

Plate Tectonics Lecture Notes:

Slide 1.

Title Slide

Slide 2.

- The interior of the Earth is divided into layers based on chemical and physical properties.
 - The Earth has an outer silica-rich, solid crust, a highly viscous mantle, and a core comprising a liquid outer core that is much less viscous than the mantle, and a solid inner core.
 - Working from the centre of the Earth out we have:
 - The **inner core** is a primarily solid sphere about 1220 km in radius situated at Earth's center.
 - Based on the abundance of chemical elements in the solar system, their physical properties, and other chemical constraints regarding the remainder of Earth's volume, the inner core is believed to be composed primarily of a nickel-iron alloy, with small amounts of some unknown elements.
 - The temperature is estimated at 5,000-6,000 degrees Celsius and the pressure to be about 330 to 360 GPa (which is over 3,000,000 times that of the atmosphere!)
 - The liquid outer core is 2300 km thick and like the inner core composed of a nickel-iron alloy (but with less iron than the solid inner core).
 - Seismic and other geophysical evidence indicates that the outer core is so hot that the metals are in a liquid state.
 - The mantle is approximately 2,900 km thick and comprises 70% of Earth's volume. (the core makes up about 30% of Earth's volume, with the outer crust [where we live] <1%!!).
 - The mantle is divided into sections based upon changes in its elastic properties with depth.
 - In the mantle, temperatures range between 500-900 degrees Celsius at the upper boundary with the crust to over 4,000 degrees Celsius at the boundary with the core.
 - Due to the temperature difference between the Earth's surface and outer core, and the ability of the crystalline rocks at high pressure and temperature to undergo slow, creeping, viscous-like deformation over millions of years, there is a convective material circulation in the mantle (mantle convection cells). Hot material rises up as mantle plumes (like a lava lamp!), while cooler (and heavier) material sinks downward to be reheated and rise up again.
 - We shall see that this process is very important for plate tectonic motion...
 - The outer most layer is the crust - this is the most familiar to us as it is where we live.
 - The distinction between crust and mantle is based on chemistry, rock types and seismic characteristics.
- Presenter: Ask the students to guess what the most abundant element in the earth's crust is.....they may be surprised to learn that it is actually Oxygen (46.6% Oxygen; 27.7% Silica; 8.1% Aluminum; 5.0% Iron; 3.6% Calcium; 2.8% Sodium; 2.6% Potassium; 2.1% Magnesium; plus trace elements)*
- Click to next slide for more on the Crust....

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- The Earth has two different types of crust: Continental crust and Oceanic crust. Each has different properties and therefore behaves in different ways.

- Continental crust:

- Continental crust forms the land (the continents, as the name suggests) that we see today.

- Continental crust averages about 35 km thick. Under some mountain chains, crustal thickness is approximately twice that thickness (about 70 km thick).

- The mountains we see on earth have deep roots in the crust that we can't see. The crust "floats" on the more dense mantle and, like how only the tip of an iceberg sticks up out of the water, we see only the tip of the continental crust - the mountain ranges.

- Continental crust is less dense and therefore more buoyant than oceanic crust

- Continental crust contains some of the oldest rocks on Earth.

- Ancient rocks exceeding 3.5 billion years in age are found on all of Earth's continents. The oldest rocks on Earth found so far are the Acasta Gneisses in northwestern Canada near Great Slave Lake (4.03 Ga) [Ga = billion years ago] and the Isua Supracrustal rocks in West Greenland (3.7 to 3.8 Ga), but well-studied rocks nearly as old are also found in the Minnesota River Valley in the USA (3.5-3.7 billion years), in Swaziland (3.4-3.5 billion years), and in Western Australia (3.4-3.6 billion years).

- Oceanic crust:

- As the name already suggests, this crust is below the oceans.

- Compared to continental crust, Oceanic crust is thin (6-11 km).

- It is more dense than continental crust and therefore when the two types of crust meet, oceanic crust will sink underneath continental crust.

