Structural Geology
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Lecture 10.1
Rheology I Basics of Rheology

Hello everyone, welcome back to this online Structural Geology course. And, today we are at our lecture number 10, where we will study rheology. We have used this term at the time of discussion of strain, stress and even in the very beginning when we were working with the geometric, kinematic and, dynamic models. In, dynamic models particularly we used this term rheology, but did not explain it in detail. So, in this week we will learn about this topic rheology.

We will cover it by 3 lectures. In the first lecture; we will discuss about very basics of rheology. The second lecture will mostly consist of some sort of complex rheology. And in the third lecture we will talk about what are the parameters, the natural parameters that we commonly experience in earth or; rocks to experience in earth how this parameters influence the rheology. Before, we go to this topic, in this lecture we mostly cover; and will introduce the subject so sort of an introduction.

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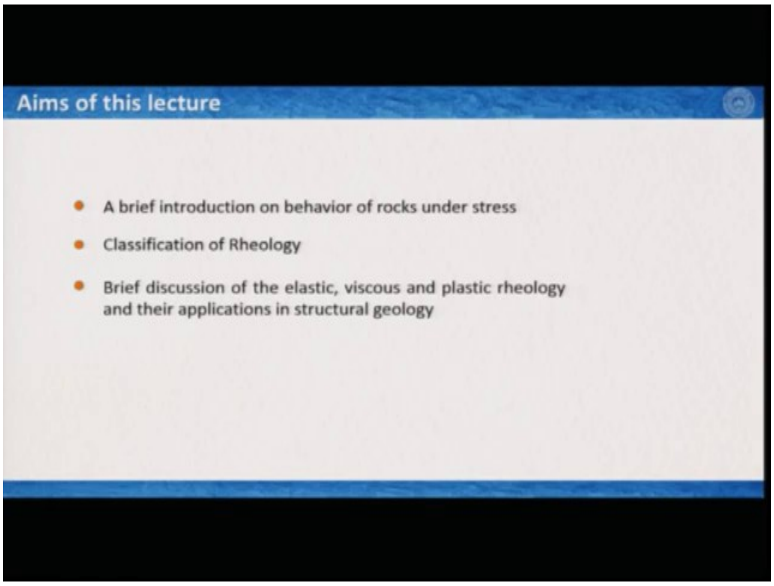

That what is, what do you mean by the behavior of rocks under stress? Which is we learn later that is the definition of rheology. We will classify the rheology in three end members and these are elastic, viscous and plastic rheology. So, we will sort of discuss this entire three briefly and at the same time we will discuss their applications in structural geology together with geodynamics. So, before we go to this particular or we take this particular topic rheology to the domain structural geology.

It is very interesting that, we as a human being we use the rheology or, applications of rheology every day or in our actions. we actually use applications of rheology very frequently knowingly or unknowingly. So, in the next slide I will have a few questions for you. And, I am sure you do this things knowingly but, if you do not do it unknowingly. Then you can try to answer why do we do that, or why it is so?

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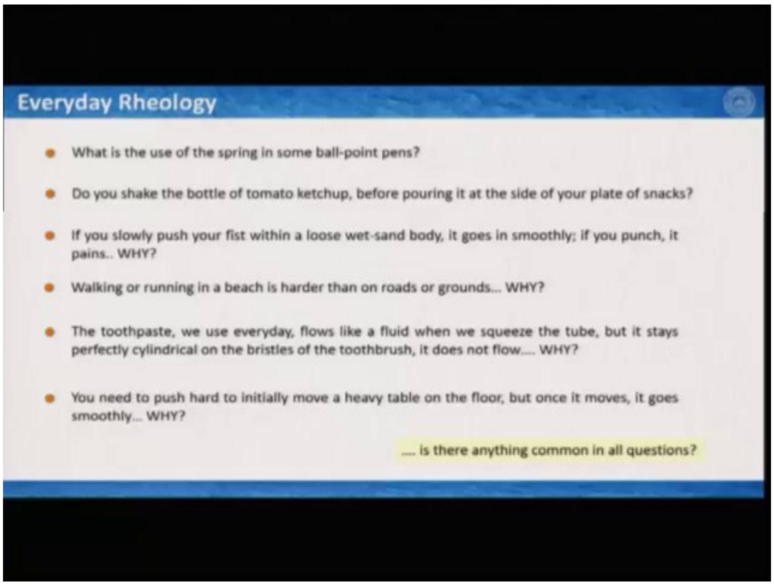

We all have used or we still use the ball point pens, and there are few ball points pens with spring at the front part of the refill. So, we just press it like this, and then we have sound tiktok tiktok. And then we see that there is spring, if you open the pen. What is the use of the spring? If you ask yourself this question I am sure you can answer. That we use the spring so, that after we press it holds the refill outside so that your nib of the ball point stays outside of the pen outside jacket of the pen.

