REMOTE SENSING FOR NATURAL HAZARD STUDIES

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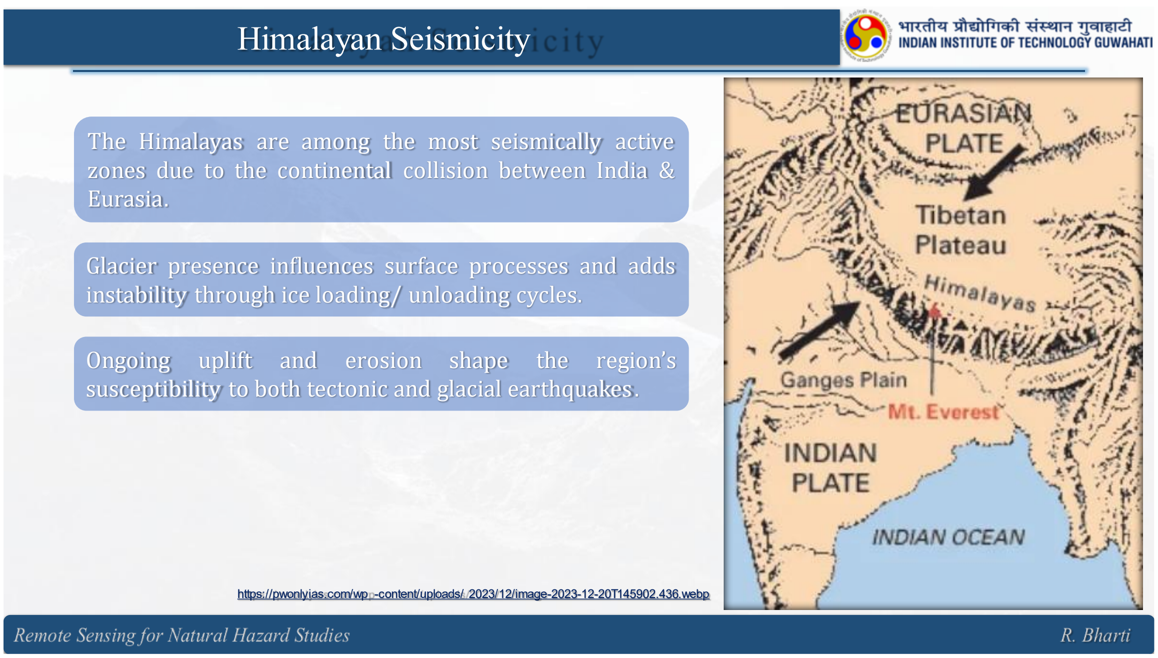
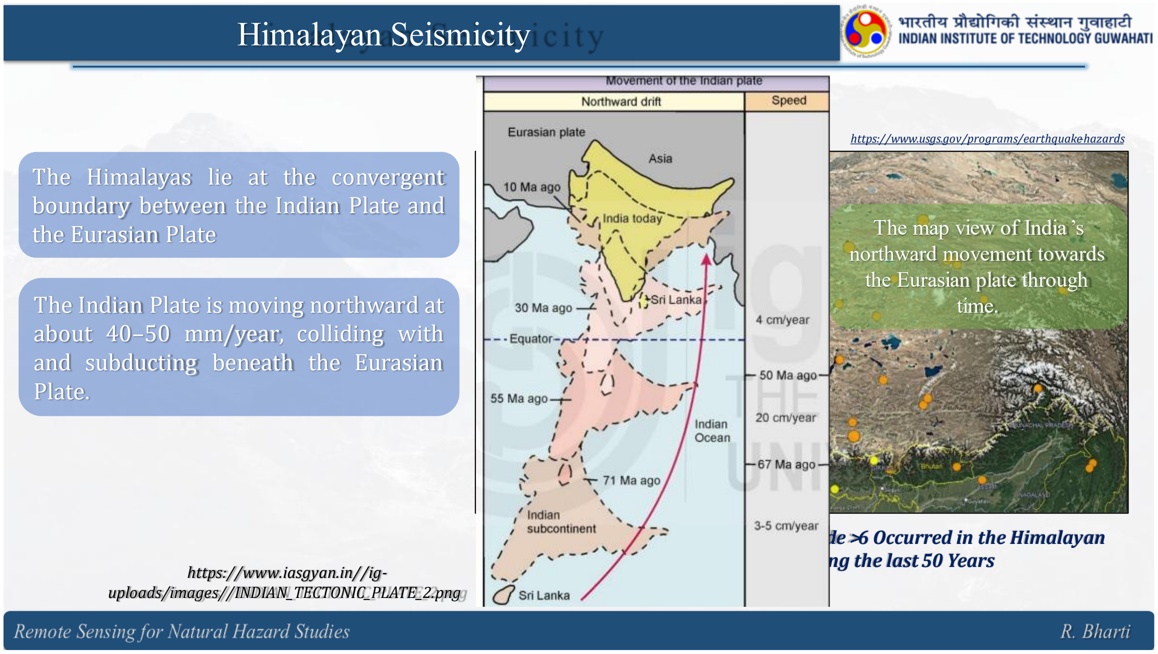
Lec 24 a: Seismic Impacts on Himalayan Glaciers- Part A

