1 ***Crustal Deformation***

Earth, Chapter 10

2 **Crustal deformation: summary in haiku form**

Anticline and syn-
normal, reverse, strike-slip faults
all a big crack-up!

3 **What Causes Rock to Deform?**

- Deformation is a general term that refers to all changes in the shape or position of a rock body in response to stress
- Rock or geologic structures are the features that result from forces generated by the interactions of tectonic plates
  - Includes folds, faults, and joints

4 **What Causes Rock to Deform?**

- Stress: The Force That Deforms Rocks
  - Stress is the force that deforms rocks
    - When stresses acting on a rock exceed its strength, the rock will deform by flowing, folding, fracturing, or faulting
    - The magnitude is a function of the amount of force applied to a given area

5 **What Causes Rock to Deform?**

- Stress: The Force That Deforms Rocks
  - Stress applied uniformly in all directions is confining pressure
  - Stress applied unequally in different directions is called differential stress

6 **What Causes Rock to Deform?**

- Stress: The Force That Deforms Rocks
  - Types of stress
    - Compressional stress squeezes a rock and shortens a rock body
    - Tensional stress pulls apart a rock unit and lengthens it
    - Shear stress produces a motion similar to slippage that occurs between individual playing cards when the top of the stack is moved relative to the bottom

7 **What Causes Rock to Deform?**

- Strain: A Change in Shape Caused by Stress
  - Strain is the change in shape of a rock caused by differential stress
  - Strained bodies lose their original configuration during deformation

    -

8 **Deformed Trilobite**

9 **How Do Rocks Deform?**

- Elastic, Brittle, and Ductile Deformation
  - Elastic deformation: The rock returns to nearly its original size and shape when the stress is removed
  - Once the elastic limit (strength) of a rock is surpassed, it either bends (ductile deformation) or breaks (brittle deformation)

10 **Rocks Exhibiting Ductile Deformation**

11 **How Do Rocks Deform?**

- Factors That Affect Rock Strength
  - Temperature: Higher temperature rocks deform by ductile deformation whereas cooler rocks deform by brittle deformation
  - Confining pressure: Confining pressure squeezes rocks, making them stronger and harder to break

12 **How Do Rocks Deform?**

- Factors That Affect Rock Strength

    - Rock type: Crystalline igneous rocks generally experience brittle deformation, whereas sedimentary and metamorphic rocks with zones of weakness generally experience ductile deformation
    - Time: Forces applied over a long period of time generally result in ductile deformation

13 **How Do Rocks Deform?**

- Ductile Versus Brittle Deformation and the Resulting Rock Structures
    - Most rocks exhibit brittle behavior in the upper 10 kilometers of the crust
        - Joints are cracks in the rocks resulting from the rock being stretched and pulled apart
        - Faults are fractures in the rocks where rocks on one side of the fault are displaced relative to the rocks on the other side of the fault

14 **How Do Rocks Deform?**

- Ductile Versus Brittle Deformation and the Resulting Rock Structures
    - Folds are evidence that rocks can bend without breaking
        - Usually the result of deformation in high-temperature and pressure environments

15 **Deformation Caused by Three Types of Stress**

16 **Folds: Rock Structures Formed by Ductile Deformation**

- During crustal deformation, rocks are often bent into a series of wave like undulations called folds
- Characteristics of folds
    - Most folds result from compressional stresses that result in a shortening and thickening of the crust

17 **Folds: Rock Structures Formed by Ductile Deformation**

- Anticline and Synclines
    - Anticlines are upfolded or arched sedimentary layers
        - Oldest strata are in the center
    - Synclines are downfolded or troughs of rock layers
        - Youngest strata are in the center

18 **Folds: Rock Structures Formed by Ductile Deformation**

- Anticline and Synclines
    - Depending on their orientation, anticlines and synclines can be described as:
        - Symmetrical—the limbs of the fold are mirror images of each other
        - Asymmetrical—the limbs of the fold are not identical
            - Overturned (recumbent)—one or both limbs are tilted beyond vertical
            - Plunging—the axis of the fold penetrates the ground

19 **Common Types of Folds**

20 **Plunging Anticline**

21 **A horizontal (A) and plunging (B) anticline**

22 **A series of anticlines and synclines**

23 **Folding**

24 **Plunging anticlines and synclines**

25 **Sheep Mountain anticline, Wyoming**

26 **Folds: Rock Structures Formed by Ductile Deformation**

- Domes and Basins
    - Domes are upwarped circular features
        - Oldest rocks are in the center
    - Basins are downwarped circular features

