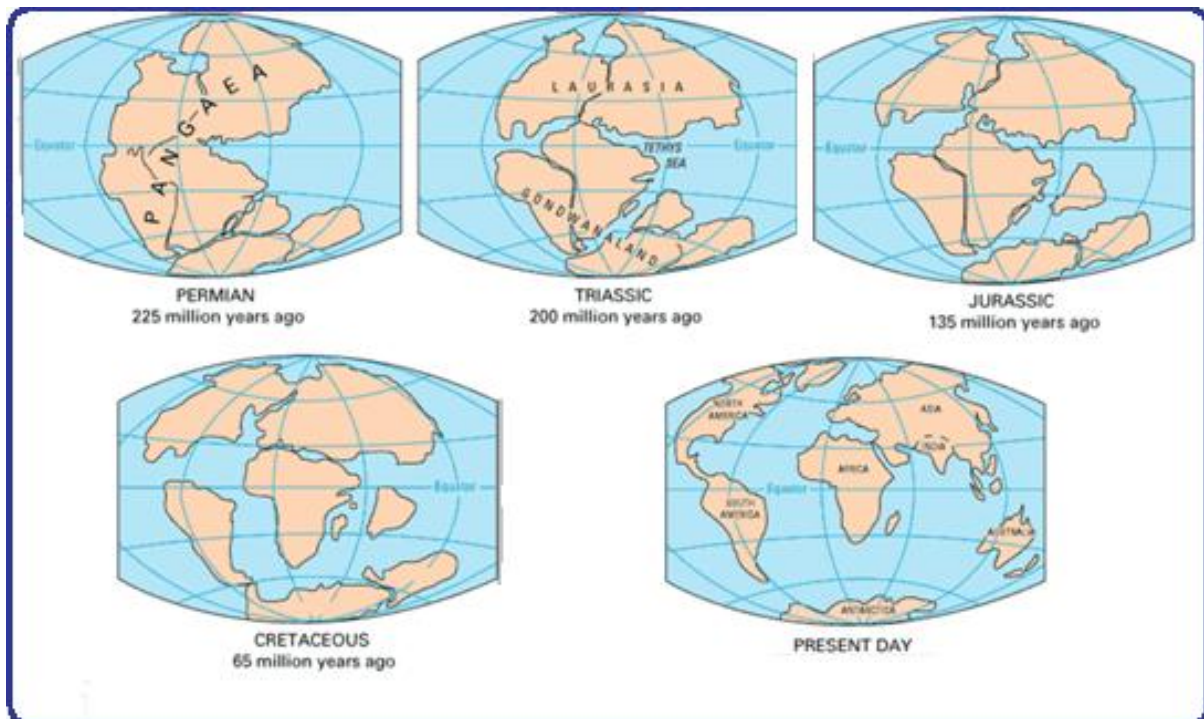


## Plate tectonics: Introduction

**Plate tectonics** describes seismic activity, volcanism, mountain building, and various other Earth processes in terms of the structure and mechanical behaviour of a small number of enormous rigid **plates** thought to constitute the outer part of the planet (*i.e.*, the lithosphere). This all-encompassing theory grew out of observations and ideas *about continental drift and seafloor spreading*.

**Plate tectonics** has revolutionized virtually every discipline of the Earth sciences since the late 1960s and early 1970s. It has served as a unifying model or paradigm for explaining geologic phenomena that were formerly considered in unrelated fashion.

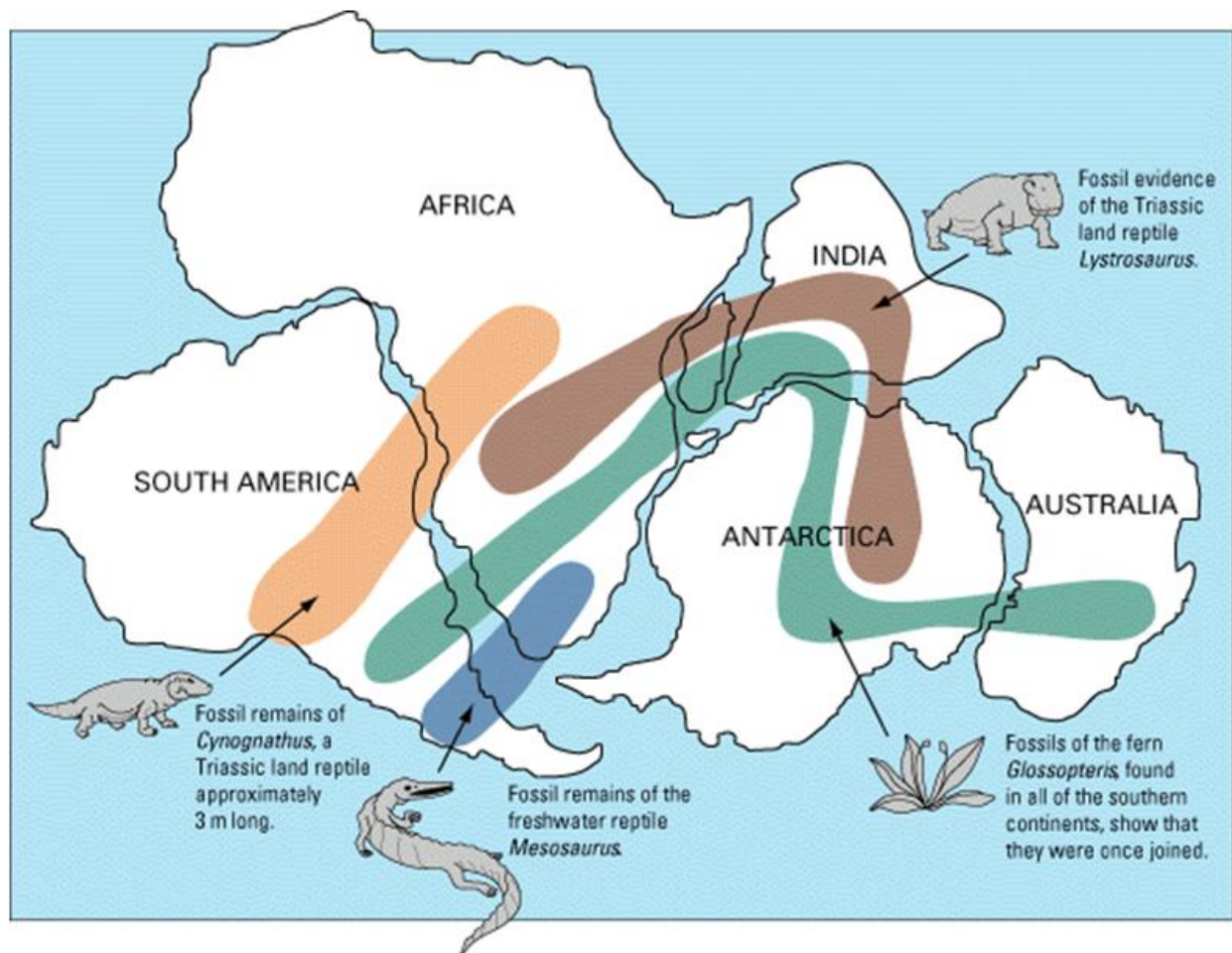
In 1912 the German meteorologist **Alfred Wegener** proposed that throughout most of geologic time there was only one continental mass, which he named Pangaea. At some time during the Mesozoic Era, Pangaea fragmented and the parts began to drift apart. Westward drift of the Americas opened the Atlantic Ocean, and the Indian block drifted across the Equator to join with Asia.