Hello everyone, welcome to the lecture. Today, we will talk about the seismic impacts on Himalayan glaciers, and here we will try to learn how we can utilize remote sensing. So, you can see here that this is an example of glaciers. So, glaciers are long-term freshwater reserves situated at high altitudes and low altitudes. The Himalayas, known as the 'Third Pole,' are the largest glacier bodies outside the polar region, covering an area of approximately 33,000 square kilometers. You can see here the activity of the seismicity in the Himalayan region.



So, the Himalayas are among the most seismically active zones due to the continental collision between the Indian and Eurasian plates. So, the presence of glaciers influences surface processes and adds instability. Through the ice loading and unloading cycle. So, if there is more melting, that will also lead to some kind of seismicity in this particular region that we will try to understand.

Ongoing uplift and erosion increase the region's susceptibility to both tectonic and glacial earthquakes. This is an example of how the Indian and Eurasian plates are colliding. So, how is India moving towards that? So, the Himalayas lie at the convergent boundary between the Indian plate and the Eurasian plate. The Indian plate is moving northward at about 40 to 50 millimeters per year, which was evident in the previous figure, colliding and subducting beneath the Eurasian plate. Because of that, we have the Himalayan ranges in this region.

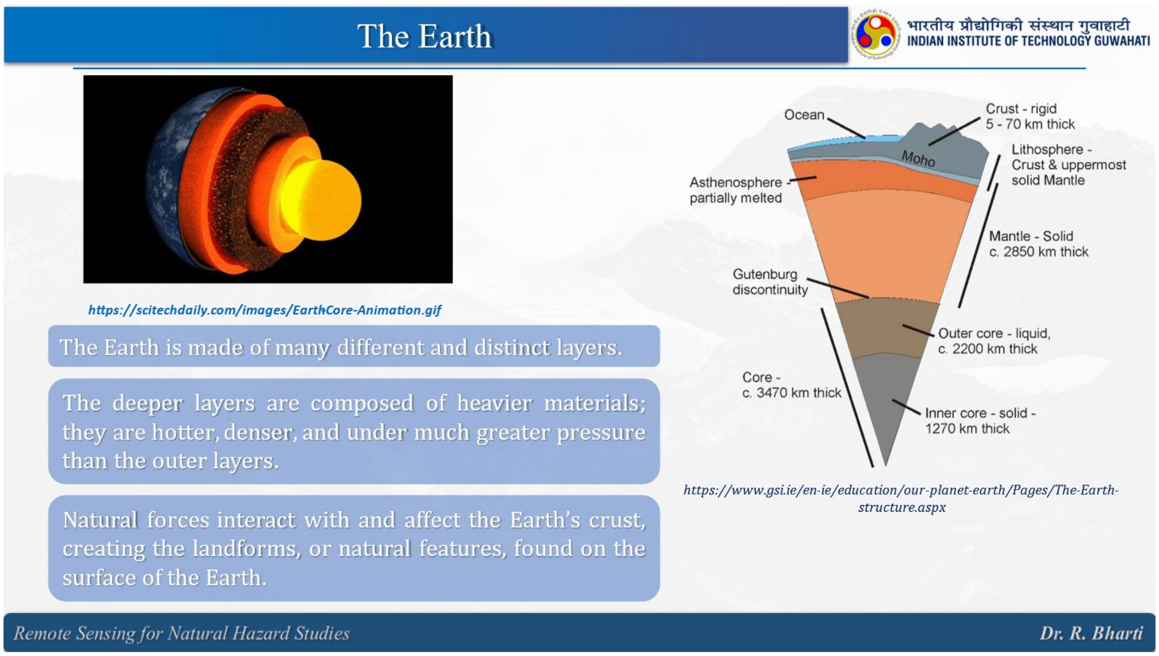


The Himalayan mountain range is formed due to the tectonic interaction of the Indian and Eurasian plates, and the region is susceptible to intense seismic activities. Hence, the region is considered one of the most tectonically active and earthquake-prone zones in the world. So, you can see here in this particular figure that you have the depth in kilometers, and this is the magnitude, and here you see these are the different positions that are marked, which show there is a prominent history of earthquakes in this particular region. So, the Himalayan arc is the arc of the Himalaya. So, it is divided into four tectonically distinct zones.

The first one is the Trans-Himalayas, then the Higher Himalayas, then the Lesser Himalayas, and then the Sub-Himalaya. When we talk about the geology of the Himalayas, particularly the tectonic zones of the Himalayas, we see that they are separated by major thrust faults, creating a well-zoned structure extending from east to west, and here we have the main. Frontal thrust (MFT), main boundary thrust (MBT), and main central thrust (MCT). So, these are very prominent in this Himalayan region. So, the MFT marks the southern boundary of the Siwalik sediments.

