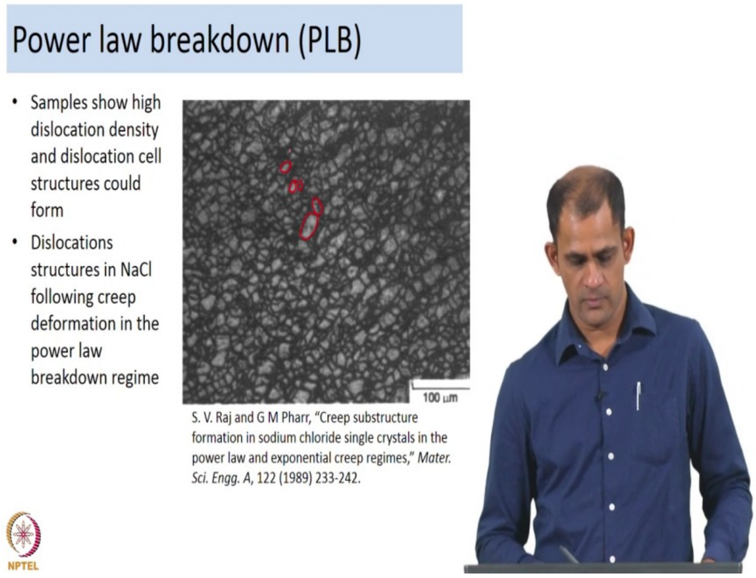


during creep in the Power law breakdown regime.

So that is the kind of microstructure. If you observe something like that after you creep test, then you can, a kind of sure that your material is certainly not in the Power law creep regime but it could be, it is most probably in the Power law breakdown regime. So that is what is happening.

So,

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Ok, so that brings me to the end of the different types of mechanisms that people have observed during creep of materials.

So we talked about these various mechanisms, we talked about n is equal to 1 as Newtonian viscous creep mechanisms, where under which you had Nabarro-Herring, you had Coble, you had Harper-Dorn.

Then we talked

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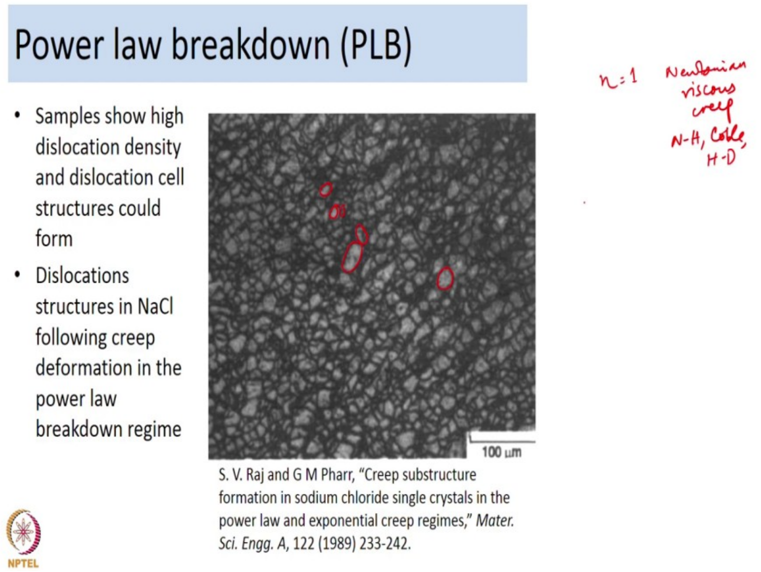