And if you press again then the spring releases and it comes back to its sheltered position inside the pen. It is done so, that it does not dry up, or maybe it does not hurt you when, you put it in your pocket or somewhere this pointed end of this refills. So, do we use the real logic here, the answer is yes. Next we all use now a day’s tomato ketchup, right?

How many of you shake the tomato ketchup bottle, before poring it to the side of the plate, which is fool of snacks. Most of us do and if do not do it, you just do ones without shaking, and you do second time with shaking the bottle of the tomato ketchup. And you will figure it out difference why shaking makes your life little easier. This is something that athletes or bodybuilders or waver they do very frequently.

They punched the sand bags but, you do not have to do that, what of course if you wish you can do it. But, this think that if you have a loose weight sand body. And, you are sort of pushing your feast within the sand body very slowly. You will see there that your feast is going in. You can try another way that you just punched it, and you will a pain at your pam if you punch it. So, same material you are going slowly, you do not feel any pain on your palm and it goes inside very smoothly.

But, if you punch it you cannot go very far in, and you will feel some pain, the question is why, why do you experience that? Now, this is also something very interesting you might have seen; that soccer players, athletes they sometime practice or they run along the beach. They could do it on the side of the roads or on the grounds. But, sometimes they do it on the beach and if you have walked or run along a beach for quite a long time; you feel the pain in the night in your calf muscles.

Then, the similar walk if you do on the roads or grounds, it does not make any difference. If you have not experience, do that if you get a chance it is the good things to do. And again the answer is or the question is, why do we feel or why it is harder to walk or run on the beach than on road grounds? Now another thing that we use every day, particularly in the morning the toothpaste. When you squeeze the toothpaste, it comes like a fluid from the tube.

But, when it comes out and we allow it to rest on the bristles of the toothbrush. Then it stays if it do it perfectly, then it stays like a cylinder over the bristles; it does not flow it does not deform it remains as a cylinder it does not flow. The question is why, why it is so, why it does not flow? But when you squeeze it is flowing very easily. And, the final example I would like to give you is that; if we have to push a table a heavy table and if you again of muscle not like me.

Then you cannot move the table instantly after you push, you have to push a little bit, then apply some sort of force and then the table starts moving. Now, when its starts moving then, it become easier to move it again the question is why. Now, all this things that we do that a 1, 2, 3, 4, 5, 6 examples that I have given here is more or less our not routine all but, few of them we do it every day and routinely. The question is what is the common in this things in all these examples, if you can find something common of it?

I tell you these are all applications or examples of rheology, that is why the header of this slide is everyday rheology. If, I try to see that what is common, in all this examples in terms of mechanics. Then, I will all ways find that in all examples, there is one or more components of force, stress, one or more components of the deformation or strain. So, when you push the tip of the ball point pen, you apply some force and then the refill comes out. So, you apply a force the deformation is happening, you shake the tomato bottle; then you squeeze it applying a force and then tomato ketchup comes out.

You apply a force to the sand body, in different ways and you get different response. The similar way in all examples you can figure out. So, based on this ideas that based on examples that we see in our daily life, these are nothing but at one side application of force, stress or in general that we have learned are dynamitic parameters. And on the other side you have your strain, deformation, displacement, rotations, and so on. And these are you kinematic parameters. So, we have learned about stress we have learned about strained.