Whereas the MBT separates the sub-Himalaya from the overthrust Lesser Himalayas. Then, when we talk about the MCT, it plays the crystalline gneisses and high-grade rocks of the higher Himalayas over the lesser Himalayas. The Himalayan region exhibits extreme elevation differences, with the Great Himalaya extending up to 8,000 meters, and here you can see the records of seismicity in the North Eastern Himalayas. So, the North Eastern Himalayas experience seismic tremors very frequently. The glacial bodies lie close to MCT, the main central thrust, and other tectonic features.

So, that shows how vulnerable this region is to seismicity. There has been a record of 179 distributed earthquake events in the area with a magnitude greater than 4. So, only magnitudes greater than 4 are represented; otherwise, this is full of epicenters. So, to understand this, we need to understand the basics of seismology and earthquake mechanics. So, to start with, I have a few questions that you will be able to understand after this lecture, and due to the time constraint, some of the things I may not cover, but you can look for these answers, and then you will be able to understand.



How is the seismicity impacting the Himalayan glaciers? So, the first question is, how is the Earth always changing? What forces inside the Earth create and change landforms on the surface? What is plate tectonics? What is continental drift and sea floor spreading? What happens when the plate moves? So, you can see here that this video nicely represents the different positions of the continent over time. So, how is it happening, why are these plates moving, why are these tectonic plates moving, and how is this seismicity coming about because of this movement? So, let us try to understand the basics: the Earth, when we talk about the Earth, is made up of different and distinct layers. Here you can see that different layers are represented. The deeper layer is composed of heavier material.

They are hotter, denser, and under much greater pressure than the outer layer. So, I am talking about this, the center one, natural force interacts with and affects the Earth's crust, creating the landforms or natural features found on the surface of the Earth. Because of these movements, the topography has formed. So, if you see the different layers, we have the lithosphere, then the mantle, then the outer core, and then the inner core.

So, when we say "crust," it is basically the Earth's rigid rocky outer surface composed chiefly of basalt and granite. The crust is thinner beneath the ocean. It is the outermost layer made up of solid rock. Then comes the mantle. Here, you can see this is the crust, then we have the mantle, then we have the core; in the core, we have the inner and outer core.

So now we are talking about the mantle. It is a rocky layer under the crust composed of silicon, oxygen, magnesium, iron, aluminum, and calcium. Convection current, so that I will be able to explain it in the next slide. So, the convection currents carry heat from the hot inner mantle to the cooler outer mantle; it slowly deforms and flows due to temperature-driven convection. Then comes the core; now we have the outer core, the molten iron-nickel layer that surrounds the inner core.