- The rocks of the oceanic crust are very young compared with most of the rocks of the continental crust. They are not older than 200 million years.

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If we can't go to the centre of the Earth (except in fictional movies!) how do we know what the internal structure of the Earth is like?

- We need to use geophysical imaging techniques to model what is going on below our feet.

- For example, when there is an earthquake it sends out seismic waves (shock waves) through the Earth. Seismologists can measure the time it takes for these waves to reach seismic monitoring stations set up around the globe. (The machine that measures seismic waves is called a seismometer).

- The different layers in the earth have been inferred using the time of travel of refracted and reflected (bent backward angularly) seismic waves created by the earthquakes (see left diagram). That is, changes in the seismic velocity occur as the waves pass through different materials. Measuring these changes tell seismologists how many layers there are and the thickness and physical properties of each layer.

- We need not wait for earthquakes to occur, on a local scale on land (cheap but slow methods) and at sea (more expensive but quicker) explosions can be set to cause shock waves to pass through the crust (simulating an earthquake) that can be measured in the same way.

•Other geophysical methods, for example measuring different gravity, magnetic and electrical anomalies by air and (or) satellite can help to reconstruct shallow crustal features.

•We can also go and examine rocks at and near the surface of the crust, through fieldwork, drilling boreholes and mining.

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Presenter: Ask the class if they have heard of Plate Tectonics before (commonly students will have some idea of the general concept), and ask them if they can explain the theory.

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If you look at a map of the world, you may notice that some of the continents could fit together like pieces of a puzzle.....the shape of Africa and South America are a good example.

This is because they DID used to fit together!

The Earth as we see it today was not always like it is now. Land masses have pulled apart and joined together by the process we call Plate Tectonics....

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There are 12 major plates on Earth, each of which slide around at a rate of centimetres per year, pulling away from, scraping against or crashing into each other.

Each type of interaction produces a characteristic “tectonic feature”, like mountain ranges, volcanoes and (or) rift valleys, that we will discuss during this lecture.

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This diagram shows the major Tectonic Plates.

Presenter: Point out the UK, sitting on the Eurasian Plate. Also the plate boundary between Africa and South America (note that it has the same shape as the coastlines in these countries).

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Plates are made of rigid lithosphere – formed of the crust and the extreme upper mantle (point out these layers on the figure).

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The asthenosphere, beneath the lithosphere, is part of the upper mantle and is so hot that it is 1 – 5% liquid (I.e. 95 – 99% solid). This liquid, usually at the junctions of the crystals, allow it to flow – which is why ‘astheno’ means weak.’ Beneath the asthenosphere is the rest of the mantle, which is completely solid – but can also flow (on geological time scales) because of the intense temperatures and pressures involved.

The base of the lithosphere-asthenosphere boundary corresponds approximately to the depth of the melting temperature in the mantle.

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How and Why do tectonic Plates move around?

- The question of how tectonic plates are moved around the globe is answered by understanding mantle convection cells.

- In the mantle hot material rises towards the lithosphere (like hot air rising out of an open oven - ever opened an oven door and felt the blast of hot air coming past your face?). The hot material reaches the base of the lithosphere where it cools and sinks back down through the mantle. The cool material is replaced by more hot material, and so on forming a large “convection cell” (as pictured in the diagram).

- This slow but incessant movement in the mantle causes the rigid tectonic plates to move (float) around the earth surface (at an equally slow rate).

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See Plate Tectonics Exercise 1.

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We are now going to discuss the processes that occur at plate tectonic boundaries. What happens when plates meet?

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Firstly, there are three types of plate boundary, each related to the movement seen along the boundary.

- Divergent boundaries are where plates move away from each other
- Convergent boundaries are where the plates move towards each other
- Transform boundaries are where the plates slide past each other.

Presenter: See diagrams for each - it is important to remember the names of the boundary types and the motion involved.

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- In plate tectonics, a **divergent boundary** is a linear feature that exists between two tectonic plates that are moving away from each other. These areas can form in the middle of continents or on the ocean floor.

