TOPIC: -
FOLDING AND FAULTING

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Folding and Faulting

Introduction

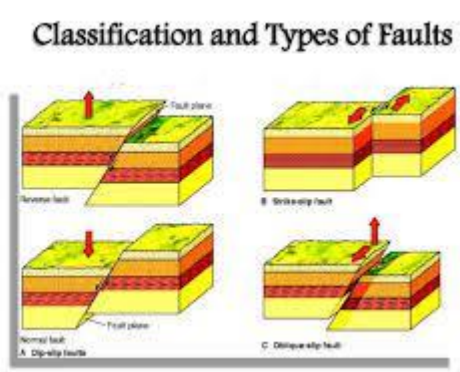
In the past geologists used to think that fold mountains were formed due to **shrinking of earth's material** i.e., when molten crust solidified it created wrinkles in the form of fold mountain. Now we know this is not the valid reason for the formation of fold mountains. Suppose initial notion about the formation fold mountain had been a reality then, they would have been arranged evenly over the surface of the earth. Therefore, question can be raised, **why mountains are confined to specific places on the earth?**

If you observe the upper part of the crust closely you will notice that it is characterized by complicated structures. This complication has been created by different types of stress resulting into folding, faulting, volcanic activity, igneous intrusion and metamorphism.

1. Stress and Strain

The understanding of concept of stress and strain is mandatory to comprehend different types of **crustal deformations**. For a layman stress may denote an activity related with pushing and pulling. Similarly, strain is considered as deformation in form of bending, breaking, stretching. But technically both terms have deeper meaning. Let us understand the meaning of **stress and strain** in context to geomorphology.

We know that **force** is a clearly definable vector quantity that changes or tends to produce a change in the motion of body (Billings, 2016). Since the force is defined by its magnitude and direction (vector quantity) therefore it may be expressed by an arrow. In



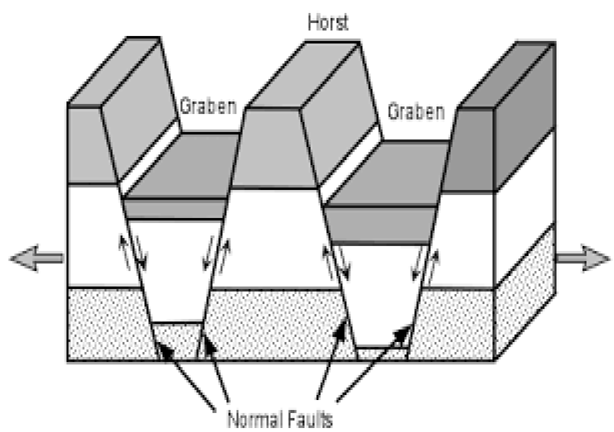
structural geology **a force** applied to material that tends to change the material's dimension is called **stress**.

The Figure is showing that **in mathematics the Stress is represented by the symbol σ meaning sigma, which is defined as the force (F) per unit area (A), or σ = F/A.** Therefore, we can consider stress as the intensity of force, or a measure of how intense a force is. Effect of stress on rocks or any other material is called **strain**. Therefore, **the strain represents deformation caused by stress.** The deformation can be in form of dilation and distortion:

(i) **Dilation**: The figure is showing that the Strain resulted in form of change in volume is called dilation.

(ii) **Distortion:** On the hand the figure is showing that the distortion denotes change in form or volume or both.

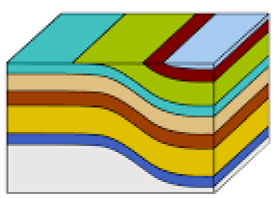
There are three types of stress i.e., **Tensional, Compressional, and Shear.**



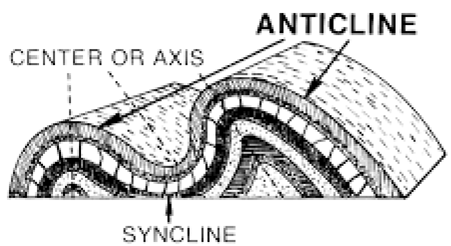
Tensional Stress: It is clear from the **module number 10 on plate tectonics** that along the **divergent** plate boundary tensional stress is produced. It can be shown by following diagram. The diagram showing that a rectangular rock body is said to be under tension when it is subjected to external forces that tend to pull it apart. It is actually a **stretching stress** which has potential to **increase the volume** of a material.