It generates the Earth's magnetic field. Then we have the inner core, which is a solid iron-nickel center of the Earth that is very hot and under great pressure. It is solid due to extremely high pressure at the Earth's center. So, this is what I am talking about. So, this is solid because of the high temperature and pressure, and the lithosphere is here.

The top layer is the rigid outer layer composed of the crust and upper mantle. So, to understand this process, we need to understand plate tectonics. So, a long time ago, scientists exploring the seafloor found that it is full of tall mountains and deep trenches. A single seafloor mountain chain circles the Earth and contains some of the tallest mountains on the Earth. which is greater than any other mountain that is available on the continent.

So, now we are talking about the sea floor along this mountain chain, which is a deep crack into the top layer of the earth. So, here when we talk about this, let us say this is the ocean floor. So, here are the mountains. Under the sea, there is a deep crack. So, here the sea floor is pulling apart, and the two parts are moving in opposite directions.

Now, this is moving in this direction; this is moving in this direction. This is one of the examples carrying along the continent and ocean that rest on top of them. So, suppose C is ending here, then we have a continent. So, if this is dividing this particular plate into two parts, one is moving to this side and the other is moving to that side. So, whatever is on top of it will also get dragged with it.

So, the piece of Earth's top layer that carries the continents and oceans is called tectonic plates. These plates are moving very slowly but constantly; most of the plates are moving about as fast as your fingernails are growing. So, you will not even notice it. So, here, according to the theory of plate tectonics, the Earth's outer shell is not one solid piece of rock. So, from outside, it looks like it is one piece, but it is not one piece.

Instead, the Earth's crust is broken into a number of moving plates. The plates vary in size and thickness, and these plates are not anchored in place but slide over a hot and bendable layer of the mantle. So, because of that, this movement is possible, and the Earth is changing its form. So, the earthquake originates in the crust or upper mantle, which is the lithosphere. The Earth's crust is divided into distinct plates called tectonic plates, which float on the more ductile asthenosphere.

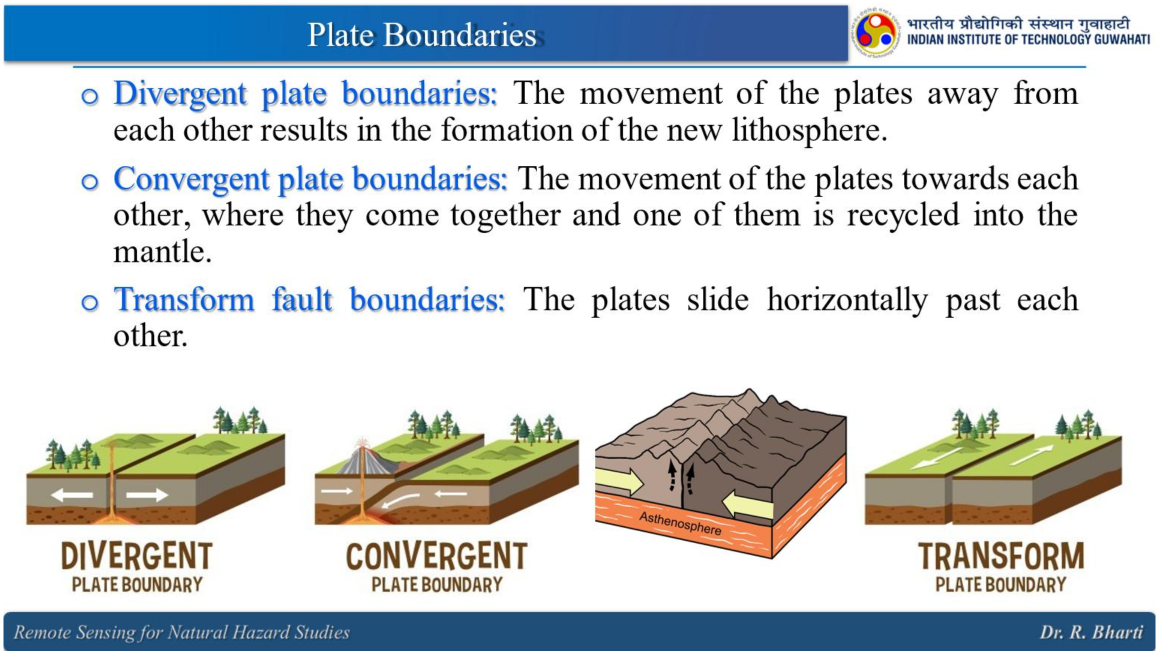
The motion of these plates causes earthquakes; hence, they are concentrated along these plate boundaries. So, here you see that these are the boundaries of the plates. So, most earthquakes are found along these plate boundaries. because of this movement that I will be able to explain with one of the videos. So, you will be able to understand why seismicity is more prominent along these plate boundaries.

