Chapter 10
Deformation, Mountain Building, and the Continents

Introduction
- Dynamic forces within the Earth cause deformation.
- Deformation is a general term that in geology applies to any change in the shape or volume of rock layers, such as when they are folded or fractured.
- Deformation occurs in building large mountain ranges at convergent boundaries thru:
  - Emplacement of plutons
  - Volcanism
  - Metamorphism
  - Continental accretion

Deformation: Modification of Rocks by Folding and Fracturing

About Deformation
- Deformation mainly occurs near plate boundaries.
- Field observations of deformation show us how to reconstruct geologic history.
- Deformation includes faulting of rigid rocks and folding of rocks that can be bent.

Lecture Outline
1. Mapping geologic structure
2. How rocks deform
3. Basic deformation structures
4. Styles of continental deformation
5. Unraveling geologic history

1. Mapping geologic structure
Outcrop – what is it? Where the underlying bedrock is exposed.
Basic source of geologic information in the field
1. Mapping geologic structure

Folds

Exposure of dipping bed
How much tilt (dip) & what direction (strike)

Measuring strike and dip
- **strike** is the compass direction of a rock layer as it intersects a horizontal surface
- **dip** is the amount of tilting of the layer and is measured at right angles to strike

Example of use of strike and dip

Water trickles down slope parallel to dip.
Strike and Dip-The Orientation of Deformed Rock Layers

- Strike and dip are measurements used to describe a rock body’s orientation with respect to the horizontal.
- Strike is the intersection of a horizontal plane with an inclined plane.
- Dip is the maximum angle of an inclined plane.

Principle of original horizontality states that most rocks are originally laid down horizontally.

When we see rocks inclined, they have been deformed by folding and/or fracturing.

1. Mapping geologic structure

Geologic maps

- **geologic maps** represent the rock formations exposed at Earth’s surface

- a common scale for geologic maps is 1:24,000 (1”=24,000” or 1”=2000’)

Geologic cross sections

- **geologic cross sections** – diagrams showing the features that would be visible if vertical slices were made through part of the crust

2. How do rocks deform

- Dynamic forces within the Earth cause deformation.

- **Deformation** is a general term that in geology applies to any change in the shape or volume of rock layers, such as when they are folded or fractured.

- **Deformation** occurs in building large mountain ranges at convergent boundaries thru:
  - Emplacement of plutons
  - Volcanism
  - Metamorphism
  - Continental accretion
Rock Deformation - How Does it Occur?

– Applied stresses can deform or strain rocks until they become contorted or fracture.
– Stresses are categorized as compressional, tensional or shear.
– While stress is a force, strain is the change in shape that results from the stress being applied.
– Deformation and strain are the same thing.

2. How rocks deform

Plate tectonic forces (on surface)

● tensional forces – stretch and pull units apart, common at divergent boundaries
● compressive forces – squeeze and shorten rock units, dominate at convergent margins
● shearing forces – push rock units pass each other in opposite directions, at transform boundaries

Tension

Action of coincident oppositely directed forces acting away from each other

Compression

Action of coincident oppositely directed forces acting towards each other

Shear

Action of coincident oppositely directed forces acting parallel to each other across a surface in a couple

Rock behavior in the laboratory

Both

● brittle (near surface, low confining pressure)
● ductile (deep burial, high confining pressure)
2. How rocks deform

Under conditions representative of the shallow crust, the marble is brittle.

Under conditions representative of the deeper crust, marble is ductile.

Rock Deformation—How Does it Occur?

- **Types of Strain**
  - Rocks will deform elastically until they reach the elastic limit unless the force is applied quickly.
  - Elastic strain occurs if rocks return to their original shape when the stress is released.
  - Plastic strain occurs when rocks fold or fracture when stress is applied and do not recover their original shape.

- **Types of Strain**
  - Rocks will deform elastically until they reach the elastic limit unless the force is applied quickly.
  - Ductile rocks show a great amount of plastic strain (they bend) before they fracture.
  - Brittle rocks fracture after only a small amount of plastic strain.

- **What determines whether a rock will bend elastically, plastically or fracture?**
  - Type of stress applied
  - Pressure and temperature
  - Rock type
  - Length of time
2. How rocks deform
Rock behavior in the Earth’s crust
- depth affects brittle v. ductile (confining pressure, & possibly heat)
- rock type affects way rocks deform (old hard rock = brittle, while newer, softer (sed.) rock = ductile)
- rate of deformation is a factor (slow = ductile, fast = brittle, silly putty)

Rock Deformation - How Does it Occur?
- Types of Strain
  - Compression
    - In compression the rocks are squeezed towards one another along the same line.
    - Rock layers in compression are shortened by folding or faulting.

