1 ***Mountain Building and the Evolution of Continents***

Earth, 9th Edition, Chapter 14

2 **Convergent Boundaries: summary in haiku form**

Continents collide -
India bumps into Asia
slow-motion train wreck.

3 ***Key Concepts***

- "Orogenesis" -- the process of building mountains.
- Convergence and subducting plates: Subduction zones.
- Subduction and mountain-building.
- Collisions of continental crust: Compressional mountain-building processes.
- Non-compressional mountain-building processes.
- The origin and evolution of the continents.

4 ***Mountain building***

- Mountain building has occurred during the recent geologic past (and continues!)
  - American Cordillera – the western margin of the Americas from Cape Horn to Alaska which includes the Andes and Rocky Mountains
  - Alpine-Himalayan chain
  - Mountainous terrains of the western Pacific

5 ***Mountain building***

- Older Paleozoic- and Precambrian-age mountains
  - Appalachians
  - Urals in Russia
- *Orogenesis* – the processes that collectively produce a mountain belt
  - Includes folding, thrust faulting, metamorphism, and igneous activity

6 ***Mountain building***

- *Orogenesis* (continued…)
  - Compressional forces producing folding and thrust faulting
  - Metamorphism
  - Igneous activity

7 ***Mountain building***

- Several hypotheses have been proposed for the formations of Earth's mountain belts
  - With the development of plate tectonics it appears that most mountain building occurs at convergent plate boundaries

8 ***Earth's Major Mountain Belts***

9 ***Plate Boundary Features***

10 ***Convergence and subducting plates***

- Major features of subduction zones
  - Deep-ocean trench – region where subducting oceanic lithosphere bends and descends into the asthenosphere
  - Volcanic arc – built upon the overlying plate
    - Island arc if on the ocean floor or
    - Continental volcanic arc if oceanic lithosphere is subducted beneath a continental block

11 ***Convergence and subducting plates***

- Major features of subduction zones
  - Forearc region is the area between the trench and the volcanic arc
  - Backarc region is located on the side of the volcanic arc opposite the trench

12 ***Convergence and subducting plates***
- Dynamics at subduction zones
  - Extension and backarc spreading
    - As the subducting plate sinks in creates a flow in the asthenosphere that pulls the upper plate toward the trench
    - Tension and thinning may produce a backarc basin
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13 ***Convergence and subducting plates***
- Dynamics at subduction zones
  - Compressional regimes
    - Occurs when the overlying plate advances towards the trench faster than the trench is retreating due to subduction
    - The resulting compressional forces shorten and thicken the crust

14 ***Subduction and mountain building***
- Island arc mountain building
  - Where two ocean plates converge and one is subducted beneath the other
  - Volcanic island arcs result from the steady subduction of oceanic lithosphere
    - Continued development can result in the formation of mountainous topography consisting of igneous and metamorphic rocks

15 **Volcanic island arc**

16 ***Figure 14.5***

17 ***Subduction and mountain building***
- Andean-type mountain building
  - Mountain building along continental margins
  - Involves the convergence of an oceanic plate and a plate whose leading edge contains continental crust
    - Exemplified by the Andes Mountains

18 ***Subduction and mountain building***
- Andean-type mountain building
    - Building a volcanic arc
      - Subduction and partial melting of mantle rock generates primary magmas
      - Magma is less dense than surrounding rock so it begins to rise buoyantly
      - Differentiation of magma produces andesitic volcanism dominated by pyroclastics and lavas
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19 ***Subduction and mountain building***
- Andean-type mountain building
  - Development of an accretionary wedge
    - An accretionary wedge is a chaotic accumulation of deformed and thrust-faulted sediments and scraps of oceanic crust
    - Prolonged subduction may thicken an accretionary wedge enough so it protrudes above sea level
    - Descending sediments are metamorphosed into a suite of high-pressure, low-temperature minerals

20 ***Passive Continental Margin***

21 ***Subduction and mountain building***
- Andean-type mountain building
  - Forearc basin
    - The growing accretionary wedge acts as a barrier to sediment movement from the arc to the trench

- This region of relatively undeformed layers of sediment and sedimentary rock is called a forearc basin

22 ***Subduction Zone Created***

23 ***Subduction and mountain building***

- Sierra Nevada and Coast Ranges
  - One of the best examples of an active Andean-type orogenic belt
  - Subduction of the Pacific Basin under the western edge of the North American plate
  - Sierra Nevada batholith is a remnant of a portion of the continental volcanic arc
  - Franciscan Formation of California's Coast ranges constitutes the accretionary wedge
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24 ***Subduction Ends***

25 ***Subduction and mountain building***

- Andean-type mountain building
  - Emplacement of plutons
    - Thick continental crust impedes the ascent of magma
    - A large percentage of the magma never reaches the surface and is emplaced as plutons
    - Uplift and erosion exposes these massive structures called batholiths (i.e., Sierra Nevada in California and Peruvian Andes)
    - Batholiths are typically intermediate to felsic compositions

26

27 ***Continental collisions***

- Two lithospheric plates, both carrying continental crust
  - Continental collisions result in the development of compressional mountains that are characterized by shortened and thickened crust
  - Most compressional mountains exhibit a region of intense folding and thrust faulting called a fold-and-thrust-belt
  - The zone where the two continents collide is called the suture

