

1 2  **Mountain Building**

- Mountain building has occurred during the recent geologic past
 - American Cordillera
 - The Alpine–Himalaya chain
 - The mountainous terrains of the western Pacific
- Several other chains are Paleozoic in age
 - The Appalachians
 - The Urals in Russia
 - These mountains are deeply eroded and topographically less prominent

3 **Earth's Major Mountain Belts**4 **Mountain Building**

- Orogenesis
 - The process that collectively produces a mountain belt
 - Mountains that display faulted and folded rocks are compressional mountains
 - Display visual evidence of compressional forces
 - Including metamorphism and some igneous activity
 - Plate tectonics provides a model for orogenesis
 - Earth's major mountains have formed along convergent plate boundaries

5 **Mount Kidd, Alberta, Canada**6 **Convergence and Subducting Plates**

- Major Features of Subduction Zones
 - Volcanic arc
 - Deep-ocean trench
 - Forearc region
 - Back-arc region

7 **Convergence and Subducting Plates**

- Volcanic Arcs
 - The subducting slab partially melts the overlying mantle wedge
 - Melt migrates upward through the overlying oceanic lithosphere and forms a growth called a volcanic island arc or island arc
 - When the melt migrates through continental lithosphere, a continental volcanic arc is created

8 **Development of a Volcanic Island Arc**9 **Convergence and Subducting Plates**

- Deep Ocean Trenches
 - Created when oceanic lithosphere bends as it descends into the mantle
 - Trench depth is related to the age of the subducting lithosphere
 - Old lithosphere is cold and dense
 - Plates subduct at a steep angle, producing a deep trench
 - Young lithosphere is warm and buoyant
 - Plates subduct at a shallower angle and produce shallower trenches (if at all)

10 **Convergence and Subducting Plates**

- Forearc and Back-Arc Regions
 - The forearc region is the area *between* the trench and the volcanic arc
 - The back-arc region is located on the side of the volcanic arc *opposite the trench*
 - Both regions consist of accumulated pyroclastic material and eroded sediments
 - Tensional forces prevalent in these regions, causing stretching


11 **Convergence and Subducting Plates**

- Extension and Back-Arc Spreading
 - Two plates converging, but not necessarily dominated by compressional forces
 - When the subducting plate is cold, the plate sinks vertically as it descends along an

angled path

- This causes the trench to “roll back” away from the overlying plate
 - Consequently, the overlying plate is *stretched*

– Tension and thinning may initiate seafloor spreading, enlarging the back-arc basin

12  **Formation of a Back-Arc Basin**

13  **Subduction and Mountain Building**

- Island Arc-Type Mountain Building
 - Results from the steady subduction of oceanic lithosphere
 - Continued growth can result in topography consisting of parallel belts of igneous and metamorphic rocks
 - Just one phase in the development of mountain belts


14  **Subduction and Mountain Building**

- Andean-Type Mountain Building
 - Subduction beneath a continent rather than oceanic lithosphere
 - Associated with long-lasting magmatic activity and crustal thickening
 - Exemplified by the Andes Mountains
 - Starts with a *passive continental margin*
 - Thick platform of shallow-water sedimentary rocks
 - Eventually, the forces that drive plate tectonics change direction and a subduction zone forms
 - Oceanic lithosphere must be dense enough to sink


15  **Andean-Type Mountain Building**

16  **Subduction and Mountain Building**

- Andean-Type Mountain Building
 - Building volcanic arcs
 - As crustal rocks descend, water and volatiles are driven from the crustal rocks into the overlying mantle wedge
 - These volatiles trigger the partial melting of ultramafic peridotite
 - Generates mafic *primary magmas* which rise through the mantle wedge
 - Magmas pool at the base on the continental crust
 - Magmatic differentiation creates less dense magmas that rise through the crust

