Mountain Building and the Evolution of Continents

Earth, 9th Edition, Chapter 14

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.

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

- 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

Mountain building (continued…)

- Compressional forces producing folding and thrust faulting
- Metamorphism
- Igneous activity

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

Earth’s Major Mountain Belts

Plate Boundary Features

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

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

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

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

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

Volcanic island arc

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

Subduction and 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

Subduction and 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

Passive Continental Margin

Subduction and 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

Subduction Zone Created

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

Subduction Ends

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

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

Convergent Margins: India-Asia Collision

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

Figure 14.9A
Figure 14.9B

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

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

Figure 14.12A,B
Figure 14.12B,C
Figure 14.12C,D
Figure 14.12D,E

Major Structural Features of the Appalachian Mountains

Valley and Ridge Province
Valley & Ridge (close-up)
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

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)

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

Terrane Formation
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

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

Terranes added to North America in the last 200 Ma
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

Sierra Nevada
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

The Teton Range
Extension in the Basin & Range Province
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

Figure 14.18
Figure 14.18A
Figure 14.18B
The Basin and Range Province

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

The principle of isostasy

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

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

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

Origin & evolution of continental crust

- Early evolution of the continents model
  - Total volume of continental crust has not changed appreciably since its origin

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

End of Chapter