Rock Deformation - How Does it Occur?
- Types of Strain
  - Tension
    - In tension the forces along the same line act in opposite directions.
    - Tension lengthens the rocks or pulls them apart.

Rock Deformation - How Does it Occur?
- Types of Strain
  - Shear
    - In shear the forces act parallel to one another, but in opposite directions.
    - Deformation occurs along closely spaced planes like the slip between cards in a deck.

Deformation & Geologic Structures
- Joints
  - Joints are fractures along which no movement has taken place.
  - Joints occur in almost all surface rocks.
  - Form in response to compression, tension, and shearing.

(a) Compression causes shortening of rock layers by folding or faulting.
(b) Tension lengthens rock layers and causes faulting.
(c) Shear stress causes deformation by displacement along closely spaced planes.
Deformation & Geologic Structures

- **Faults** are fractures along which the opposite sides have moved relative to one another and parallel to the fracture surface.

3. Basic deformation structures

Types of faults

- **dip-slip** – normal, reverse, and thrust
- **strike-slip** – right- and left-lateral
- **oblique-slip**

Normal faulting is caused by tensional forces that stretch a body and tend to pull it apart.

Reverse faulting is caused by compressive forces that squeeze and shorten a body.

A thrust fault is a reverse fault with a shallow-dipping fault plane.
Deformation & Geologic Structures

- **Faults**
  - Dip-slip Faults
  - Normal faults form in response to tensional forces.

Joints & Faults – Deformation by Fracturing

- **Faults**
  - Reverse Faults

- Thrust Faults – Lewis Overthrust

- Dip-slip faults form in tensional strain
- Reverse faults form in response to compressional forces.
- Thrust faults are a type of reverse fault that dips at less than 45 degrees, often as low as 5 degrees!
• **Faults**
  – Strike-slip faults

• Faults in which all movement is in the direction of the strike of the fault plane are known as strike-slip faults.

• Strike-slip faults are classified as right-lateral or left-lateral depending on the apparent direction of the offset between blocks.

• **Faults**
  – Strike-slip faults

• **Faults**
  – Oblique-slip faults

  – Oblique-slip faults have both strike-slip and dip-slip components of movement.

• Oblique-slip faulting is caused by a combination of forces, in this case left-lateral shearing with tension.
3. Basic deformation structures

**Folded Rock Layers**
- Folds are layers of rock that were once planar that are bent or crumpled.
- Folds form during compression and undergo plastic strain.
- This occurs deep in the crust where the rocks behave ductilely.
- There are 3 kinds of folds:
  - Anticlines
  - Synclines
  - Monoclines

Deformation & Geologic Structures

**Folded Rock Layers**
- All folds exhibit their own fold anatomy.
- Folds have an axial plane that divides the fold in half.
- Each half is called a limb. Adjacent anticlines and synclines share a limb.
- The axis is an imaginary line formed by the intersection of the axial plane and the folded beds.

Deformation & Geologic Structures

**Folded Rock Layers**
- Anticlines and Synclines
  - Anticlines are up-arched folds. The oldest rocks are in the core.
  - Synclines are down-arched folds. The youngest rocks are in the core.

Deformation & Geologic Structures

**Folded Rock Layers**
- Anticlines and Synclines
  - Upright folds
    - Axial plane is vertical
    - Both limbs dip at the same angle.

Deformation & Geologic Structures

**Folded Rock Layers**
- Monoclines
  - A monocline is a flexure in otherwise horizontal or uniformly dipping rock layers.
  - One limb is horizontal.
  - The fold axis is inclined.

**Fold Identification**
- Monocline – like carpet draped over stairstep.
  - Generated by blind faults in the basement rock.
  - These faults do not cut through to the surface.
  - Instead, displacement folds overlying sedimentary cover.
Deformation & Geologic Structures

**Folded Rock Layers**
- Plunging folds

**Fold axis is not horizontal**
- Axial plane may be vertical or inclined

Fig. 10.12a-b, p. 256

**Fold Identification**
- Folds are described by hinge geometry.
  - Plunging fold – Has a hinge that is tilted.
  - Non-plunging fold – Has a horizontal hinge.
- Erosion of plunging folds can create zig-zag outcrops.