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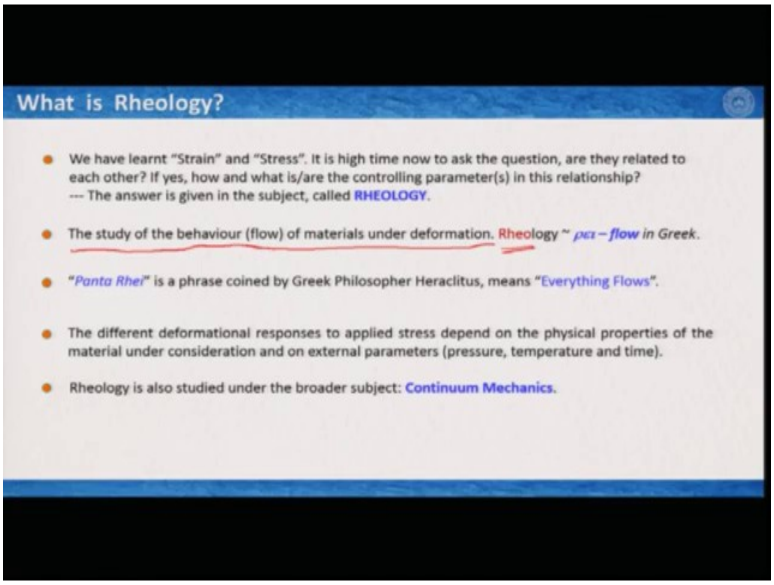

Now, this the point that we should asked in the context of studying mechanics, or in very particular studying structural geology or the deformation of rocks. That, whether these two terms stress and strained which are applicable to our subject very much are related each other or not? And, if they are related then how they are related, and what are the controlling parameters in their relationship? And the study of the relationship between stress and strain is the study of rheology.

That is not only valid or not only important for our subject, but for most of the subjects particularly food industries and so on. So, if I have to define rheology it is very simple. The second point narrates the definition of rheology. The study of the behavior or flow of materials under deformation is rheology. Now, rheology is derived from a Greek word rhei that means flow in Greek. Now, there is a Greek philosopher Heraclitus, he coined a term or a phrase panta rhei.

So, panta rhei in Greek means everything flows and in his philosophy everything means everything. And, we should be happy with this phrase. When, someone says everything flows because, than we can immediately connect that do the rocks flow as well. And, we try to see the answer and Is will tell you the answer is ‘ye’s rocks also do flow. So, this everything flows concept is very interesting and, there are therefore different deformational response to the applied stress.

And, these responses are functions of their physical properties of the concern material that, you are thinking of or working with and together with their some sort of external parameters. That, means the envy and the environment you are exposing your material and allowing it deform. Needless to mention that because, its relationship between stress and strain. The mathematical or the physical understanding of this subject rheology is also consider under the umbrella of continuum mechanics. Now, we will again go back to this very interesting term of panta rhei means everything flows.

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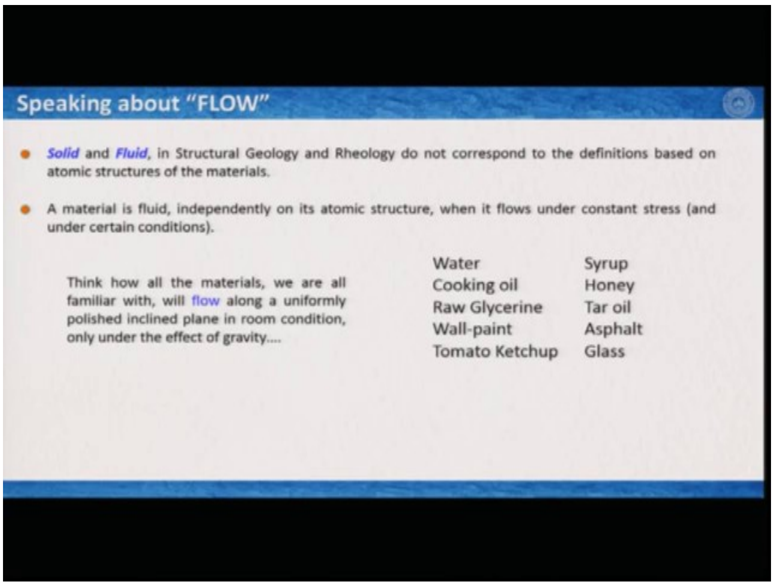

And, here therefore, when we talk about flow the definition of solid and fluid are not really classical, as do people define it based on atomic structures of the material. So, there is one set of definitions what is solid, fluid, and gas, in terms of solid liquid and gas, in terms of their atomic structures there interaction some arrangements. But in the study of rheology, as i said that everything flows, so the definition fluid goes little funny it is a materialist fluid independently on its atomic structure.