Compressional Stress: The Plate tectonic theory reveals that, **convergent** boundaries create compressional stress. The figure shows that rectangular rock body is said to be under compression when it is subjected to external forces that tend to compress it. Therefore, compression tends to decrease the volume of the material but under certain condition or upto a certain limit.

Shear stress: In case of transform plate boundaries shear stress is produced. The figures are showing that shear stress produces change in shape of the rock material



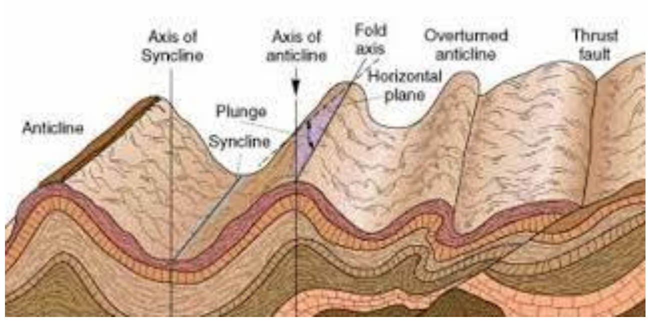
Monocline Diagram



2. Strength of Rocks

It is also important to note that rupturing, distortion of rocks or deformation also depends on the strength of the rock. The laboratory test reveals that rocks respond to compression strength, shear strength and tension strength. Accordingly we classify the rock material as brittle and ductile.

In this regard it is important to note that, at surface under intense tensional or compressional stress rocks may break under less pressure conditions.



On the other hand the figure is exhibiting at depths under pressure and increasing temperature rocks may take time to break. Therefore in real world pressure and temperatures are important component of strength of the rocks.

3. Folds and Basic Fold Geometry

Folds are manifestation of compressional stress representing **undulated rock deformation**. A fold can be considered as a structural feature that is formed when planar surfaces are bent or curved and rocks are deformed. **The term deformation refers to changes in shape, position, or orientation of a body resulting from the application of a differential stress**. In fold rocks are deformed by **compressional stress** which forms wavy undulations on the surface of the earth. In style and intensity they differ from place to place, and from rock to rock. For example, their size may range from minute wrinkle in a small piece of metamorphic rock to huge fold mountains like Himalayas. In terms of their inter-limb angle they may very gentle to very tight category. The types of folding depend on the strength of the rock, **magnitude and direction of stress** under the specific condition of pressure and temperature.

Generally folds are recognized by rock outcrop patterns, direct field observations, photo-geological methods and by structural studies. Nowadays satellite imageries are gaining importance to identify the fold patterns accorss the surface of the earth. For example above satellite imagery (Google Earth) is showing the beautiful pattern of folds along the Fink River in Australia.

Basic Fold Geometry

The basic fold geometry includes: Hinge, Limb, Hinge Line, Axial Plane, Interlimb Angle, and Wavelength of the Fold, Crest, Trough and Fold Profile Plane.

(i). **Hinge:** It represents the zone of **maximum curvature** of the surface. The figure shows that the hinge separates the two limbs.

(ii). **Limb:** It is the area between two hinges. A point in a limb where the sense of curvature changes is recognized as **inflection point**. It is clear from the above diagram that in a fold there are two limbs and **one hinge.**

(iii). Hinge Line: It is a line of intersection with a bedding plane. It denotes the line of the greatest curvature in a folded surface. It is important to note from the figure (below) that hinge line may be straight which is designated as ‘Straight Line Hinge’ or cylindrical fold. The adjacent figure also exhibits that hinge line may be curved. In this case it is designated as
‘Curved Line Hinge’ which recognizes non-cylindrical fold

iv) Axial Plane: The plane which bisects the angle between the two limbs is called an **axial** plane. The yellow colour in above diagram is showing the axial plane. It should be noted that axial surface does not necessarily divide the fold into equal halves.

(v) **Interlimb Angle:** The angle made by the limbs of the fold (profile plane) is designated as fold angle or **interlimb angle.**

It is also important to note that the smaller the interlimb angle, the greater the intensity of folding.