28 ***Convergent Margins: India-Asia Collision***

29 ***Continental collisions***

- Himalayan Mountains
  - Youthful mountains – collision began about 45 million years ago
  - India collided with Eurasian plate
  - Similar but older collision occurred when the European continent collided with the Asian continent to produce the Ural mountains

30 ***Figure 14.9A***

31 ***Figure 14.9B***

32 ***Continental collisions***

- Appalachian Mountains
  - Formed long ago and substantially lowered by erosion
  - Resulted from a collision among North America, Europe, and northern Africa
  - Final orogeny occurred about 250 million to 300 million years ago
    -
    -

33 ***Continental collisions***

- Compressional mountain belts have several major events
  - After the breakup of a continental landmass, a thick wedge of sediments is deposited along the passive continental margin
  - Due to a change in the direction of plate motion the ocean basin begins to close and continents converge

34 ***Figure 14.12A,B***

35 ***Figure 14.12B,C***

36 ***Figure 14.12C,D***

37 ***Figure 14.12D,E***
38 ***Major Structural Features of the Appalachian Mountains***
39 ***Valley and Ridge Province***
40 ***Valley & Ridge (close-up)***
41 ***Continental collisions***
- Compressional mountain belts have several major events
  - Plate convergence, subduction of the intervening oceanic slab, extensive igneous activity
  - Continental blocks collide
  - A change in the plate boundary ends the growth of mountains

42 ***Terranes and mountain building***
- Another mechanism of orogenesis
- The nature of terranes
  - Small crustal fragments collide and merge with continental margins
  - Accreted crustal blocks are called terranes (any crustal fragments whose geologic history is distinct from that of the adjoining terranes)

43 ***Terranes and mountain building***
- The nature of terranes
  - Prior to accretion some of the fragments may have been micro-continents
  - Others may have been island arcs, submerged crustal fragments, extinct volcanic islands, or submerged oceanic plateaus

44 ***Terrane Formation***
45 ***Terranes and mountain building***
- Accretion and orogenesis
  - As oceanic plates move they carry embedded oceanic plateaus, island arcs, and micro-continents to Andean-type subduction zones
  - Thick oceanic plates carrying oceanic plateaus or “lighter” igneous rocks of island arcs may be too buoyant to subduct

46 ***Terranes and mountain building***
- Accretion and orogenesis
  - Collision of the fragments with the continental margin deforms both blocks adding to the zone of deformation and to the thickness of the continental margin
  - Many of the terranes found in the North American Cordillera were once scattered throughout the eastern Pacific

47 ***Terranes added to North America in the last 200 Ma***
48 ***Fault-block mountains***
- Continental rifting can produce uplift and the formation of mountains known as fault-block mountains
  - Fault-block mountains are bounded by high-angle normal faults that flatten with depth
  - Examples include the Sierra Nevada of California and the Teton Range of Wyoming

49 ***Sierra Nevada***
50 ***Fault-block mountains***
- Basin and Range province
  - One of the largest regions of fault-block mountains on Earth
  - Tilting of these faulted structures 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

51 ***The Teton Range***
52 ***Extension in the Basin & Range Province***
53 ***Fault-block mountains***
- Basin and Range province
  - High heat flow and several episodes of volcanism provide evidence that mantle upwelling caused doming of the crust and subsequent extension

- 54 ***Figure 14.18***
- 55 ***Figure 14.18A***
- 56 ***Figure 14.18B***
- 57 ***Figure 14.18C***
- 58 ***Figure 14.18D***
- 59 ***The Basin and Range Province***
- 60 ***Vertical movements of the crust***
  - Isostasy
    - Less dense crust floats on top of the denser and deformable rocks of the mantle
    - Concept of floating crust in gravitational balance is called isostasy
    - If weight is added or removed from the crust, isostatic adjustment will take place as the crust subsides or rebounds
- 61 ***The principle of isostasy***
- 62 ***Figure 14.D***
- 63 ***Vertical movements of the crust***
  - Vertical motions and mantle convection
    - Buoyancy of hot rising mantle material accounts for broad upwarping in the overlying lithosphere
    - Uplifting whole continents
      - Southern Africa
      - Crustal subsidence - regions once covered by ice during the last Ice Age
- 64 ***Figure 14.21A***
- 65 ***Figure 14.21B***
- 66 ***Figure 14.21C***
- 67 ***Origin & evolution of continental crust***
  - How continents grow
    - Most continental growth occurs along convergent plate boundaries
    - Most researchers agree that the volume of continental crust has increased over time
- 68 ***Origin & evolution of continental crust***
  - Early evolution of the continents model
    - One proposal is that continental crust formed early in Earth's history
      - Chemical differentiation resulted in less dense, silica-rich constituents of the mantle forming a "scum" of continental-type rocks
      - Shortly after chemical differentiation, continental crust was reworked and recycled by a mechanism similar to plate tectonics
- 69 ***Origin & evolution of continental crust***
  - Early evolution of the continents model
    - Total volume of continental crust has not changed appreciably since its origin
- 70 ***Origin & evolution of continental crust***
  - Gradual evolution of the continents model
    - Continents have grown larger through geologic time by the gradual accretion of material derived from the upper mantle
    - Earliest continental rocks came into existence at a few isolated island arcs
- 71
- 72 **End of Chapter**