When, it flows under constant stress and of course certain conditions please note it does not define time. In generally know that water is a fluid, because it takes a shape of container you feel it up with. So, I have a tea cup and there is tea inside so, it takes the shape of the cup, if it was a beaker it would take shape of beaker and so on. Now, fluid in rheology is not defining in such a way, so its independent on its atomic structure. So, anything that flows under stress is fluid in rheology.

It does not talk about time, and let us think of certain experiment. Say you have sloping board with uniform friction or no friction if you can make it. And, then from one end you have an opening, where water can flow. Then, series of opening so if cooking oil, then may be raw glycerin, wall paint, tomato ketchup, syrup ,honey, tar oil, asphalt and so on the last one you may ignore. We will see this but, if you want you can also put some glass.

And, if you release all this fluids at the same time, you will see the water is the fastest to touch the base of this sloping plain. And, probably tar oil and asphalt are extremely sluggish and to touch the base it may take few days. Now, we generally classify all of them as fluid or we consider them as fluid. So, the difference between water, cooking oil, raw glycerin, tomato ketchup, and asphalt and so on, there is something in their material properties is that they are their fluids that hey flow differently under the same conditions.

So, the gravity is the force working on them, the slope is same the frictional surface is same. And, why do they flow differently what are the conditions that can change their flow differently? That can change their flow properties; that what should I do if I have to make the flow faster of tar oil or asphalt for some particular applications? So, if we have these questions in our mind then we study all in this things under the subject rheology.

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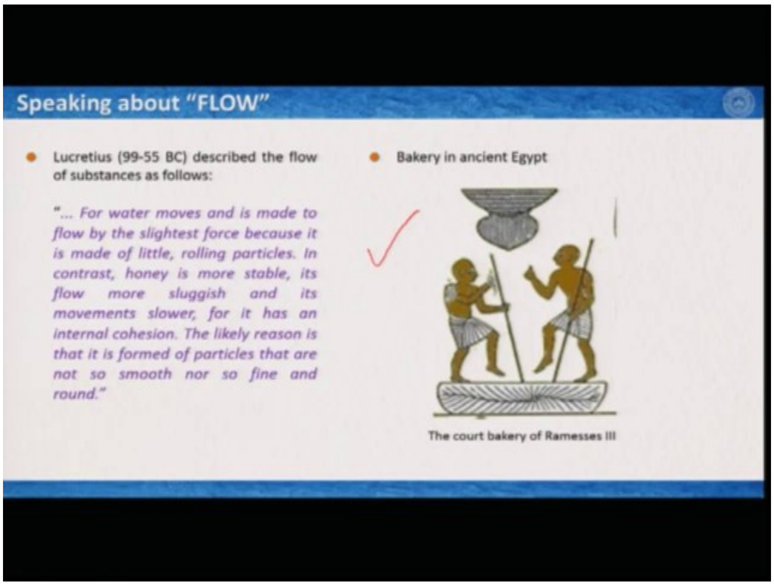

Now, rheology is essentially a very old topic. So, here is I found something very interesting, it is very old text by Lucretius, he was a roman philosopher and also poet. And, he wrote a book on the nature of things something like that if am not a remembering correctly, on the nature of things. So, he wrote for water moves and it made to flow by the slightest force. Because, is made of little rolling particles. In contrast honey is more stable, its flow more sluggish, and its movements slower for it has an internal ovation.

The lightly reason is that, it is formed of particles that at not so smooth nor so fine and round. Now, he wrote this at around up he was there 99 to 55 b c. So, wrote it long time back and the one of the most famous generals of rheology, that is journal of rheology: and one editorial on him on Lucretius one of the pioneers of rheological studies. So, there is something and you see he is mentioning some sort of he is finding the difference between the water and honey. And people also knew the rheology in the ancient Egypt's.

