1

2 ***Chapter 14 – Convergent Boundaries***

3 **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

4 **Earth's Major Mountain Belts**

5 **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

6 **Mount Kidd, Alberta, Canada**

7 **Convergence and Subducting Plates**

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

8 **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

9 **Development of a Volcanic Island Arc**

10 **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)

11 **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

12 **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

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

14 **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

15 **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

16 **Andean-Type Mountain Building**

17 **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

18 **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

19 **Subduction and Mountain Building**

20 **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

21 **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

22 **Subduction and Mountain Building**

23 **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)

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

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

26 **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

27 **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

28 **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

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

30 **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

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

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

33 **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

34 **Formation of the Appalachian Mountains**

35 **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

36 **Formation of the Appalachian Mountains**

37 **Formation of the Appalachian Mountains**

38 **Fault-Block Mountains**

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

39 **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

40 **The Basin and Range Province**

41 **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

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

43 **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

44 **The Principle of Isostasy**

45 **Isostasy and Changes in Elevation**

46 **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

47 **Gravitational Collapse**

48 **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

49 **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