So, to understand plate tectonics, the current form of the Earth was not like what we see today. So, India, which is located here, was not actually here. So, it was somewhere here, and slowly it is moving, and then it is colliding with the Eurasian plate, and because of that, there is the formation of a mountain which we call the Himalayas. So, how is the Earth always changing? What is the impact of these changes on the surface? Because of this, you are having different topographic features. What are plate tectonics, and how do they work? So, you need to understand.

So, to understand this, you need to understand the concepts of continental drift and sea floor spreading. To understand how Earth has taken its current shape. So, for example, you take this particular map and cut out all the pieces. So, separate all the land masses, and then try to join them together; you will find they fit together, which shows that at one point in earlier times, they were together. So, because of that, they are fitting with each other.
So, it will be one large mass surrounded by the ocean; just imagine what it will look like. So, you can see here the initial form it is fitting with each other, and then slowly it is changing its form because it is floating on the mantle. So, perhaps in 250 million years' time from now, there will be a new supercontinent. So, these things are explained in this particular paper. So, earlier we had Pangea, which was 250 million years ago.

This is the present form of our Earth, how the landmasses and the oceans are distributed. Then we are expecting that in 2050, a million years from now, there will be a new one which we will call Novo Pangea. Then, from that point in time, after another 250 million years, we will have the Amacia. From there, 250 million years later, we will have

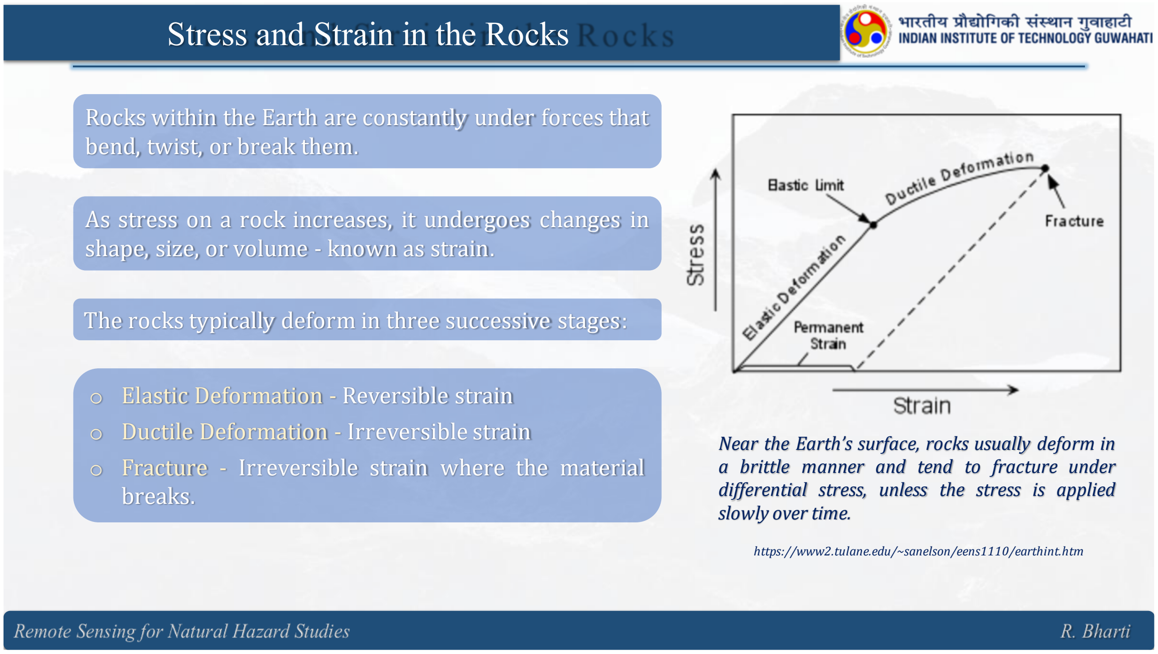
Pangaea Proxima. So, it is kind of a development that we will not be able to see, but we can model it with the current velocity at which the plates are moving, how much time it will take, and in which direction it will go, which is possible to model.