(vi) **Wavelength:** The distance between the two hinges or zone of maximum curvature is called **wavelength of the fold**. From the diagram (below) it is clear that the amplitude of the fold is half the height of the structure measured from crest to trough.

(vii) Crest and Trough: the uppermost and lowest points of a fold are called the crest and trough, respectively.

(vii) Fold profile plane: It signifies the shape of the fold with reference to a plane which is perpendicular to hinge line.

4. Classification of Folds

Fold can be classified into several ways.

(A) Based on Interlimb angle: We already know that the angle made by the limbs of the fold is designated as **interlimb angle**. The classification of folds on the basis of interlimb angle signifies the **tightness and openness** of the fold. In this way geologists can also infer amount of deformation through the present classification. In general we can identify four types of fold on the basis of interlimb angle. They are as follows:

(i) Gentle Fold: In this case the interlimb angle remains between 120° to 180°

(ii) Open Fold: In this case in general the interlimb angle ranges beteeen 60° to 120°

(iii) Tight Fold: in this case the interlimb angle ranges between 10° to 60°

(iv) Isoclinal fold: It denotes the special fold where the interlimb angle is nearly 0°

(B) On the Basis of Symmetry of the Fold:

(i) Symmetrical Fold: When the axial plane bisects the fold at a right angle or perfectly vertical in an ideal situation then it is regarded as Symmetrical Fold.

(ii) **Asymmetrical Fold:** The diagram shows that the inclination or presence of dip in a fold makes the fold asymmetrical.

(iii) Recumbent Fold: The diagram shows that when we find axial plane of the fold in a horizontal position we classify that type of fold as **'Recumbent Fold'**. It is actually an overturned fold. They are well exposed in the Alps (Billings, 2016). The figure shows that naturally under the immense pressure of overlying rock in **recumbent Fold** the strata in the inverted limb region are much thinner than the beds in the normal limb which is thicker than the inverted limb. The sub-features of this fold are as follow

Arch-bend: The figure shows that the curved part of the recumbent fold between the normal and inverted limb is known as arch-bend.

Shell and Core: The outer part of the fold is called shell and the inner part is recognized as core of the recumbent fold. It is noteworthy that generally core is composed of crystalline rocks surrounded by shell of sedimentary rocks.

Digitations: The figure shows that the fingers like subsidiary fold attached to the recumbent fold are called digitations.

(iv) **Isoclinal fold:** We already know that isoclinal fold denotes a fold where the interlimb angle is nearly 0°. Isoclinal is a Greek word which means **"equally inclined".** The figure shows that in this fold two limbs dip at **equal angles** and in the same direction. It should be noted that many recumbent folds are also considered as isoclinal.

(v) Overturned Fold: In this fold the axial plane is inclined and limbs of the fold dip in the same direction but **at different angle**.

(C) On the Basis of Appearance in Cross Section:

(i) Anticline: The figure shows that convex shaped upfolded rock beds are designated as anticlines i.e., a type of fold which is convex upward. The figure also exhibits that they may be symmetrical and asymmetrical in nature. Accordingly they are also named as symmetrical anticline and asymmetrical anticline. Likewise on the basis of interlimb angle they may be in form of gentle anticline and steep anticline.

(ii) Syncline: The digram shows that it is a fold which is concave upward and generally dips towards the axial plane.

(iii) Anticlinorium: It is a large anticline containing subsidiary folds of smaller size. In

Scotland mountainous area one can find example of this category of fold.

(iv) Synclinorium: It denotes a large syncline containing subsidiary folds of smaller size. They are found in the central part of Aravali Ranges.

(v) Geosyncline: it means "earth syncline" but the note of caution is that, this term should not be used for large synclines. Geosyncline is considered as huge elongated basin containing huge stock of sediments.

(D) Special Types of Folds

(i) Chevron: The digram shows that they are angular folds in which hinges are very sharp. They are also known as zig zag.

(ii) Box Fold: The picture shows that it is a type of fold in which the crest is broad and flat. They are also known as Coffer Fold.

(iii) **Fanfold:** When the upper shell of the Anticlinorium is eroded due to exogenic forces the remnant outer shell is regarded as fanfold. They are found in Chota Nagpur Plateau region of our country.