So, this is the picture that we see here so, this people found from the tomb of Ramesses 3. And, what we figure out that the series of paintings. So, they are making breads so it is a bakery, and they all it court bakery of Ramesses 3. What this two people were trying to do here, probably this container has door so flour and water, and there doing it with and they are sort of trying to press it or role it with their feet. And then this two little rods or whatever are there to check consistency of this flour. And they know that when the, by experience probably they know when the consistency is their then they send it to the next stage. So, the study of rheology is very old and we use it for pretty long time.

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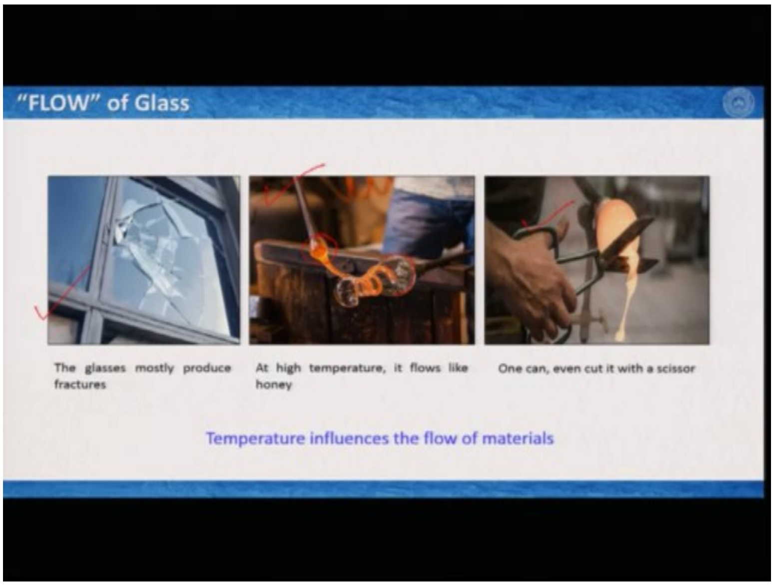

Now, let us slowly move to sum similar materials that we commonly, see through commonly compare rocks. Talk about the flow of the glass now of course we all have done it, you had played cricket and soccer and we have broken glass. So, this is an example, so if you apply some load on the glass normal glass that we every day. If we heat it with some peace of stones, or you cricket ball, or soccer ball then the glass breaks. It produces fractures and you can certainly say it does not flow.

But, the glass where you make it when you elevate the glass at high temperature. Then it flows like honey, as if you can see this is a jar or whatever; and then he is designing it by rolling with another glass ball. And interestingly you can also cut it by a creaser. So, it is extremely frazzle it produces fracture, here it rolls like honey and here you also can cut it. So, temperature at least from this example you can figure out, that it certainly has an influence on the flow of the materials.

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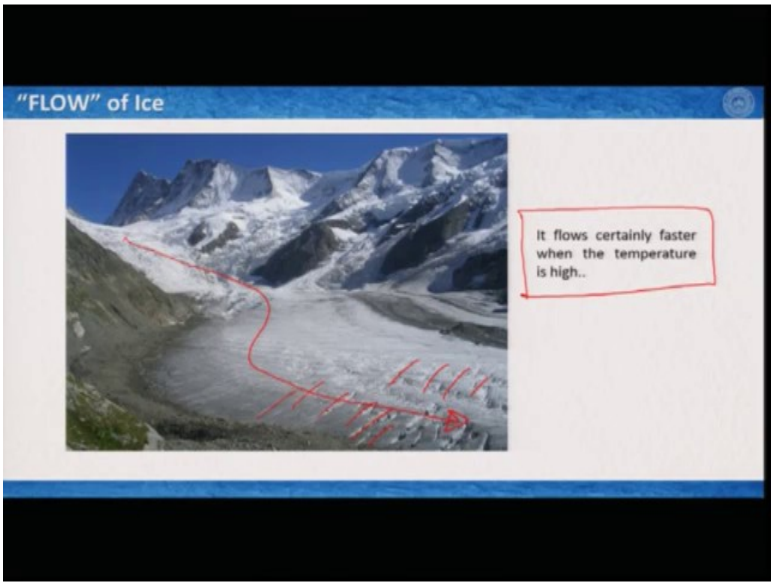

Let, us talk about relatively closer examples to the rocks, if the ice the flow of ice in glaciers. Now, what we see in this image this if I remember it is from a Switzerland from glee oval. We went for tracking here, and you see this looks like that a river is flowing. But, a river of frozen ice. And the flow of this ice is much slower than the water in a river.