To understand plate tectonics, one important concept is the plate boundary and how the plate boundaries are behaving with each other. So, the first is the divergent plate boundaries; the movement of the plates away from each other results in the formation of new lithosphere. So, here you can see an example of a divergent plate boundary where both plates are moving away from each other. Then comes the convergent plate boundary, the movement of the plates towards each other where they can come together, and one of them is recycled into the mantle. So, here you can see this plate is subducting and it is going towards the mantle, and there will be some interaction between these two plates at the top right; then we have the transform fault boundary.

So, the plates slide horizontally past each other. So, here one plate is moving in this direction, and another is moving in this direction. So, here is what will happen: there will be more interaction between these two plates, the surface area will be larger, and we are expecting more seismicity in this particular region. So, this is one example that I was talking about.

So, suppose this particular plate. is moving downward. So, these are not smooth surfaces. So, what will happen if there is a hinge? So, they get stuck here, and because of that, after a certain amount of time, the stress will build up and then be released later. So, this is what we are experiencing in terms of earthquakes. So, earthquakes are triggered when energy stored in the elastically strained rock is abruptly released.



The sudden release generates seismic waves that cause strong ground shaking near the source. These seismic waves spread out in all directions through the Earth's interior. The amount of shaking depends on the energy released and the distance from the focus. So, this particular conceptual diagram explains how these faults will be found at the lay fault plane. So, the stress and strain in the rock can be understood here.

So, rocks within the Earth are constantly under a force that bends, twists, and breaks them. As stress on a rock increase, it undergoes changes in shape, size, or volume known as strain. The rock typically deforms in three successive stages. So, the first one is elastic deformation. So, it is reversible, ductile, which is irreversible, and then fracture, which is again irreversible, where the material breaks.

So, the occurrence of earthquakes which are commonly found on the plate boundaries. So, these are composed of many faults; when these plates move, stress accumulates along the faults. Earthquakes occur when the stress overcomes the friction and the rock suddenly slips. The surface where the slip occurs is called the fault or the fault plane. This movement releases energy in the form of seismic waves, as you can see, which can result in ground shaking and surface ruptures.

FAULT: Normal Fault

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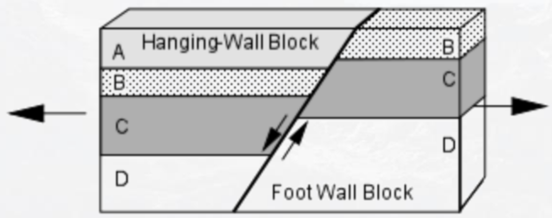
- Here, the block above the fault moves downward relative to the block below.
- This type of faulting occurs in response to extension.
- e.g. Faults along oceanic ridge systems.



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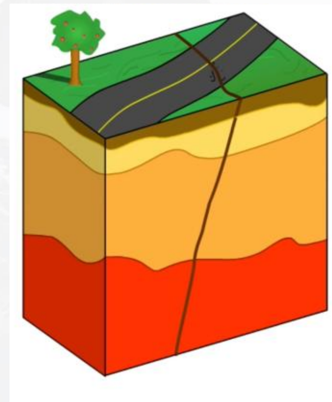

Movement Along Normal Fault

https://www2.tulane.edu/~sanelson/eens1110/earthint.htm

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So, here you can understand the mechanism of earthquake generation and how it happens when we have a normal fault. So, this particular hanging wall is going down, and because of this interaction, you will have earthquake generation. So, the hypocenter and the epicenter are very critical for the earthquake. So, the focus or hypocenter is the point below the Earth's surface where the fault rupture, that is the earthquake, starts.