(iv) Kink Bands: they are the narrow bands of beds ranging from few inches to a few feet wide. The beds acquire a dip which is either steeper or gentler than the adjacent bed.

Similarly there are many other types of folds such as: Drag fold, monocline, Homocline, Diapir Folds, Plunging Fold and Dome.

5. Fault and Basic Geometry

Faults reflect ruptures or crakes in the earth along which one side is relatively displaced with reference to the other side. Sometimes they are also known as disjunctive dislocation. In size and total displacement they may range from a few inches to hundreds of kilometers long.

Above picture shows that since are formed due to **great stresses** therefore they reflects **brittle deformation**. The brittle deformation results in fracturing and faulting. You can also notice brittle deformation if you drop a glass (but by mistake!) on a hard floor you will notice that it breaks into several pieces. Similarity crakes in building formed due to earthquake, gravitational effect, subsidence also denotes brittle deformation. Geomorphologists and geologists recognize the fault by indentifying omission of strata, dislocation of structure or the discontinuity, geometry of fault plane, sudden changes in topography.

Basic Fault Geometry

Wall: Rock adjacent to a fault surface is the wall of the fault

Fault block: the body of rock that moved as a consequence of slip on the fault is a fault block

Hanging-Wall Block: It is a fault block or rock body above the fault plane**.**

Foot-Wall Block: The fault block below the fault plane is recognized as foot-wall block**.**

Strike: It denotes the trend of horizontal line in the plane of the fault**.**

Dip: generally we recognize fault as steep or vertical to tell about image of a fault, which in turn reflects the dip of the fault. The dip represents the angle between a horizontal surface and fault plane. It makes right angle to the strike of the fault.

Hade: is the complement angle of the dip i.e., **Hade = 90° - Dip**

Throw: Normally under the gravitational pull during the faulting vertical displacement of rock occurs. The figure (below) shows that this vertical displacement is recognized as Throw. In nutshell it denotes the vertical component of dip separation.

Heave: The above figure shows that apparent horizontal displacement of fault block is known as heave. It denotes the horizontal component of dip separation

6. Classification of Faults

Like folds faults can also be classified into several ways.

(A) Classification on the Basis of Apparent Movement

There are three types i.e., Normal Fault, Thrust or Reverse Fault and Strike Slip Fault.

1. Normal Fault: The normal fault is also known as gravity fault, tensional fault or extensional fault. They occur when the vertical stress is greater than the horizontal stress. The picture shows that in normal fault primarily displacement or movement is vertical. In this case the downthrown block is the hanging-wall block which is influenced by the gravity that is why normal fault is also recognized as gravity or tensional fault. On a global level normal fault system leads to

lengthening the earth's crust. This process occurs along the rift valleys and either side of mid-ocean ridges. Normal faults are also visible along the edge of mountain ranges in California. The cliff formed by faulting is commonly called a fault scarp, or escarpment. Process of Normal Faulting can give rise to following geomorphic features:

(i) **Horst**: An upstanding fault block bounded by two normal faults is regarded as horst. The figure (below) shows that in appearance it looks like block plateau or mountain generally flat on top but with steep sides. Horst may be formed by upliftment of block between two normal faults or may be left upstanding due to subsidence of either sides of the middle block. The **Shillong Plateau** is an example of horst. **(ii) Graben:** Graben is from the German word for **"trough".** The figure shows that graben is a valley like depression or trough representing a sloped fault block bounded by normal faults. It is like a trench with straight parallel walls created by tensional force on the contrary the horst represents a narrow elevated block between two normal faults.

(iii) Half Graben: The figure (below) shows that in the Half Graben the upper part of the hanging-wall block is tilted towards the fault due to rotation of displaced block along the normal fault line. This type of displaced rotational movement creates half graben depression. Half graben are common in the Basin and Range Province of the Western United States.