    - Youngest rocks are in the center

27 **Black Hills, South Dakota: a large dome**

28 **Circular outcrop patterns are typical for both domes and basins**

29 **Domes Versus Basins**

30 **Domes Versus Basins**

31 **Folds: Rock Structures Formed by Ductile Deformation**

- Monoclines
  - Monoclines are large, steplike folds in otherwise horizontal sedimentary strata
    - As blocks of basement rocks are displaced upward, the ductile sedimentary strata drape over them

32 **The East Kaibab Monocline, Arizona**

33 **Monoclines are often the result of movement along buried faults**

34 **My favorite monocline:**

35 **Image from WorldWind software:**

36 **Topo map:**

37 **Faults and Joints: Rock Structures Formed by Brittle Deformation**

- Faults are fractures in rocks, along which displacement has occurred
- Sudden movements along faults are the cause of most earthquakes
- Polished, smooth surfaces, called slickensides, provide evidence for direction of movement along the fault

38 **Slickensides**

39 **Faults and Joints: Rock Structures Formed by Brittle Deformation**

- Dip-Slip Faults
  - Dip-slip faults occur when movement is parallel to the inclination
    - The hanging wall is rock surface above the fault
    - The footwall is the rock surface below the fault
  - The vertical displacement along the fault produces long, low cliffs called fault scarps

40 **Hanging Wall Block and Footwall Block**

41 **Faults and Joints: Rock Structures Formed by Brittle Deformation**

- Dip-Slip Faults
  - Normal faults are characterized by the hanging wall moving down relative to the footwall
    - Associated with tensional stress as the rocks pull apart
  - Larger scale normal faults are associated with fault-block mountains
    - Example: Basin and Range Province
    - Uplifted blocks are called horsts
    - Down-dropped blocks are called grabens

42 **Normal Faulting in the Basin and Range Province**

43 **Faults and Joints: Rock Structures Formed by Brittle Deformation**

- Dip-Slip Faults
  - Fault Block Mountains
    - Half-grabens are tilted fault blocks
    - Detachment faults represent the boundary between ductile and brittle rock units

44 **Faults and Joints: Rock Structures Formed by Brittle Deformation**

- Dip-Slip Faults
  - Reverse faults are characterized by the hanging wall moving up relative to the footwall

        - Associated with compressional stress as the crust shortens
    - Thrust faults have an angle less than 45º, so the overlying plate moves almost horizontally
        - Most pronounced along convergent plate boundaries
        - Example: Glacier National Park

45 **Faults**

46 **Normal fault:**

47 **On a reverse fault, the hanging wall moves up relative to the footwall**

48 **Thrust fault: Lewis Thrust, Montana**

49 **Types of Dip-Slip Faults**

50 **Faults and Joints: Rock Structures Formed by Brittle Deformation**

- Strike-slip faults are characterized by placement that is horizontal and parallel to the strike of the fault
    - Types of strike-slip faults
        - Right-lateral—As you face the fault, the opposite side of the fault moves to the right
        - Left-lateral—As you face the fault, the opposite side of the fault moves to the left

51 **Aerial View of a Strike Slip Fault**

52 **Faults and Joints: Rock Structures Formed by Brittle Deformation**

- Strike-Slip Faults
    - Large strike-slip faults that cut through the crust to accommodate plate motion are called transform faults

53 **The Alpine Fault, New Zealand**

54 **A block diagram showing the features along a strike-slip fault**

55 **The San Andreas fault <u>system</u> is a major transform fault**

56 **Faults and Joints: Rock Structures Formed by Brittle Deformation**

- Oblique-slip faults exhibit both a strike-slip and a dip-slip movement
- Joints are fractures in a rock where there has been no rock movement
    - Most joints appear in parallel groups

57 **Oblique-Slip Faults**

58 **Parallel Joints**

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63 **Mapping Geologic Structures**

- A geologist identifies and describes the dominant rock structures in a region
    - Using a limited number of outcrops (sites where bedrock is exposed at the surface)
    - Work is aided by aerial photography, satellite imagery, global positioning systems (GPS), and seismic reflection profiling

64 **Mapping Geologic Structures**

- Strike and Dip
    - Sedimentary rocks that are inclined or bent indicate that the layers were deformed following deposition
        - Strike
            - The compass direction of the line produced by the intersection of an inclined rock layer or fault with a horizontal plane
            - Generally expressed as an angle relative to north
            -

65 **Mapping Geologic Structures**

- Strike and Dip
  - Dip
    - The angle of inclination of the surface of a rock unit or fault measured from a horizontal plane
    - Includes both an inclination and a direction toward which the rock is inclined
      -

66 **Strike and Dip of Rock Layers**

67 ***A geologic map illustrates the geologic structures of an area***

68 ***Strike and dip of a rock layer***

69