17  **Subduction and Mountain Building**

- Andean-Type Mountain Building
 - Emplacement of batholiths
 - Thick continental crust impedes the ascent of magma
 - Most magma crystallizes underground as massive plutons called *batholiths*
 - Eventually, uplift and erosion expose the batholiths
 - Example: The Sierra Nevada in California
 - Batholiths typically range from diorites to granites

18  **Subduction and Mountain Building**

19  **Subduction and Mountain Building**

- Andean-Type Mountain Building
 - Development of an accretionary wedge
 - An accretionary wedge is the accumulated sediments and scraped upper crust of the subducting plate plastered against the edge of the overriding plates
 - Similar to soil and sediments being pushed by a bulldozer
 - Prolonged subduction may thicken an accretionary wedge enough so that it protrudes above sea level
 - Forearc basin
 - The accretionary wedge acts as a barrier to sediment movement from the volcanic arc to the trench
 - The region of relatively undeformed layers of sediment and sedimentary rock is called a

forearc basin

20  **Subduction and Mountain Building**

- The Sierra Nevada, Coast Ranges, and Great Valley
 - One of the best examples of features associated with an Andean-type subduction zone
 - Features produced by the subduction of the Farallon Plate (part of the Pacific basin) under the western margin of California

21  **Subduction and Mountain Building**

22  **Collisional Mountain Belts**


- Cordilleran-Type Mountain Building
 - Associated with the Pacific Ocean
 - Highly likely that subduction zones will form island arcs which will eventually collide with a continental crust
 - The collision and accretion of small slivers of continental crust form the mountainous regions that rim the Pacific
 - Terranes (crustal fragments of exotic material) make up much of the western United States
 - The nature of terranes
 - Prior to accretion onto the continent, some terranes were microcontinents (similar to Madagascar)
 - Other terranes were island arcs (similar to Japan)

23  **Collision and Accretion of Small Crustal Fragments to a Continental Margin**


24  **Collision and Accretion of Small Crustal Fragments to a Continental Margin**

25  **Collisional Mountain Belts**

- Cordilleran-Type Mountain Building
 - Accretion and orogenesis
 - Small features on the ocean floor are subducted with the plate
 - Large, buoyant features do not subduct
 - These features are *peeled off* the subducting plate and accreted onto the continental crust
 - Subduction continues on the other side of the crustal fragment
 - The North American Cordillera
 - Many terranes that make up the North American Cordillera were scattered through the eastern Pacific
 - During the breakup of Pangaea, the Farallon plate began to subduct under North America
 - Resulted in the piecemeal addition of crustal fragments to the western side of North America


26  **Collisional Mountain Belts**


- Alpine-Type Mountain Building: Continental Collisions
 - Named for the Alps—two continental masses collide
 - The zone where two continents collide is called a suture
 - Typically contains slivers of oceanic lithosphere
 - May also include accreted terrane
 - Most compressional mountains exhibit the deformation of a thick sequence of sedimentary rocks called a fold-and-thrust belt

27  **Collisional Mountain Belts**

- The Himalayas
 - Collision began about 50 million years ago
 - India collided with Asia following the subduction of oceanic lithosphere
 - As Pangea fragmented, India moved rapidly northward
 - Following the closing of the ocean basin, India “docked” into Eurasia

- Precambrian rocks of India resisted deformation while the younger crustal fragments of southeast Asia were highly deformed
- Followed by a period of uplift that raised the Tibetan Plateau

28  **Continental Collision, the Formation of the Himalayas**

29  **Collisional Mountain Belts**


- The Himalayas
 - India is still moving northward
 - Crust is shortening and thickening, accommodating some of this movement
 - Much of the remaining penetration into Asia caused lateral displacement of large blocks of the Asian crust by *continental escape*
 - The thick, cold slab of India has stayed essentially intact