We also see that top part is characterized by, a lot of fractures bottom part may be not and I tell it is not. And it flows extremely slowly but, the flow is certainly faster when the temperature is high that has been recorded. So, it does not flow like water, it does not flow like honey; it flow like ice should do but, certainly it flows much slower rate than water, or honey, or even tomato ketchup.

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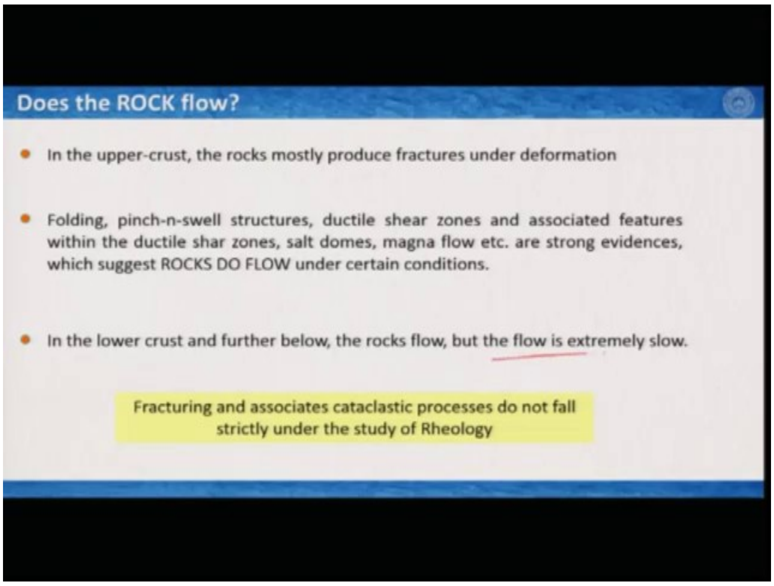

Now we really have to ask the questioned that does the rock flow? As we live, or survive mostly on the upper crafts on the surface of the earth. We do not see every day the rocks are flowing except some videos of magma flows, and things like that from Hawaii and some other places. So, what common assumption is that? Those rocks do not flow, and they mostly fractures under deformation. And, this assumption is perfectly right, when you consider them with the ambiance of the surface or near surface conditions.

But, when you go to mountains or when you go to a hilly terrain or in rocky terrain we see a number of structures, which may not be produce by fracturing or cracking. Look here are some examples I have given folding, pinch and swell structures, ductile shear zones and many associated features within the ductile shear zones the salt zone magma flows I mentioned these are the evidences that rocks do flow. We do not see it most likely because, the flows are extremely slow. It is so slow that we not see it

But, it certainly flows and the evidences are structure that we see like folds pinch n swell and so on. So, based on that we now are convincing the fact that, the study of rocks act under some conditions can be expressed; or can be evaluated we this subject rheology that people have been using historically. And, if we can do that then maybe we understand the process of deformation of rocks in a better and comprehensive way.

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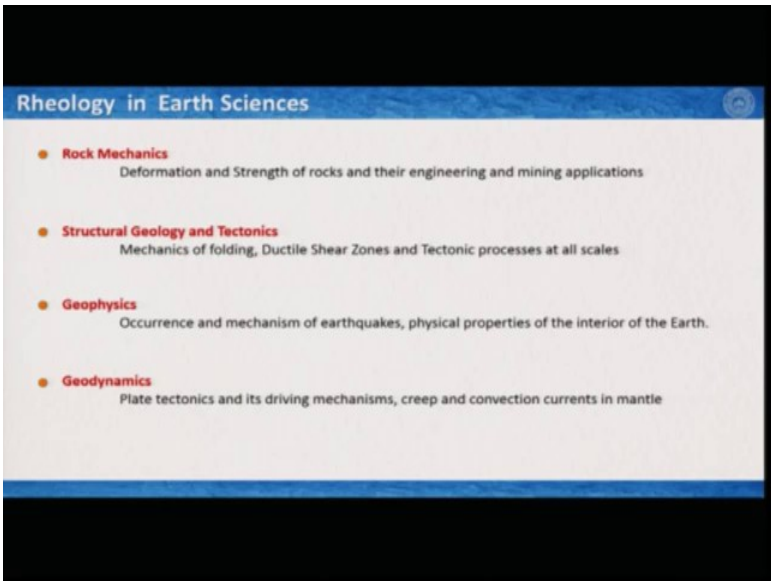