In 1937 the South African **Alexander Du Toit** modified Wegener's hypothesis by suggesting the existence of two primordial continents: Laurasia in the north and Gondwanaland in the south.

Aside from the congruency of continental shelf margins across the Atlantic, proponents of continental drift have amassed impressive geologic evidence to support their views.

Similarities in fossil terrestrial organisms in pre-Cretaceous (older than 140Ma) strata of Africa and South America and in pre-Jurassic rocks (older than 200Ma) of Australia, India, Madagascar, and Africa are explained if these continents were formerly connected but difficult to account for otherwise.



Fitting the Americas with the continents across the Atlantic brings together similar kinds of rocks and structures. Evidence of widespread glaciation during the Upper Paleozoic is found in Antarctica, southern South America, southern Africa, India, and Australia. If these continents were formerly united around the South Polar Region, this glaciation becomes explicable as a unified sequence of events in time and space.

**Rock magnetism:** Rock magnetism is the permanent magnetism locked in rocks, resulting from the orientation of the Earth's magnetic field at the time of formation of the rock in a past geological age. It is the source of information for the paleomagnetic studies of polar wandering and continental drift.

Rock magnetism can derive from several natural processes, generally termed **natural remanent magnetism**, the most important being thermo-remanent magnetism. This arises when magnetic minerals forming in igneous rocks cool through the Curie point and when the magnetic domains within the individual minerals align themselves with the Earth's magnetic field, thus making a permanent record of its orientation. Ferromagnetic minerals such as magnetite acquire a permanent magnetization when they crystallize as components of igneous rock. The direction of their magnetization is the same as the direction of the Earth's magnetic field at the place and time of crystallization.

A second mechanism operates when small grains of magnetic minerals settle into a sedimentary matrix, producing **detrital remanent** magnetism. It is hypothesized that the tiny grains orient themselves in the direction of the Earth's magnetic field during deposition and before the final consolidation of the rock.

Volcanic rocks such as basalt are especially good recorders of **paleomagnetism**, but some sediments also align their magnetic particles with the Earth's field at the time of deposition.

Investigators therefore have at their disposal fossil compasses that indicate, like any magnet suspended in the Earth's field, the direction to the magnetic pole and that yield the latitude of their origin.

Studies of the **remanent magnetism** in suitable rocks of different ages from over the world indicate that the magnetic poles were in different places at different times. When we join these poles we get what are called polar wander paths.

The **polar wandering paths** are different for the several continents, but in important instances these differences are compensated when we assume that continents now separated were formerly joined. The curves for Europe and North America, for example, are reconciled by the assumption that America has drifted about 30° westward relative to Europe since the Triassic Period (195 to 230Ma ago).

In the early 1960s a major breakthrough in understanding the way the modern Earth works came from two studies of the ocean floor.

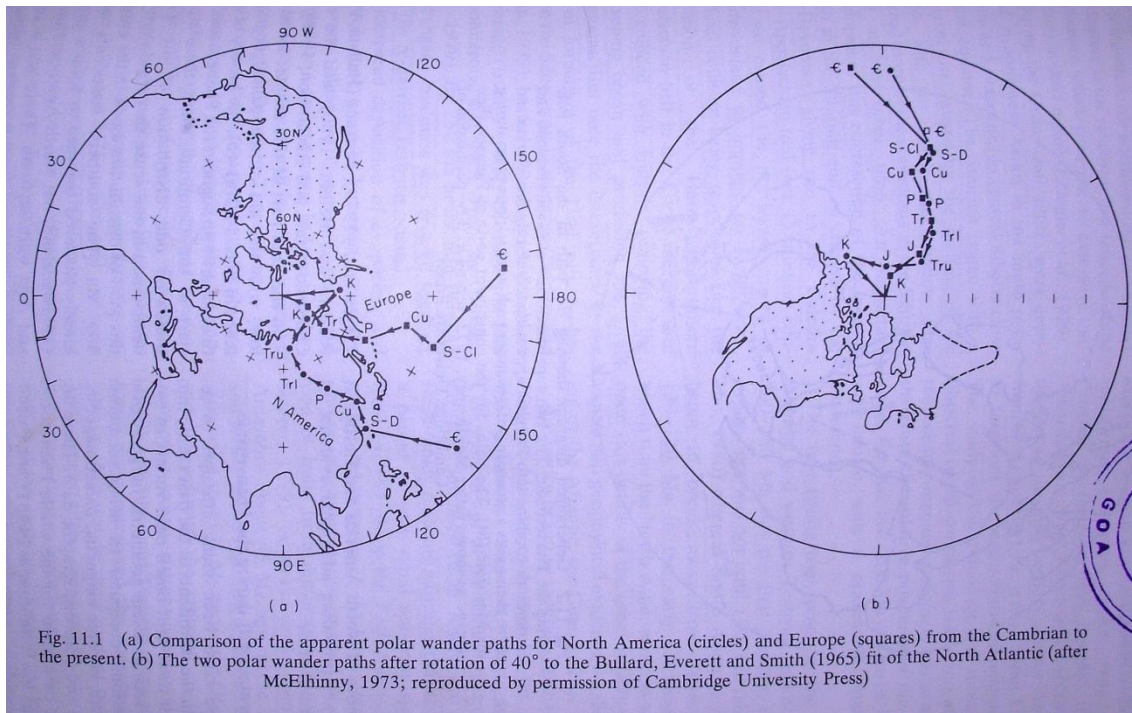


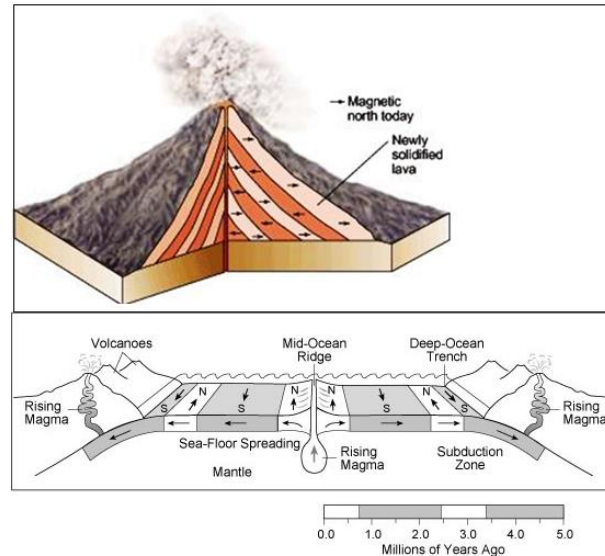
Fig. 11.1 (a) Comparison of the apparent polar wander paths for North America (circles) and Europe (squares) from the Cambrian to the present. (b) The two polar wander paths after rotation of 40° to the Bullard, Everett and Smith (1965) fit of the North Atlantic (after McElhinny, 1973; reproduced by permission of Cambridge University Press)

Harry **H. Hess** and Robert S. Dietz suggested that new ocean crust was formed along mid-oceanic ridges between separating continents.