about n is equal to 2 we said it is grain boundary sliding where you could have

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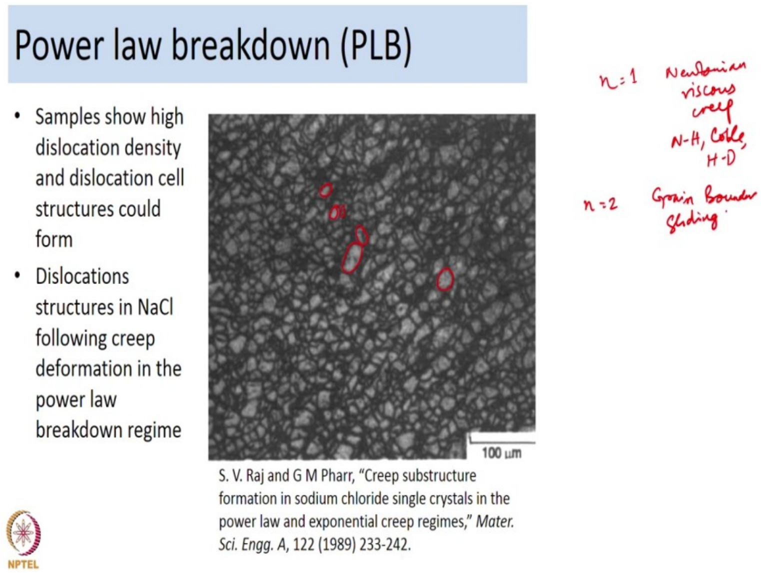


offsets, the sliding of the grains leads to offsets in fiducial markers, then you had n is equal to 3, we said it is viscous glide controlled creep

And then we said

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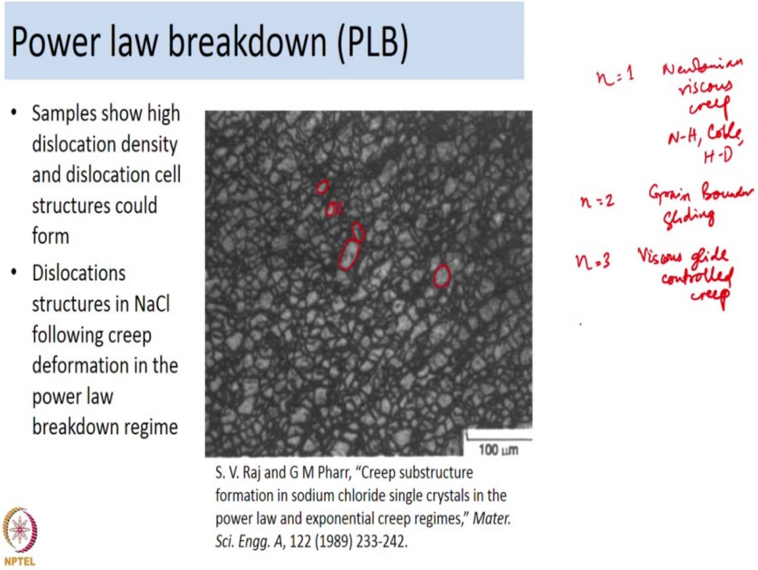


n is equal to 4 to 7, it is Power law where it could be either Weertman's model or it could be the Jogged screw model

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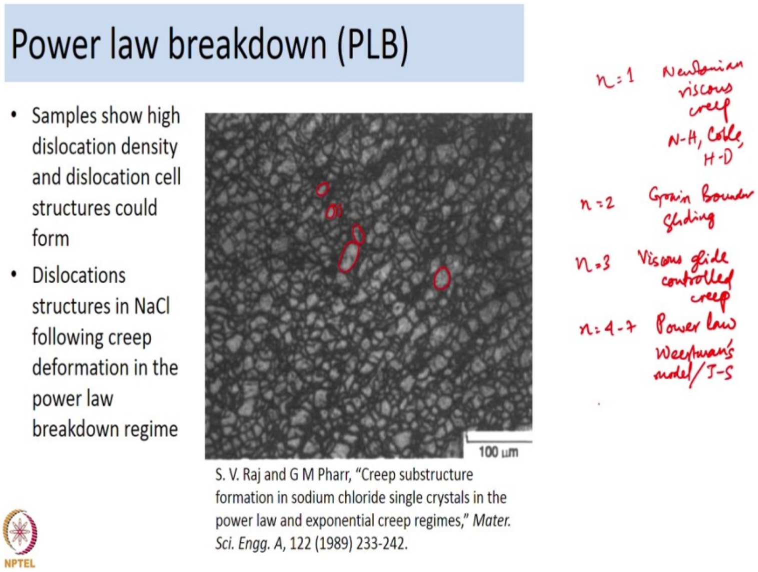


and then we said of n greater than 7 which is the Power law breakdown regime.