So, when you do that then there are many subjects, or many branches of art sciences were applied by us in the rheology. I must say that which was written in the previous slide, that the typical study of rock mechanics is not included under the bordered umbrella of rheology. But, sometimes it is included particularly the strength of the rocks at little elevated pressure and temperatures for their engineering, and mining applications. Structural geology and tectonics essentially we use the rheology particular to understand better. The mechanics of folding ductile share zones and various tectonics processors at different scales.

We, consider rheology heavily when, you try to understand the process of soldiery of physics. Like mechanism of earthquakes, a physical properties of the interior of the earth and so on. And, of course geodynamics that uses the applications of rheology heavily. So, plate tectonics and its driving mechanisms, creep and convection currents in the mantle. A Polling of (()) (25:33) and what not. So, all these things are being studied under the topic of rheology.

Now, we will move to the consideration of the fact that how we can express or how we can study rheology. So, we have stated earlier that mechanical state of a body is defined by, mostly by dynamic parameters, and kinematic parameters. So, kinematic parameters mostly include motion, displacement, velocity, acceleration, distortion etc. Whether dynamic parameters mostly include different type of forces; and their derivatives acting on the rock volume.

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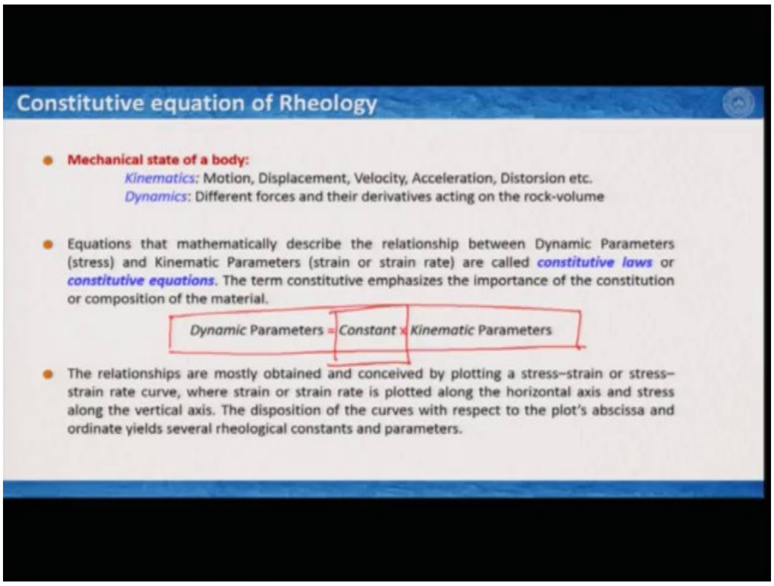

So, therefore one has to derive or one has to find, a balanced equation to mathematically describe the relationship between the dynamic parameters, and kinematic parameters. And these are known as constitutive laws or constitutive equations. And this term constitutive emphasizes the importance of the constitution or composition of the materials. So, if I try to write in general, any rheological equation should have a form like this dynamic parameters, kinematic parameters should be equated by a constant.

And, if you see that this is probably coming to the second law of newton where, force is equated to the acceleration multiplied by mass. Where acceleration is your kinematic parameter, mass is a constant, and force is the one of the dynamic parameters. Now, in earth sciences or in many other subjects including structural geology and so on. The relationships are mostly obtained the rheology relationship that is particularly the constant finding the constant is the challenge.

And these are mostly obtained and conceived by deformation experiments at various conditions in the laboratory. So, they are seen in the form of a stress strain or stress strain rate curves. Where, strain or strain rate is plotted along horizontal axis, and stress in plotted along the vertical axis. And the disposition of the curves they are different orientations different way they appear within the frame work of the stress strain or stress strain rate plot. One can figure out what are the rheological properties or rheological constants for that particular formation behavior.

So, we will take a break and we will move to the next segment where we try to classify the rheological part and that we will cover in the next segment.