FAULT: Reverse or Thrust Fault

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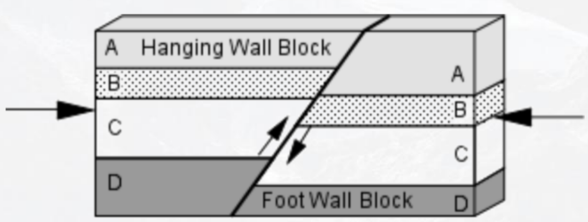
- Here, the upper block, above the fault plane, moves up and over the lower block.
- This faulting type occurs in response to compression.
- e.g. Main Himalayan faults.



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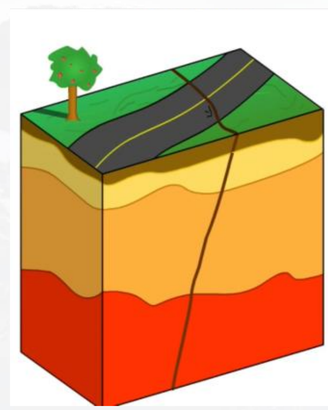

Movement Along Reverse Fault

https://www.usgs.gov/media/videos/thrust-fault

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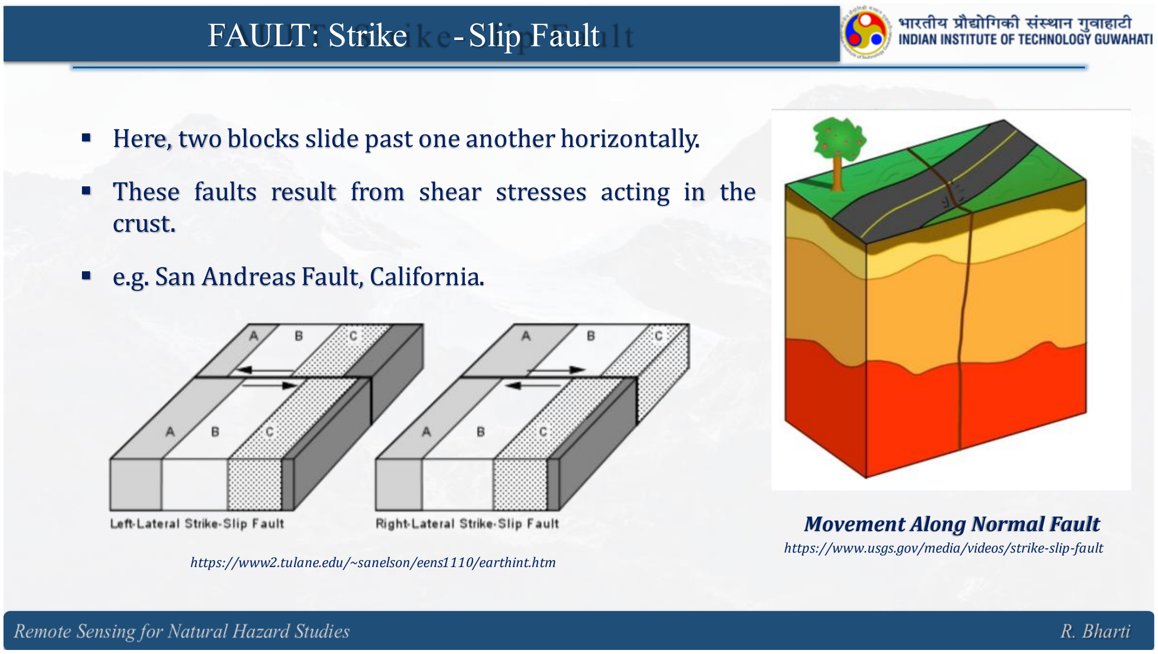
The epicenter is the point directly above the hypocenter on the Earth's surface. The hypocenter and epicenter help to locate and describe the origin of the earthquake. So, here you can see that this is the epicenter, this is the fault plane, and here we have the hypocenter. Earthquake damage is often greatest near the epicenter, and its intensity primarily depends on the distance from the epicenter and local geology. What kind of rocks and soils are present in this particular area that will define the severity of the earthquake that occurred at a particular location? So, there are different types of faults.