- As the plates pull apart, hot molten material can rise up this newly formed pathway to the surface - causing volcanic activity.

Presenter: Reiterate the process by going through the diagram, including the presence of mantle convection cells causing the plates to break apart and also as a source for new molten material.

- Where a divergent boundary forms on a continent it is called a RIFT or CONTINENTAL RIFT, e.g. African Rift Valley.

Where a divergent boundary forms under the ocean it is called an OCEAN RIDGE.

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Ocean Ridges: This map shows the age of the oceanic crust. The red colouring shows the youngest ages, whilst the dark blue shows the oldest ages (around 200 million years old).

Presenter ask: Where are the Ocean Ridges located? I.e. where are the divergent boundaries?

Answer: The divergent boundaries are where the plates are pulling apart and new material is being produced. Therefore the Ocean ridges are in the middle of the red areas (the boundaries are in fact shown on the map). We can see a progression of the oceanic crust getting older away from the ocean ridges (like a conveyer belt).

Presenter: Before moving on to the next slide, point out Iceland. The divergent boundary runs straight through Iceland....

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- Iceland is located right on top of a divergent boundary. In fact, the island exists because of this feature.

- As the North American and Eurasian plates were pulled apart (see map) volcanic activity occurred along the cracks and fissures (see photographs).

- With many eruptions over time the island grew out of the sea!

- Question: Why don't we have islands like Iceland wherever we get an Ocean Ridge?

Answer: Scientists believe that there is a large mantle plume (an upwelling of hot mantle material) located right underneath where Iceland has formed. This would mean that more material would be erupted in the Iceland area compared with if there was just the divergent boundary without the plume underneath it.

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Convergent boundaries are where the plates move towards each other.

There are three types of convergent boundary, each defined by what type of crust (continental or oceanic) is coming together.

Therefore we can have: continent-continent collision, continent-oceanic crust collision or ocean-ocean collision....

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When continental crust pushes against continental crust both sides of the convergent boundary have the same properties (think back to the description of continental crust: thick and buoyant). Neither side of the boundary wants to sink beneath the other side, and as a result the two plates push against each other and the crust buckles and cracks, pushing up (and down into the mantle) high mountain ranges. For example, the European Alps and Himalayas formed this way.

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Example:

- India used to be an island, but about 15 million years ago it crashed into Asia (see map).
 - As continental crust was pushing against continental crust the Himalayan mountain belt was pushed up.
 - “Mountains” were also pushed down into the mantle as the normally 35 km thick crust is approximately 70 km thick in this region.
- Mt Everest is the highest altitude mountain on our planet standing 8,840 metres high. This means that below the surface at the foot of the mountain the crust is a further 61 km deep!!

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At a convergent boundary where continental crust pushes against oceanic crust, the oceanic crust which is thinner and more dense than the continental crust, sinks below the continental crust.

- This is called a Subduction Zone.
 - The oceanic crust descends into the mantle at a rate of centimetres per year. This oceanic crust is called the “Subducting Slab” (see diagram).
 - When the subducting slab reaches a depth of around 100 kilometres, it dehydrates and releases water into the overlying mantle wedge (*Presenter: explain all of this using the diagram*).
 - The addition of water into the mantle wedge changes the melting point of the molten material there forming new melt which rises up into the overlying continental crust forming volcanoes.
- Subduction is a way of recycling the oceanic crust. Eventually the subducting slab sinks down into the mantle to be recycled. It is for this reason that the oceanic crust is much younger than the continental crust which is not recycled.

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The Andes mountain range along the western edge of the South American continent is an example of a mountain belt formed by subduction.

The continental crust of the South American plate has buckled under the compressional strain of converging with the Nasca and Antarctic plates. Additionally there are many volcanoes, the result of melting of the subducting slab and the production of new material that has risen through the crust to the surface.

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When two oceanic plates converge, because they are dense, one runs over the top of the other causing it to sink into the mantle and a subduction zone is formed.

The subducting plate is bent down into the mantle to form a deep depression in the seafloor called a trench.