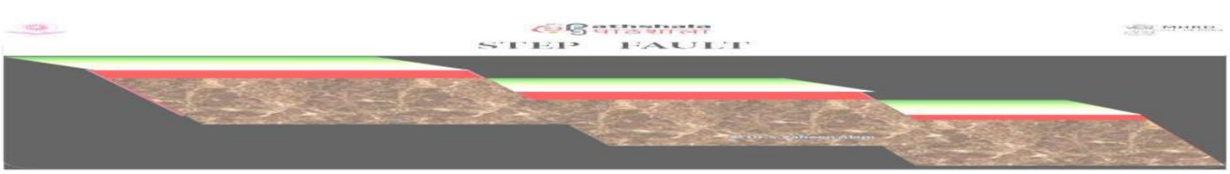
(iv) Fault Scarp: From the figure it is apparent that the steep straight cliff-like topography created along the normal fault plane is called fault scarps. In length they may go up to 300 kilometers. The height of fault scarp may range between a few meters to a few hundred meters.

(iv) Block Mountain: The long and ridge like horst is called block mountain.. Vosges Black
Forest in Germany is also well known example of Block Mountain.

(v) Rift Valley: A long narrow fault trough created along the divergent plate boundary (due to tectonic activity) is called rift valley. The East African Rift Valley is the well know example of rifting. The map shows the areal extent of **East African Rift Valley** along the divergent plate boundary**.** This belt extends from Ethiopia to Tanzania. This rift valley is also the sites of **volcanic activity**. The volcano Kilimanjaro in Tanzania is a well known example of this belt. As rift valleys open, water flows into the new lowlands. The Red Sea and the Gulf of California are examples of this process they are actually confined in larger rift valleys.

Similarly the rifting due to tensional stress can also occur at local level. For example **Narmada and Tapti river India flow throw rift valleys**.

(vi) Step Fault: Sometimes due to normal faulting several parallel series of faults are formed they appear like giant steps of the stairs. They are known as step faults. They are generally common in **rift valley regions.**



2. Thrust or Reverse Fault

Unlike normal fault the thrust faults are created by **compressional stress**. From the figure (Below) it is apparent that, they are formed when h**anging wall block has overridden the footwall block** generally at a very shallow angle. That is why they are also known as **"contractional faults".** It should be noted that in the thrust fault **maximum stress is horizontal** and minimum stress is vertical which leads to **shortening of the earth crust**. There is a minor difference between thrust and reverse fault. In former the dip angle is less than 45° and in later it is more than 45°. The subduction zones along the convergent plate boundaries are characterized by thrust fault. In such tectonic settings, thrusting occurs in combination with formation of folds. In the Alps and Himalayas , several such over thrusts result from compressional stresses of the ongoing collision between different plates. For detail kindly refer module number 10 on Plate Tectonics.

(i) Ramp Valley: A valley like depression formed by **commprssional stress** may create ramp valley. The figure shows that in this category of thrust fault the two hanging blocks move upward side and one foot wall block appears to remain stationary. The Brahmaputra valley between Himalaya and Shillong Plateau is an example of ramp valley.

3. Strike Slip Fault: As the name suggests in this category of fault the relative displacement of fault blocks remains mainly **parallel to the strike** of the fault. They are formed when rocks are torn by lateral-shearing stress. On the basis standing position of the observer they are divided into two categories which are as follows:

(i) Right Lateral Strike Slip Fault: From the above diagram it is clear that in this type of fault the displacement appears to the right side of the observer.

(ii) Left lateral Strike Slip Fault: If a person is standing at the fault and looks across to see that a block or a portion of land has been displaced to the left hand direction, it is designated as a left-lateral strike-slip fault.

(iii) Transform Fault:

Transform faults are associated with plate tectonics. The Transform Fault represents **plate boundary** at which lithosphere is neither created nor destroyed. Therefore, they are **devoid of stunning landform** features in comparison to convergent and divergent boundaries. San Adreas fault in California is best known example of this category. One can also identify the trace of the transform fault through offset roads, fences. It is also noteworthy that any relative sudden displacement of rocks along the transform fault may cause immense loss of life property. For detail kindly **refer module number 12 on Earthquakes and module number 10 on Plate Tectonics**.

7. Folding-Faulting and the Society

The study of folding and faulting is useful for academic purpose to create awareness about associated hazards and benefits of folding and faulting. It is equally useful for exploration geologists to explore natural gas, oil in anticlinal areas and to discover occurrence minerals along the fault line. The construction of mega-structures such as dams, skyscrapers, nuclear power plants and town planning requires deeper understanding of the fold and fault settings.