Drummond H. Matthews and Frederick J. Vine proposed that the new oceanic crust acted like a magnetic tape recorder insofar as magnetic anomaly strips parallel to the ridge had been magnetized alternately in normal and reversed order, reflecting the changes in polarity of the Earth's magnetic field.

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This theory of seafloor **spreading** then needed testing, and the opportunity arose from major advances in deep-water drilling technology. The Joint Oceanographic Institutions Deep Earth Sampling (JOIDES) project began in 1969, continued with the Deep Sea Drilling Project (DSDP), and, since 1976, with the International Phase of Ocean Drilling (IPOD) project.

These projects have produced more than 500 boreholes in the floor of the world's oceans, and the results have been as outstanding as the **plate-tectonic** theory itself. They confirm that the oceanic crust is everywhere younger than about 200Ma and that the stratigraphic age determined by micropaleontology of the overlying oceanic sediments is close to the age of the oceanic crust calculated from the magnetic anomalies.

The **plate-tectonic** theory, which embraces both continental drift and seafloor **spreading**, was formulated in the mid-1960s by J. Tuzo Wilson.

This theory holds that the Earth's upper shell, or lithosphere, consists of six major and 22 or so minor rigid slabs called plates. The thickness of each of these plates extends to a depth of roughly 80 to 150 kilometers. These plates move horizontally in relation to one another on a more ductile asthenosphere.

New lithosphere is created at mid-oceanic ridges by the upwelling and cooling of magma from the Earth's mantle. The horizontally moving plates are believed to be consumed at the ocean trenches, where a subduction process carries the lithosphere downward along the Benioff zones into the Earth's interior. Perhaps these two processes help maintain the volume of the earth at a constant.

Location of major earthquake belts is broadly in agreement with this kinematic model. Earthquake sources are concentrated along the mid-oceanic ridges, which correspond to **divergent plate** boundaries.

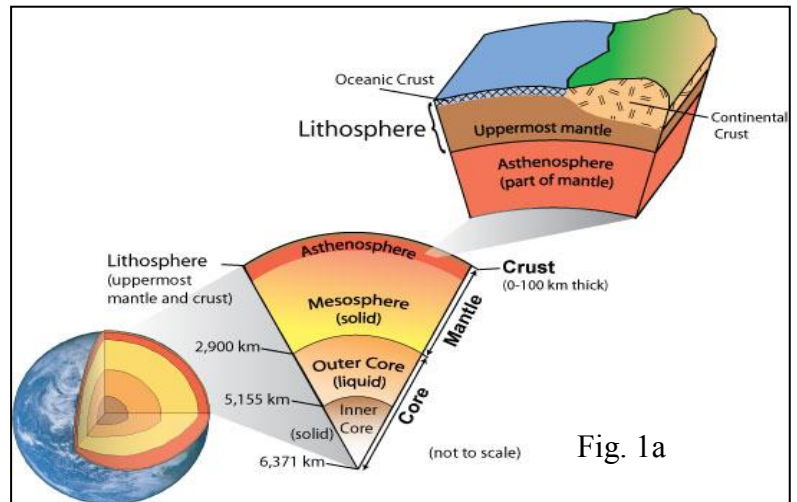
At the subduction zones, which are associated with **convergent plate** boundaries, intermediate- and deep-focus earthquakes in the Benioff zone mark the location of the upper part of a dipping plate. The focal mechanisms indicate that the stresses are aligned with the dip of the lithosphere underneath the adjacent continent or island arc.

Some earthquakes associated with mid-oceanic ridges are confined to strike-slip faults that offset the ridge crests. The majority of the earthquakes occurring along such horizontal shear faults are characterized by slip motions.

Examples of plate boundaries of this kind, which are sometimes called fracture zones, include the **San Andreas Fault** in California and the **North Anatolian** fault system in Turkey. Such plate boundaries are the site of interplate earthquakes of shallow focus.

## CRUSTAL DEFORMATION

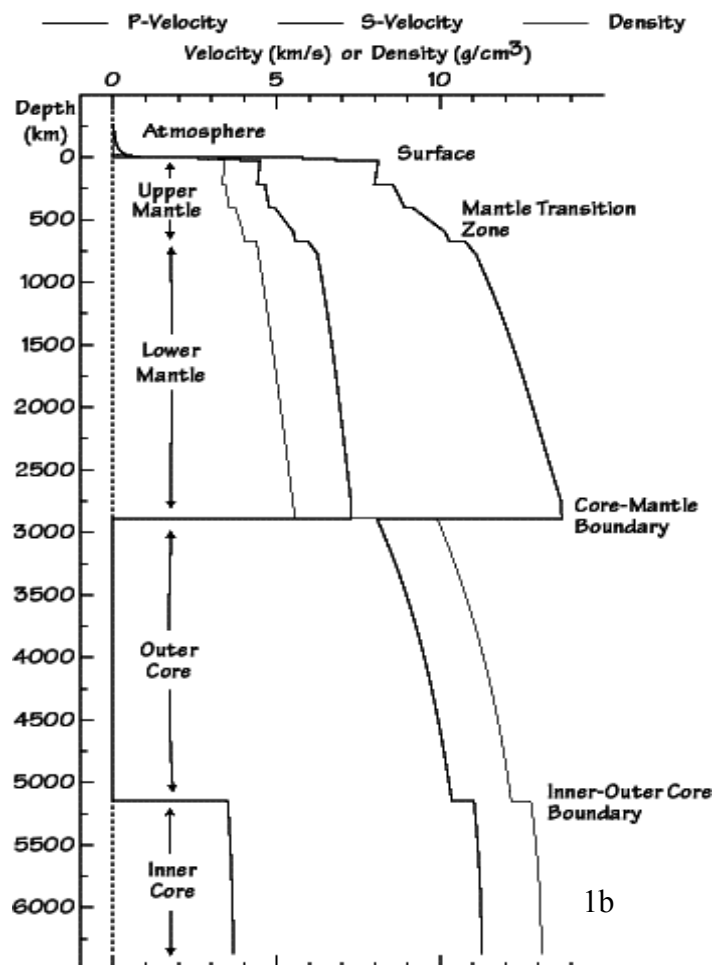
According to Webster's Collegiate Dictionary the term "Deformation" means alteration of form and shape due to stress. Crust is the upper most layer of the earth. The crust is a relatively cool, rigid, and brittle layer. Two types of crust are recognized: oceanic and continental. The oceanic crust ranges in thickness from 2 - 5 km and the continental crust may vary in thickness from 35 in the stable shield areas like the south Indian peninsula to 75 to 80 km beneath orogenic regions like the Alpine – Himalayan mountains.



Below the crust is the mantle which is again divided into the Upper Mantle (extending up to a depth 1000km and the Lower Mantle (from 1000km up to 2900km). Below that is the Outer Core (2900 to 5155km) and the Inner Core or the Seed of the Earth (up to 6371km).

### How do we know this?

Through deep drilling and seismic evidence scientists have learned about the structure of the Earth. Seismic evidence comes in the form of different kinds of waves that are generated through the earth during earth quakes. These earthquake waves travel through different rocks with different velocities. Their transmission depends on the physical and mechanical properties of the medium through which they travel. This helps us in understanding heterogeneities in the interior of the earth (Fig.1a&b)



**Seismic waves** are the waves of energy caused by the sudden breaking of rock within the earth. They may also be caused by an explosion. They travel through the earth and are recorded on seismographs.