Trenches are the deepest parts of the ocean and remain largely unexplored.

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Manned or unmanned submersible vehicles (top right photo) have explored small parts of trenches discovering new species (like the fish photographed here) and amazing ecosystems.

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The third type of boundary are transform boundaries, along which plates slide past each other.

The San Andreas fault, adjacent to which the US city of San Francisco is built is an example of a transform boundary between the Pacific plate and the North American plate.

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This map summarises all the known plate boundaries on Earth, showing whether they are divergent, convergent or transform boundaries.

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See Plate Tectonics Exercise 2.

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What's the connection between volcanoes and plate tectonics....?

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This map shows the margins of the Pacific tectonic plate and surrounding region. The red dots show the location of active volcanism. Notice how the majority of the volcanism is focused in lines along the plate boundaries? For this region this area is known as the "Pacific Ring of Fire".

But why are all of the volcanoes located at the plate margins?

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Volcanoes can be formed in three ways:

1. Via subduction. The subducting slab dehydrates to form new melt that will rise through the crust to be erupted at the surface.
2. Via rifting. When two plates pull apart magma rises, producing volcanic eruptions at the surface.

At "Hotspots"...hotspot do not necessarily occur along a plate boundary. So hotspot volcanoes can form in the middle of tectonic plates....Click for example

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Hotspot volcanoes in the middle of the Pacific plate.

Can anyone guess where they are?

Answer: Hawaii

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Firstly, what are hotspot volcanoes and how do they form?

- A **hotspot** is a location on the Earth's surface that has experienced active volcanism for a long period of time.
- The source of this volcanism is a mantle plume of hot mantle material rising up from near the core-mantle boundary through the crust to the surface (see left diagram).
- A mantle plume may rise at any location in the mantle, and this is why hotspot volcanoes are independent from tectonic plate boundaries.

The Hawaiian island chain are an example of hotspot volcanoes (see right photograph).

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Hotspot's commonly form volcanic island chains (like the Hawaiian islands). These result from the slow movement of a tectonic plate over a FIXED hotspot.

Persistent volcanic activity at a hotspot will create new islands as the plate moves the position of the "old" volcanic island from over the hotspot.

Therefore at one end of the island chain you see the youngest, most active volcanic islands (directly over the hotspot) and along the island chain the extinct volcanoes become older and more eroded (see diagram).

This way geologists can use hotspot volcano chains to track the movement of the tectonic plate through time.

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We have seen the connection between volcanoes and plate tectonics.

Is there a connection between earthquakes and plate tectonics?

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The black dots on this map of the world depict where earthquake activity is occurring. You can see that, as with volcanoes, the earthquakes are NOT randomly distributed around the globe. Instead they occur in linear patterns associated with plate boundaries.

(Note this diagram of earthquake distribution closely resembles the Pacific Ring of Fire distribution of volcanism).

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We know there are three types of plate boundaries: Divergent, Convergent and Transform. Movement and slipping along each of these types of boundaries can form an earthquake.

- Depending on the type of movement, the earthquakes occur in either a shallow or deep level in the crust.
 - The majority of tectonic earthquakes originate at depths not exceeding tens of kilometers.
 - In subduction zones, where old and cold oceanic crust descends beneath another tectonic plate, “Deep Focus Earthquakes” may occur at much greater depths (up to seven hundred kilometers!).
 - These earthquakes occur at a depth at which the subducted crust should no longer be brittle, due to the high temperature and pressure. A possible mechanism for the generation of deep focus earthquakes is faulting.
- Earthquakes may also occur in volcanic regions and are caused there both by tectonic faults and by the movement of magma (hot molten rock) within the volcano. Such earthquakes can be an early warning of volcanic eruptions.

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The take home messages from this lecture:

- See if the students remember what each layer, type of plate and type of boundary are called.
 - Can they describe the motion of the three plate boundary types?
 - Where does volcanism occur in relation to plate tectonics?
- Where do earthquakes occur in relation to plate tectonics?