30  **Continental Collision, the Formation of the Himalayas**

31  **Continental Collision, the Formation of the Himalayas**


32  **Collisional Mountain Belts**

- The Appalachians
 - Of a similar origin to the mountains in the British Isles, Scandinavia, northwest Africa, and Greenland
 - Formed from three main orogenic events that cumulated with the formation of Pangaea
 - *Taconic Orogeny*
 - Volcanic arc located east of North America was thrust over the continental block 450 million years ago
 - The volcanic rocks and marine sedimentary rocks were metamorphosed and are exposed in New York

33  **Formation of the Appalachian Mountains**

34  **Collisional Mountain Belts**

- The Appalachians
 - *Acadian Orogeny*
 - Continued closing of the ocean basin resulted in a micro-continent colliding with North America 350 million years ago
 - Thrust faults, metamorphism, and granite intrusions are associated with this event
 - Substantially added to the width of North America
 - *Alleghanian Orogeny*
 - Africa collided with North America 250–300 million years ago
 - Material was displaced 250 km inland on North America
 - Pangaea began rifting 180 million years ago
 - Rift was eastward of the suture, leaving a remnant of Africa welded to North America

35  **Formation of the Appalachian Mountains**

36  **Formation of the Appalachian Mountains**

37  **Fault-Block Mountains**

- Continental rifting can produce uplift and the formation of mountains known as fault-block mountains
 - Example: The Tetons of Wyoming

38  **Fault-Block Mountains**

- The Basin and Range Province
 - One of the largest regions of fault-block mountains on Earth
 - Located between the Sierra Nevada and the Rocky Mountains
 - Extends N–S roughly 3000 km, encompasses all of Nevada, portions of surrounding states, and a large part of New Mexico
 - Tilting of faulted structures, called half-grabens, has produced nearly parallel mountain

ranges that average 80 km in length

– Extension beginning 20 million years ago has stretched the crust twice its original width

39  **The Basin and Range Province**

40  **Fault-Block Mountains**


- The Basin and Range Province

– Two different theories of formation

- Following the subduction of the Farallon plate, the northwest movement of the Pacific plate produced tensional forces that have stretched the region

- 20 million years ago, the lower lithospheric mantle decoupled from the crust beneath the region

- This *delamination* resulted in the upwelling and lateral spreading of hot mantle rocks, producing tensional forces in the crust

41  **Model for the Formation of the Basin and Range Province**

42  **What Causes Earth's Varied Topography?**

- The Principle of Isostasy

- Less dense crust floats on top of the denser rocks of the mantle

- Isostasy is the concept of floating crust in gravitational balance


- Envision a series of different-sized floating blocks on water

– How is isostasy related to changes in elevation?

- If weight is added or removed from the crust, isostatic adjustment will take place as the crust subsides or rebounds

- Crustal rebound is present in Canada's Hudson Bay region following the melting of ice sheets in that region

43  **The Principle of Isostasy**

44  **Isostasy and Changes in Elevation**

45  **What Causes Earth's Varied Topography?**

- The Principle of Isostasy

– How high is too high?

- As mountains grow, gravity acts on the warm and weak rocks inside the mountains

- Eventually, the gravitational forces are so large that these rocks will flow laterally

- This ductile spreading and consequential subsidence is called gravitational collapse

46  **Gravitational Collapse**

47  **What Causes Earth's Varied Topography?**

- Mantle Convection: A Cause of Vertical Crustal Movement

– Uplifting whole continents

- Mantle plumes (*superplumes*) can elevate a region on continental crust

- Southern Africa has large-scale vertical motion

- Elevation is nearly 1500 m higher than would be expected for a stable craton

48  **What Causes Earth's Varied Topography?**

- Mantle Convection: A Cause of Vertical Crustal Movement

– Crustal subsidence

- Extensive areas of downwarping

- The slabs of oceanic lithosphere will detach from the trailing lithosphere

- A downward flow is created as the detached slab continues to sink, pulling down the crust into a basin structure

- Example: nearly circular basins in Michigan and Illinois

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End of Chapter 14