### Types of seismic waves:

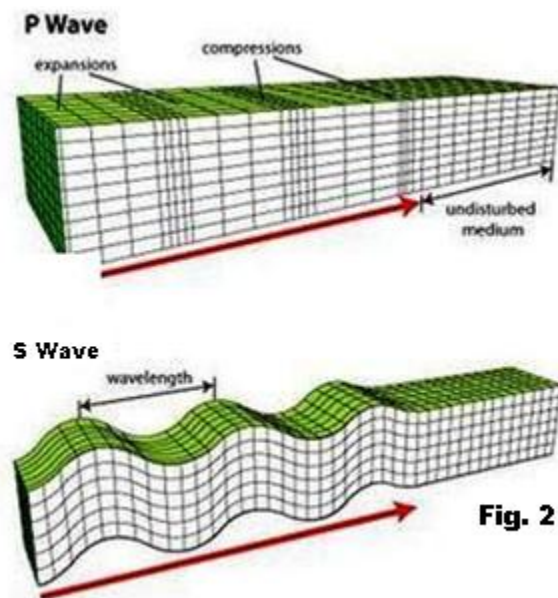
There are different kinds of seismic waves, and they all move in different ways. The two main types of waves are **body waves** and **surface waves**. Body waves can travel through the earth's inner layers, but surface waves can only move along the surface of the planet like ripples on water. Earthquakes radiate seismic energy as both body and surface waves.

### BODY WAVES

Traveling through the interior of the earth, **body waves** arrive before the surface waves emitted by an earthquake. These waves are of a higher frequency than surface waves.

### P WAVES

The first kind of body wave is the **P wave** or **primary wave**. This is the *fastest* kind of seismic wave, and, consequently, the *first to 'arrive' at a seismic station*. The P wave can move through solid rock and fluids, like water or the liquid layers of the earth. It pushes and pulls the rock it moves through just like sound waves push and pull the air. Have you ever heard a big clap of thunder and heard the windows rattle at the same time? The windows rattle because the sound waves were pushing and pulling on the window glass much like P waves push and pull on rock (Fig.2). Sometimes animals can hear the P waves of an earthquake. Dogs, for instance, commonly begin barking hysterically just before an earthquake 'hits' (or more specifically, before the surface waves arrive). Usually people can only feel the bump and rattle of these waves.



P waves are also known as **compressional waves**, because of the pushing and pulling they do. Subjected to a P wave, particles move in the same direction that



the wave is moving in, which is the direction that the energy is traveling in, and is sometimes called the 'direction of wave propagation'.

## ***S WAVES***

The second type of body wave is the **S wave** or **secondary wave**, which is the second wave you feel in an earthquake. An S wave is slower than a P wave and can only move through solid rock, not through any liquid medium. It is this property of S waves that led seismologists to conclude that the Earth's **outer core** is a liquid. S waves move rock particles up and down, or side-to-side--perpendicular to the direction that the wave is traveling in (the direction of wave propagation).

## ***SURFACE WAVES***

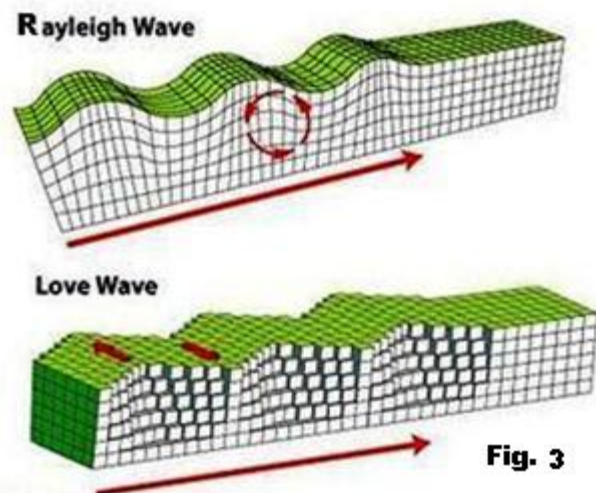
Travelling only through the crust, **surface waves** are of a lower frequency than body waves, and are easily distinguished on a seismogram as a result. Though they arrive after body waves, it is the surface waves that are almost entirely responsible for the damage and destruction associated with earthquakes. This damage and the strength of the surface waves are reduced in deeper earthquakes.

## ***LOVE WAVES***

The first kind of surface wave is called a **Love wave**, named after A.E.H. Love, a British mathematician who worked out the mathematical model for this kind of wave in 1911. It's the fastest surface wave and moves the ground from side-to-side. Confined to the surface of the crust, Love waves produce entirely horizontal motion.

## ***RAYLEIGH WAVES***

The other kind of surface wave is the **Rayleigh wave**, named after John William Strutt, Lord Rayleigh, who mathematically predicted the existence of this kind of wave in 1885. A Rayleigh wave rolls along the ground just like a wave rolls across a lake or an ocean. Because it rolls, it moves the ground up and down and side-to-side in the same direction that the wave is moving. Most of the shaking felt from an earthquake is due to the Rayleigh wave, which can be much larger than the other waves.



**Fig. 3**

## WHERE DO EARTHQUAKES HAPPEN?

Earthquakes occur all the time all over the world, both along plate edges and along faults.

### Along Plate Edges

Most earthquakes occur along the edge of *lithospheric* plates. The earth's outer layer is made up of several brittle or rigid pieces or blocks, called the lithospheric plates. These plates may largely be made up of oceanic or continental crust or a combination of both. These plates comprise the entire crust and a portion of the upper mantle of the Earth. The thickness of lithospheric plates can be anywhere between 150 to 300km. The plates are moved around by the convective motion of a deeper part of the earth called the *asthenosphere* that lies underneath the lithosphere. This layer is where most magmas are produced. It is not completely molten but somewhat plastic in nature and the continents float on this layer. The top 100 to 150km of the asthenosphere is called the seismic low velocity layer because the seismic waves get slowed down here. Because of perturbations in the asthenosphere the crust is subjected to enormous *stress* at the boundaries of the lithospheric plates. This *stress results in deformation* of the rocks that make up the crust. Deformation may be a *change in shape or volume or both*. The *change in shape* as a result of imposing a stress is called *strain*.