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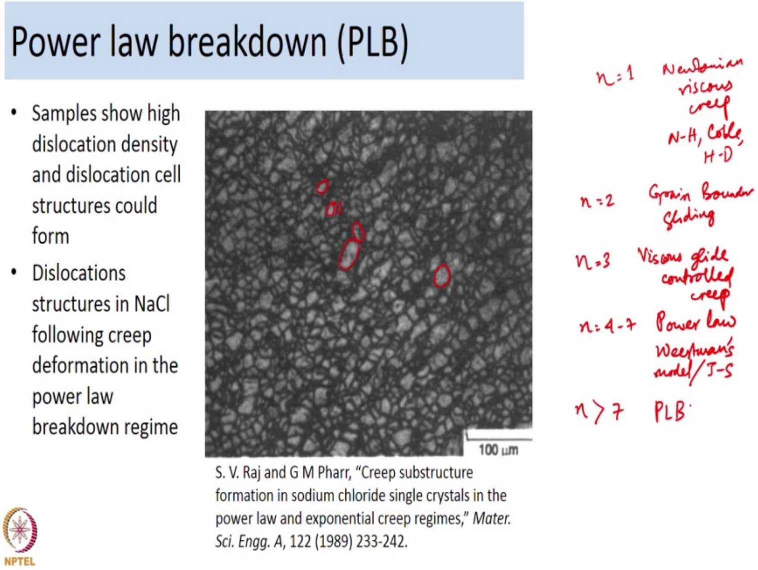


And what is interesting is one can go from this n is equal to 1 regime to n greater than 7 by increasing stress. So if you increase the stress or another way of saying is if you increase the sigma by E

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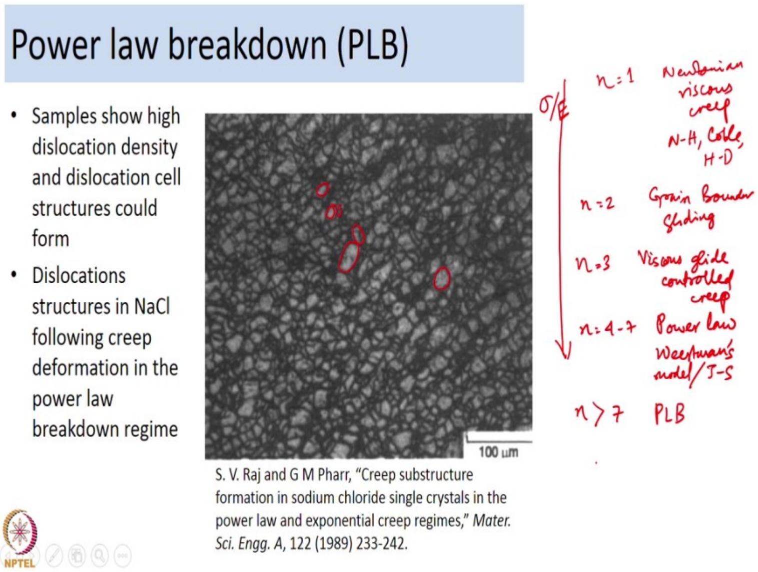


value which is the normalized stress value, higher the normalized stress value greater is the probability that you will be either, the material will creep either in the n is equal to 4 to 7 regime or n greater than 7 regime.