Fig. 10.12c, p. 256

**Plunging fold**

**Upright, non-plunging folds**

3. Basic deformation structures

**Types of folds - Summary**
- symmetrical folds — anticlines and synclines
- asymmetrical folds – monocline
- overturned folds
- plunging folds
3. Basic deformation structures

Deformation & Geologic Structures

- Folded Rock Layers
  - Domes and basins
    - Domes and basins are circular to oval structures which have rock layers occurring in age-position contexts which are the same as anticlines and synclines, respectively.

9. Circular structures

- dome
- basin

Dome or basin?

Dome!
3. Basic deformation structures

Other features

- joints
- fault breccia
- mylonite
Deformation, Mountain Building, and the Continents

A mountain is an area of land that stands at least 300 meters above the surrounding country and has a restricted summit area.

A mountain range is a group of linear peaks and ridges that formed together.

A mountain system is a complex group of linear peaks and ridges that is composed of several mountain ranges. Mountain systems are the result of plate movements and interactions along plate boundaries.

The Tetons Range is part of the Rocky Mountain system. The Smoky Mountains are a range in the Appalachian mountain system.

Mountain Building

Mountain building can involve faulting and folding, but can arise without these types of deformation.

Ways mountain form
- Volcanism
- Erosion
- Compression
- Block-faulting - tension

Plate Tectonics and Mountain Building

Orogeny – an episode of mountain building

Most orogenies are produced along convergent plate boundaries where one plate is subducted beneath another or where two continents collide.

Orogenies are accompanied by the emplacement of batholiths, metamorphism and thickening of the Earth’s crust.

Sedimentary rocks that formed in marine environments are often found emplaced high in the mountains as a result of orogenies.

Orogenies are also closely associated with
- Mass Wasting, including land-slides
- Glaciers
- Running Water

Erosion is responsible for carving the most majestic peaks!

Orogenies at Oceanic-Oceanic Plate Boundaries

Orogenesis along oceanic-oceanic plate boundaries includes deformation, igneous activity, island arc formation, and metamorphism.
Subduction of oceanic lithosphere along an oceanic-continental plate boundary also results in orogeny.

Mountain systems such as the Himalayas occur within continents, distant from present plate boundaries as the result of continent-continent collisions and suturing.

Orogenesis & Origin of Mountains
- Continent – continent collision...
  - Creates a broad welt of crustal thickening.
  - Thickening due to thrust faulting and flow folding.
  - Center of belt consists of high-grade metamorphic rocks.
  - Fold and thrust belts extend outward on either side.
  - The resulting high mountains may eventually collapse.

Terranes and the Origin of Mountains
- Continental accretion – a process of adding material to a continent
  - Includes preexisting crust, as well as new plutons and volcanic rocks.
  - Terranes are exotic pieces, fragments of seamounts or small pieces of continents that get transported on the plates.
  - Common along convergent oceanic-continental plate boundaries

Orogenesis & Origin of Mountains
- Island fragments of continental lithosphere may be carried into trenches but they won’t subduct.
- These blocks are added to the overriding plate.
- These exotic terranes have geologic histories unlike surrounding rocks.

Earth’s Continental Crust
- Continental crust is less dense and much thicker than oceanic crust.
  - This helps explain why mountains on land stand higher on continents than in ocean basins.
- Floating continents?
  - Gravity allows the continents to float
  - A gravimeter detects gravity anomalies.
**Earth’s Continental Crust**

- **Principle of Isostacy** – Earth’s crust floats in the denser mantle.

- **Airy and Pratt’s Models**
  - Airy stated that mountains have a low density root that allows them to project both far above and far below the surface.
  - Pratt stated that mountains are high because they are less dense than the adjacent rocks (like the mantle and the ocean crust).
  - Both models explain the behavior of the crust.

**Isostacy**

- Surface elevation represents a balance between forces.
  - Gravitational attraction – Pushes plate into the mantle.
  - Buoyancy – Causes plate to float higher on the mantle.
- The term isostatic equilibrium describes this balance.
- Isostacy is compensated after a disturbance.
  - Adding glacial ice pushes lithosphere down.
  - Melting glacial ice causes isostatic rebound.
  - Eroding rock from an orogenic belt results in rebound.
- Compensation is slow, requiring asthenospheric flow.

**Origin of the Himalayas and Isostacy**

- Isostatic Rebound – When glaciers melt or mountains erode away, the crust rises back up to its equilibrium level.
  - Rebound occurs slowly.
  - The ice sheets that covered Alaska and most of Europe 10,000 years ago have melted away but the continents are still rebounding!
  - Scandinavia is rebounding at about 1 meter every century, Alaska is rebounding at about 5 meters every 10 years!