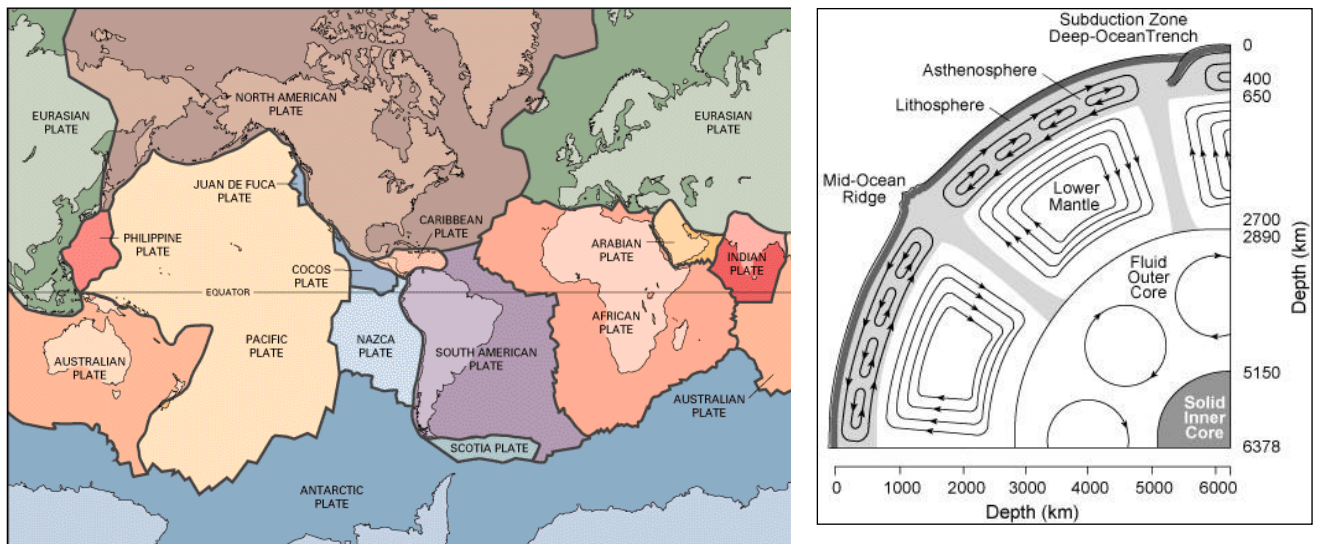


Fig. 4a Picture showing lithospheric plate boundaries. 4b. Convection cells in the interior of the earth.

There are three basic kinds of stress. *Compression* occurs when rock masses are pushed together when plates collide. Rocks tend to shorten laterally and thicken vertically due to folding when exposed to compressional stress. *Tension*, or tensional stress, pulls the crust apart, like that which occurs along diverging plate boundaries. Tension extends the crust causing it to thin and lengthen. Rifting, like

that which created the Great Rift Valley of Africa, is a result of tension. Rift Valleys are valleys that are bound by faults. When plates slide past one another in opposite directions along **transform** plate boundaries, a shearing stress is created. **Shearing stress** cuts the crust into parallel blocks displacing them horizontally relative to one another. Shearing takes place along the San Andreas Fault where the Pacific Plate is moving past the North American Plate.

Rocks behave in a variety of ways when stress is imposed on them. The relationship between stress and deformation is shown in stress-strain diagrams (Fig. 5). The reaction of rock material to an imposed stress depends on the temperature and pressure conditions. As stress is imposed on rock it starts to deform up to its **yield point**. Before it gets to the yield point, the rock will undergo **elastic deformation** (Figure 5a). Like a rubber band, if the stress is released before reaching the yield point, the rock material will return to its original shape. However, *under low temperature and pressure conditions*, once the rock reaches its yield point it will break, called **brittle failure** (Figure 5b). Brittle failure may occur if stress is imposed suddenly as well. Upon reaching the yield point *under high pressure and temperature conditions*, the rock may undergo **plastic deformation** in which case it behaves more like your molding clay (Figure 5c). In this case, once the rock changes shape and if stress is released, it will not return to its original form. During plastic deformation mineral bonds adjust to the stress by breaking, moving about, and then re-forming. Once it reaches its **rupture point**, the material will break.

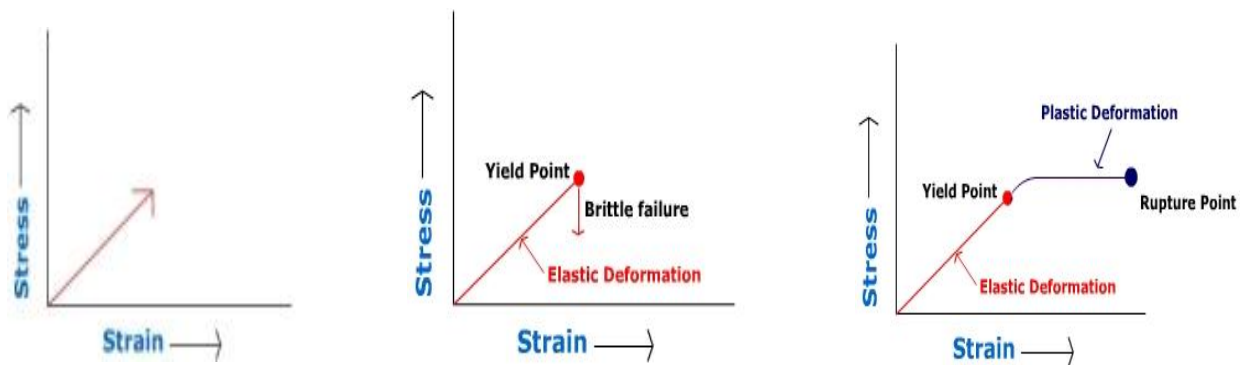


Fig.5a

b

c

These plates are always bumping into each other, pulling away from each other, or past each other. The plates usually move at about the same speed that your fingernails grow (an average of 2 to 5cm a year). Earthquakes usually occur where two plates are running into each other or sliding past each other.

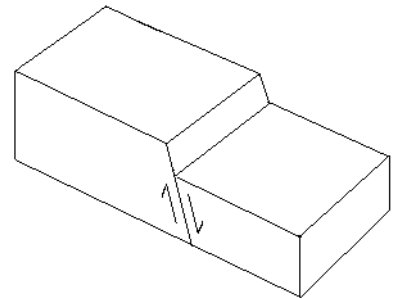
### Along Faults

Earthquakes can also occur far from the edges of plates, along faults. Faults are cracks in the earth where sections of a plate (or two plates) are moving in different

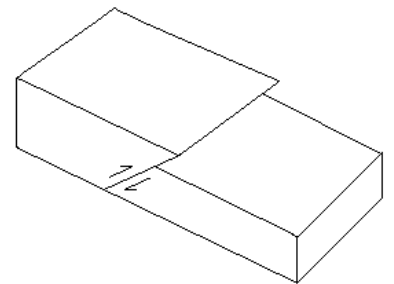
directions. Faults are caused by all that bumping and sliding the plates do. They are more common near the edges of the plates.

### Types of Faults

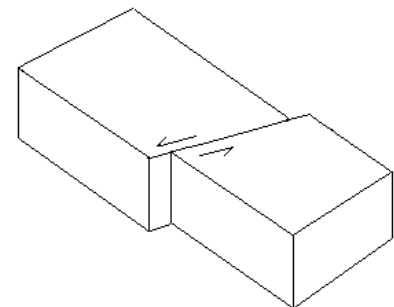
**Normal faults** are the cracks where one block of rock is sliding downward and away from another block of rock. These faults usually occur in areas where a plate is very slowly splitting apart or where two plates are pulling away from each other. A normal fault is defined by the hanging wall moving down on the footwall, which is moving up.



**Reverse faults** are cracks formed where one plate is pushing into another plate. They also occur where a plate is folding up because it's being compressed by another plate pushing against it. At these faults, one block of rock is sliding underneath another block or one block is being pushed up over the other. A reverse fault is defined by the hanging wall moving up relative to the footwall, which is moving down.



**Strike-slip faults** are the cracks between two plates that are sliding past each other. You can find these kinds of faults in California. The San Andreas Fault is a strike-slip fault. It's the most famous California fault and has caused a lot of powerful earthquakes.