Of course when we say higher sigma by E, we are also assuming that

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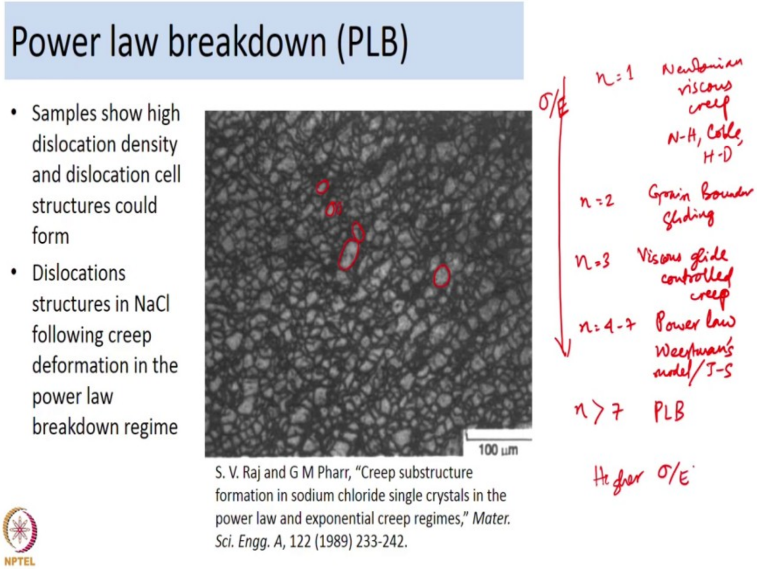


the grain, the microstructure is also favorable for that particular deformation mechanism to operate because we know microstructures such as grain size also has a significant role to play

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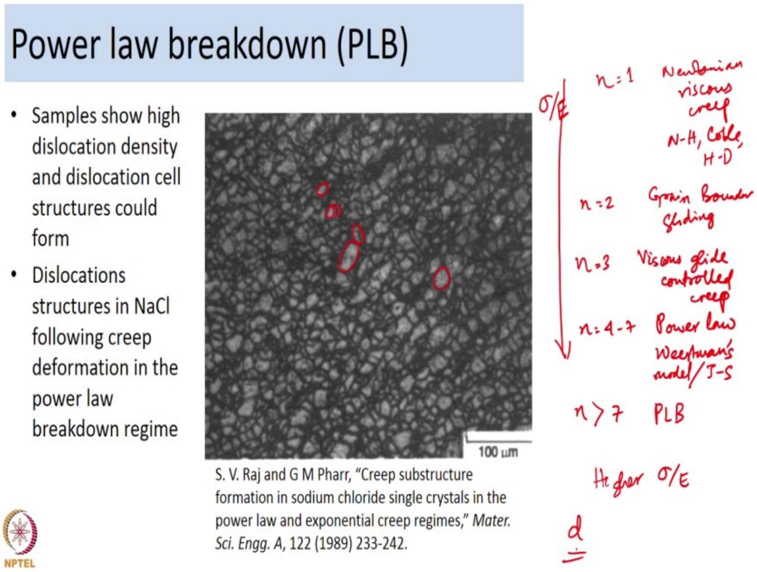


in determining the rate controlling mechanism of deformation.

But ignoring the effect of microstructure, if you generally talk of sigma by E, what people have noticed is, as you increase the sigma by E value, you go from one mechanism of creep, so basically you transit from one mechanism of creep to another

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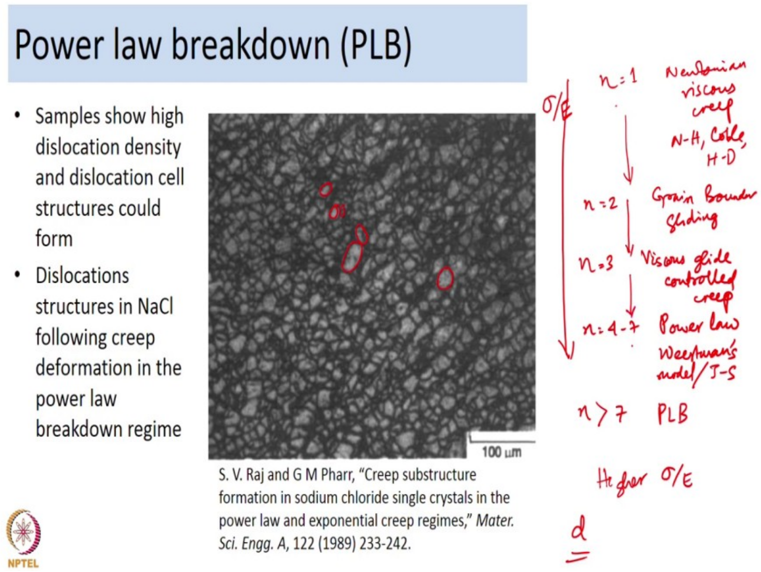