A fault is a fracture or zone of fractures between two blocks of rock. The length of a fault may vary from a few millimeters to thousands of kilometers, and it causes recurrent displacement over geologic time. The faults are classified based on dip, which is the angle of the fault with respect to the surface, and the direction of the slip along the fault. I will be able to explain this using a diagram later.

So, faults are classified into three major types. So, the dip-slip fault, then strike-slip faults, and then we have the oblique-slip fault. In a dip-slip fault, these have an inclined fault plane and movement occurs along the dip direction. When we talk about the strike-slip fault, the displacement occurs along the horizontal direction. Then we have the oblique slip fault, which shows a combination of both dip-slip and strike-slip movement.

So, it will have both vertical and horizontal movements. So, this is one example of a fault plane. So, here you can see this is an example of a normal fault. So, here the block above the fault moves downward relative to the block below. So, this type of faulting occurs in response to extension faults along the oceanic ridge system; these are examples of normal faults.

Then comes the reverse or thrust fault. Here, the upper block above the fault plane moves up and over the lower block. The faulting type occurs in response to compression. So, here you can see that the main Himalayan fault is an example of this reverse or thrust fault. This is, again, a semantic diagram. I hope you understand this. This is very simple. Then there are two blocks when we talk about the strike-slip fault; here, the two blocks slide past one another horizontally. These faults result from shear stress acting in the crust. So, the San Andreas Fault in California is one of the examples of this strike-slip fault that you can see here. So, now we have understood the basics of earthquakes, how they occur, and what their impacts could be.

But what are the impacts of these earthquakes on glacial bodies that we need to understand? So, until now, we have seen how the tectonic plates and tectonic activities can trigger an earthquake and how we can experience earthquakes or seismic tremors. But what will be the impact of rapid melting or rapid mass loss in the glacial region, whether it can trigger a minor or major seismic event, is what we will try to understand. So, glacial earthquakes are seismic events generated by sudden glacier movements such as calving, basal slip, or surging. These events typically have a long duration, like 30 to 60 seconds, and are dominated by low-frequency seismic energy because they are not tectonic movements.

Unlike tectonic quakes, they often go undetected by traditional short-period seismic monitoring system. So, here you can see an example of glacier calving. The seismic sources include brittle ice quakes, calving events, basal crevasse collapses, and subglacial lake drainages. Calving of icebergs and basal slip events often produce low-frequency, long-duration signals. Ice-rocks and ice-water interactions contribute to additional seismic wave generation. So, the dynamic processes are highly sensitive to climate variations and basal conditions. The glacial earthquakes are modeled as downhill sliding masses where ice shifts suddenly, generating large, slow surface waves. Their detection relies on long-period global seismic arrays and waveform inversion techniques. So, here you can see the example centroid single force models that are used here. These quakes indicate dynamic glacier bed interaction, reflecting stress accumulation and sudden release at the glacial bed interface.

So, these are very common in glacial regions. So, how can remote sensing help, because we are talking about the high-altitude glaciers? So, these are very difficult to approach, and then we have great difficulty in measuring all the parameters that are needed to model a particular seismic activity in a particular region. So, satellite remote sensing aids seismic data by providing spatial insight into glacier motion, surface changes, and calving activities. Synthetic aperture radar and interferometric SAR are key tools for detecting glacial displacement, uplift, and basal slip. These can be modeled very easily using radar.

Microwave remote sensing data. Whereas optical sensors like Landsat and Sentinel-2 can be used to track changes in glacier extent, surface crevasses, and terminus retreat. So, we have seen in the previous few lectures how optical remote sensing is useful. These observations help locate and confirm seismic signals associated with glacial dynamics, such as calving or sub-glacial drainage. So, I hope you understand the role of remote sensing in seismic study. So, remote sensing helps to identify the source area of glacial earthquakes when field access is impossible or dangerous.

Combining time-stamped satellite imagery with seismic wave arrival times enhances the understanding of event timing and triggers. Post-event imagery can verify morphological changes such as crevasses, widening, calving fronts, and surface collapse. Integrated analysis supports the early warning system and expands our understanding of glacier behavior under climate stress. I hope you understand the potential of remote sensing in seismic studies.

So, with this, I will end part 1 of this lecture. We will continue this discussion in the next part. Thank you.