### Why Do Earthquakes Happen?

Earthquakes are usually caused when rock underground suddenly breaks along a fault. This sudden release of energy produces the seismic waves that make the ground shake. An earthquake is a sudden vibration of some portion of the lithosphere. It is caused by the quick release of potential energy through motion. Most earthquakes are the result of rock moving because of faults, tectonic *subduction*, or *rifting*. The Earth experiences about 150,000 significant tremors a year. But most of these events are not strong enough to be felt, only a few cause large-scale damage.

Earthquake energy is transmitted to surrounding rocks by seismic waves. The strength of earthquakes is usually measured relative to the Richter scale. This scale is logarithmic so each increase in magnitude represents 10 times more energy released by the quake.

When two blocks of rock or two plates are rubbing against each other, they stick a little. They don't just slide smoothly; the rocks catch on each other. The rocks are still pushing against each other, but not moving. After a while, the rocks break because of all the pressure that's built up. When the rocks break, the earthquake occurs. During the earthquake and afterward, the plates or blocks of rock start moving, and they continue to move until they get stuck again. The spot underground where the rock breaks is called the **focus** of the earthquake. The place right above the focus (on the ground) is called the **epicenter** of the earthquake.

The **seismic moment** is a measure of the size of an earthquake based on the area of fault rupture, the average amount of **slip**, and the force that was required to overcome the friction sticking the rocks together that were offset by faulting. Seismic moment can also be calculated from the amplitude **spectra** of seismic waves.

*Slip is the relative displacement of formerly adjacent points on opposite sides of a fault, measured on the fault surface.*

*Displacement is the difference between the initial position of a reference point and any later position. It is the amount that any point affected by an earthquake has moved from where it was before the earthquake.*

*The spectrum is a curve showing amplitude and phase as a function of frequency or period, or how much of each type of shaking there is from an earthquake.*

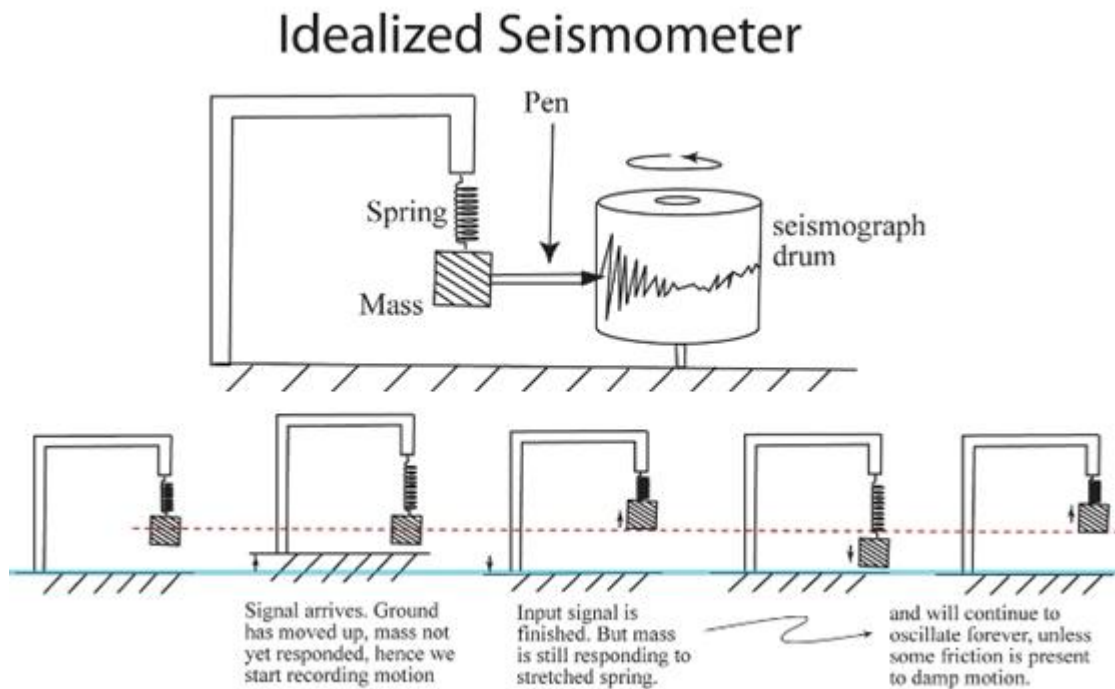
## **How Are Earthquakes Studied?**

Seismologists study earthquakes by going out and looking at the damage caused by the earthquakes and by using seismographs. A **seismograph** is an instrument that records the shaking of the earth's surface caused by seismic waves. The term **seismometer** is also used to refer to the same device, and the two terms are often used interchangeably.

## **Modern Seismographs**

Most seismographs today are electronic, but a basic seismograph is made of a drum with paper on it, a bar or spring with a hinge at one or both ends, a weight, and a pen. The one end of the bar or spring is bolted to a pole or metal box that is bolted to the ground. The weight is put on the other end of the bar and the pen is stuck to the weight. The drum with paper on it presses against the pen and turns constantly. When there is an earthquake, everything in the seismograph moves except the weight (due to inertia) with the pen on it. As the drum and paper shake next to the pen,

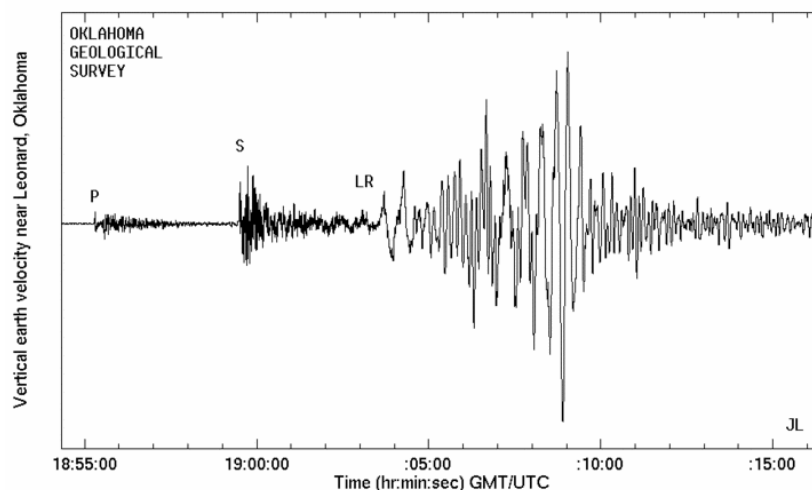
the pen makes squiggly lines on the paper, creating a record of the earthquake. This record made by the seismograph is called a *seismogram*.