and so around sigma by E greater than 10 to the power minus 3,

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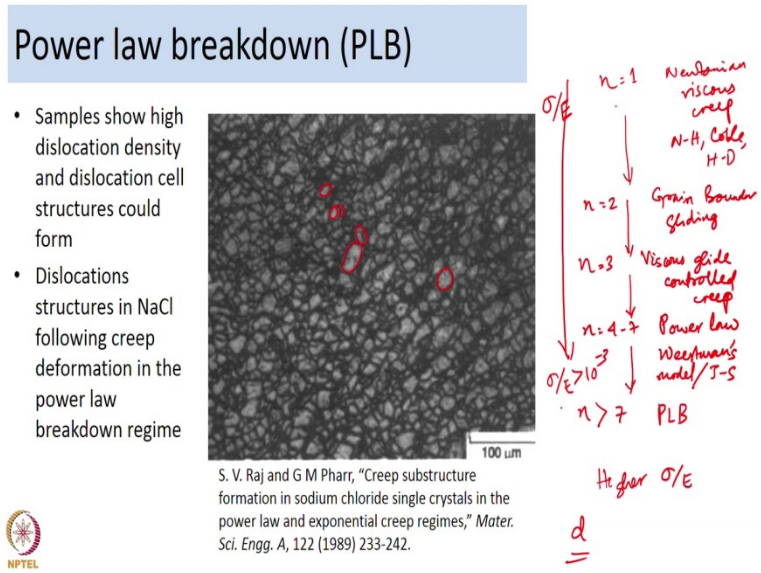


you are basically

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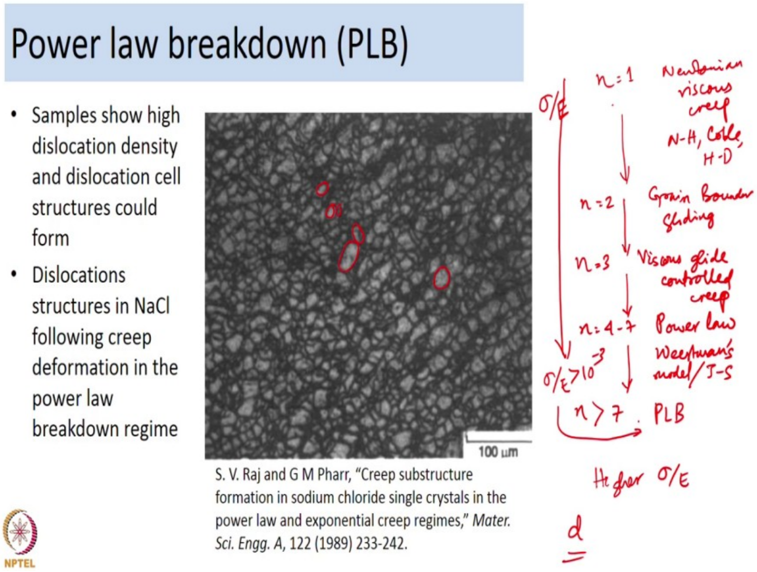


in the P L B regime.

So basically the point is creep mechanism, the deformation mechanisms can undergo transitions. So basically you can see change in the deformation behavior as a function of applied stress, temperature and grain size.