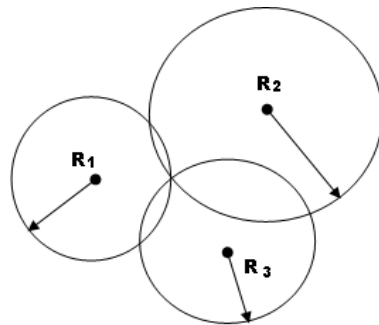
## Location of epicenter of earthquakes

By studying the seismogram, the seismologist can tell how far away the earthquake was and how strong it was. This record doesn't tell the seismologist exactly where the epicenter was, just that the earthquake happened so many miles or kilometers away from that seismograph. To find the exact epicenter, you need to know what at least two other seismographs in other parts of the country or world recorded. The epicenter of an earthquake can be obtained from the arrival time of earthquake waves from a minimum of three stations. The distance of each station from the epicenter of the earthquake is calculated from the difference between arrival time of P waves (first to arrive) and the slower S waves. For any station the location of the epicenter may

2001 Feb 28, Tacoma-Olympia earthquake, Ms=6.9(OGS)



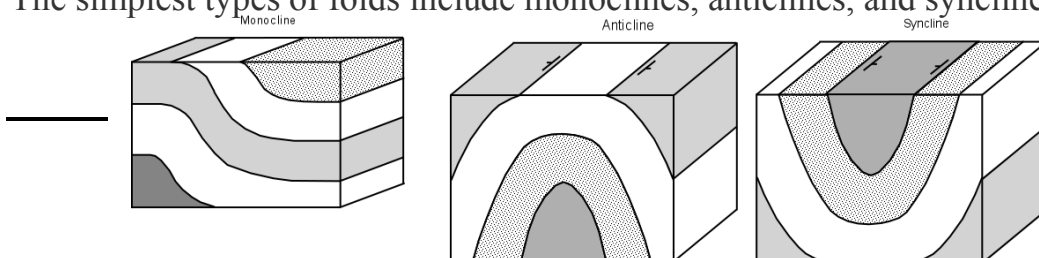
be anywhere within a circle of radius  $R_1$ . So also for any other station far away from the first one. If we draw circles of radius equal to the distance to epicenter, the point of intersection of the three circles will be the location of the epicenter.



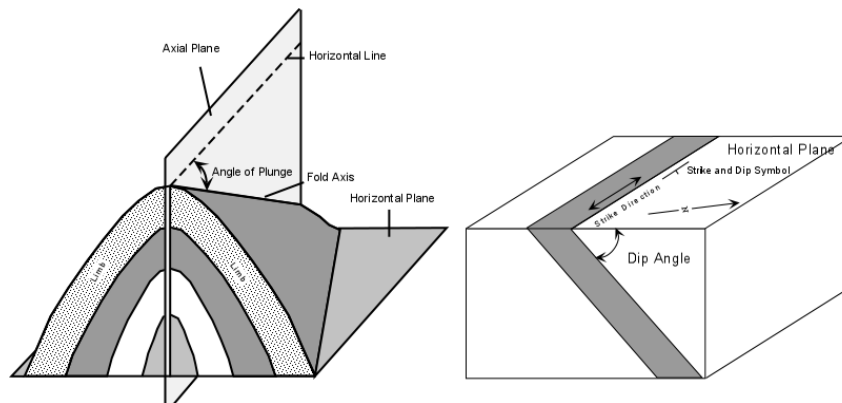
In figure (convection cells in the asthenosphere) the locations where the convection cells spread away from each other (diverge) the two blocks of the lithosphere are pushed aside by faulting resulting in a continental rift valley (for e.g., the Narmada valley). If the continental blocks so split continue to be pushed aside, a new ocean may develop ( for e.g., the Red Sea). More often than not, the faults are so deep that they tap that part of the mantle where magma is produced resulting in a chain of volcanoes which are known by the common name of Mid-oceanic Ridges. Where the convection cells come towards each other (converge) the lithospheric plates are pushed against each other resulting in subduction (sinking) of the denser (that which is largely oceanic) plate beneath the lighter or less dense one (the continental). Very often oceans are engulfed completely like in the case of the Sea of Tethys, leading to pushing of one continental plate against another resulting in the folding of rocks. The net result is **orogeny** or mountain building e.g., The Himalaya. In the former case the forces acting are tensional and therefore the crust is pulled apart. In the latter, the forces are compressional and the plates are pushed against each other. In both instances, however, the crust is subject to severe stresses and therefore subjected to deformation.

## FOLDS

We have just seen what happens when rocks fail by brittle rupture. Another manifestation of deformation is the folding of rocks. Folds are a result of ductile deformation of rocks. Folds are most obvious in sedimentary rocks that have beds or strata that were originally laid down horizontally. Rocks are folded when they are subject to compressional forces over a long period of time. One may ask how long? Very long indeed – a few million years! That is because the strain rate is very slow – of the order of a couple centimeters to an average of about 5 cm a year. The simplest types of folds include monoclines, anticlines, and synclines.



Geometry of Folds - Folds are described by their form and orientation. The sides of a fold are called limbs. The limbs show maximum curvature at the tightest part of the fold, called the hinge. A line connecting all points on the hinge is called the fold axis. In the diagrams above, the fold axes are horizontal, but if the fold axis is not horizontal the fold is called a plunging fold and the angle that the fold axis makes with a horizontal line is called the plunge of the fold. An imaginary plane that includes the fold axis and divides the fold as symmetrically as possible is called the axial plane of the fold.



Monoclines occur when horizontal strata are bent upward so that the two limbs of the fold are still horizontal. **Anticlines** are folds where the originally horizontal strata have been folded upward, and the two limbs of the fold dip away from the hinge of the fold. **Synclines** are folds where the originally horizontal strata have been folded downward, and the two limbs of the fold **dip** inward toward the hinge of the fold. Synclines and anticlines usually occur together such that the limb of a syncline is also the limb of an anticline. Dip is the angle the limbs make with the horizontal surface. And the horizontal expression of the limbs is called the **strike** of the bed.

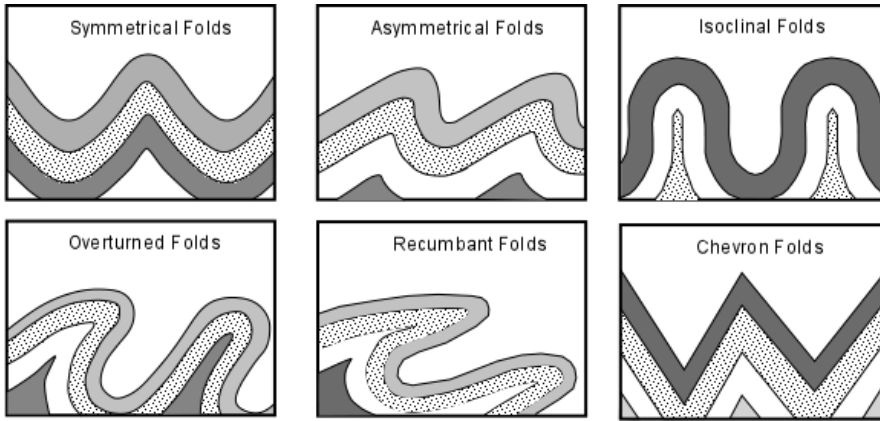
When we study very large or regional folds in field we measure the strike and dip of rock formation in many locations and infer folds after plotting the strike and dip of beds/ rocks on a map.

### Classification of folds

Folds are classified based on their appearance. If the two limbs of a fold dip away from each other by a similar angle it is called a symmetrical fold and if they dip away at different angles it is called asymmetrical fold. If the limbs are so tightly folded that they are almost parallel to each other they are called isoclinal folds. If the folding is so intense that the strata on one limb of the fold becomes nearly upside down, the fold is called an overturned fold. An overturned fold with an axial plane that is nearly horizontal is called a recumbent fold. A fold that has no curvature in its hinge and straight-sided limbs that form a zigzag pattern is called a chevron fold.

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As we shall see later, different effects of deformation as a result of distribution of stress are better understood in the context of plate tectonics and seafloor spreading.

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# Physical Geology (Earth SC 202) Notes and Visual Aids

Steven Dutch, Natural and Applied Sciences, [University of Wisconsin-Green Bay](#)

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## Power Point and Photographic Slides

**Please Note:** Not all slides or figures are presented. Slides and figures from outside sources that may present copyright problems are not available here. Slides may not match the order presented in class. Also, several slides may be combined into one image. **Do not attempt to print these pages - you will consume a lot of cartridges and paper for no purpose.**

Course Topic	Notes and Graphics	PowerPoint Slides	Slides
Introduction to the course	<a href="#">Introduction to the course</a>	<a href="#">What is Physical Geology?</a>	<a href="#">Geologic Maps</a>
Minerals	<a href="#">Minerals</a>	<a href="#">Minerals</a>	
Igneous Rocks and Volcanoes	<a href="#">Igneous Rocks and Volcanoes</a>	<a href="#">Igneous Rocks and Volcanoes Pompeii</a>	<a href="#">Volcanoes</a>
Weathering and Erosion	<a href="#">Weathering and Soils</a> <a href="#">Ground Water</a> <a href="#">Mass-Wasting</a>	<a href="#">Weathering and Soils</a> <a href="#">Ground Water</a> <a href="#">Mass-Wasting</a>	<a href="#">Weathering and Soils</a> <a href="#">Ground Water</a>
Evolution of Landscapes	<a href="#">Evolution of Landscapes</a> <a href="#">Drainage Diversion</a>	<a href="#">Evolution of Landscapes</a> <a href="#">Arid Climate Landscapes</a> <a href="#">Drainage Diversion</a>	<a href="#">Evolution of Landscapes</a>
Sedimentary Rocks	<a href="#">Sedimentary Rocks</a>	<a href="#">Sedimentary Rocks</a>	<a href="#">Sedimentary Rocks</a>
Evolution, Fossils, Geologic Time	<a href="#">Fossils and Evolution</a> <a href="#">Geologic Time</a>	<a href="#">Fossils</a> <a href="#">Fossils and Evolution</a> <a href="#">Geologic Time and Earth History</a>	<a href="#">Fossils and Evolution</a>
Glaciers	<a href="#">Glaciers and Ice Ages</a> <a href="#">How Glaciers Change</a> <a href="#">Geography</a>	<a href="#">Glaciers</a> <a href="#">Glaciers and Geography</a> <a href="#">Ice Ages</a>	<a href="#">Glaciers</a>
Wind and Wave Erosion	<a href="#">Wind Erosion</a>	<a href="#">Wind Erosion</a>	<a href="#">Wind Erosion</a>
	<a href="#">Tides</a> <a href="#">Wave Erosion and Marine</a> <a href="#">Geology</a>	<a href="#">The Oceans</a> <a href="#">Tides</a> <a href="#">Wave Erosion and Marine</a> <a href="#">Geology</a>	<a href="#">Coastal Processes</a>
Metamorphism and Deformation	<a href="#">Metamorphism</a>	<a href="#">Metamorphism</a>	
	<a href="#">Deformation</a>	<a href="#">Crustal Deformation</a>	<a href="#">Deformation of the Crust</a>
Earthquakes and Earth's Interior	<a href="#">Earthquakes and Earth's Interior</a>	<a href="#">Faults and Earthquakes</a>	<a href="#">Faults and Earthquakes</a>
Continental Drift and Plate	<a href="#">Continental Drift and Plate Tectonics</a>	<a href="#">Continental Drift and Plate Tectonics</a> <a href="#">Breakup and Assembly of Pangaea</a>	

Tectonics	<a href="#">Orogeny</a>	<a href="#">Closure of the Tethys Plate Tectonics and Western North America</a>	
Resources from the Earth	<a href="#">Resources from the Earth</a>	<a href="#">Earth Resources</a>	<a href="#">Mineral Resources</a>
Geology of other Worlds	<a href="#">Geology of other Worlds</a>	<a href="#">Earth, Moon and Impact Inner Solar System</a> <a href="#">Outer Solar System</a>	<a href="#">Planetary Geology</a>

Also of Interest:

[Geology of Wisconsin](#): Geologic maps, geologic history, earthquakes.

[History of the Great Lakes](#)

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# Physical Geology (Earth SC 202) Notes and Visual Aids

Steven Dutch, Natural and Applied Sciences, [University of Wisconsin-Green Bay](#)

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## Power Point and Photographic Slides

**Please Note:** Not all slides or figures are presented. Slides and figures from outside sources that may present copyright problems are not available here. Slides may not match the order presented in class. Also, several slides may be combined into one image. **Do not attempt to print these pages - you will consume a lot of cartridges and paper for no purpose.**

Course Topic	Notes and Graphics	PowerPoint Slides	Slides
Introduction to the course	<a href="#">Introduction to the course</a>	<a href="#">What is Physical Geology?</a>	<a href="#">Geologic Maps</a>
Minerals	<a href="#">Minerals</a>	<a href="#">Minerals</a>	
Igneous Rocks and Volcanoes	<a href="#">Igneous Rocks and Volcanoes</a>	<a href="#">Igneous Rocks and Volcanoes Pompeii</a>	<a href="#">Volcanoes</a>
Weathering and Erosion	<a href="#">Weathering and Soils</a> <a href="#">Ground Water</a> <a href="#">Mass-Wasting</a>	<a href="#">Weathering and Soils</a> <a href="#">Ground Water</a> <a href="#">Mass-Wasting</a>	<a href="#">Weathering and Soils</a> <a href="#">Ground Water</a>
Evolution of Landscapes	<a href="#">Evolution of Landscapes</a> <a href="#">Drainage Diversion</a>	<a href="#">Evolution of Landscapes</a> <a href="#">Arid Climate Landscapes</a> <a href="#">Drainage Diversion</a>	<a href="#">Evolution of Landscapes</a>
Sedimentary Rocks	<a href="#">Sedimentary Rocks</a>	<a href="#">Sedimentary Rocks</a>	<a href="#">Sedimentary Rocks</a>
Evolution, Fossils, Geologic Time	<a href="#">Fossils and Evolution</a> <a href="#">Geologic Time</a>	<a href="#">Fossils</a> <a href="#">Fossils and Evolution</a> <a href="#">Geologic Time and Earth History</a>	<a href="#">Fossils and Evolution</a>
Glaciers	<a href="#">Glaciers and Ice Ages</a> <a href="#">How Glaciers Change</a> <a href="#">Geography</a>	<a href="#">Glaciers</a> <a href="#">Glaciers and Geography</a> <a href="#">Ice Ages</a>	<a href="#">Glaciers</a>
Wind and Wave Erosion	<a href="#">Wind Erosion</a>	<a href="#">Wind Erosion</a>	<a href="#">Wind Erosion</a>
	<a href="#">Tides</a> <a href="#">Wave Erosion and Marine</a> <a href="#">Geology</a>	<a href="#">The Oceans</a> <a href="#">Tides</a> <a href="#">Wave Erosion and Marine</a> <a href="#">Geology</a>	<a href="#">Coastal Processes</a>
Metamorphism and Deformation	<a href="#">Metamorphism</a>	<a href="#">Metamorphism</a>	
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Resources from the Earth	<a href="#">Resources from the Earth</a>	<a href="#">Earth Resources</a>	<a href="#">Mineral Resources</a>
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