1 *Divergent Boundaries: Origin and Evolution of the Ocean Floor*

Earth, 9th Edition, Chapter 13

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

Undersea mountains
forty-some thousand miles long
nothing but basalt.

3 ***Key Concepts***

- The nature of the ocean floor.
- Continental margins.
- Deep-ocean basins.
- Oceanic crust, oceanic lithosphere and oceanic ridges.
- Continental rifting: Creation of new ocean basins.
- Destruction of oceanic lithosphere and the "supercontinent cycle."

4 **Mapping the ocean floor**

- Depth was originally measured by lowering weighted lines overboard
- Echo sounder (also referred to as sonar)
  - Invented in the 1920s
  - Primary instrument for measuring depth
  - Reflects sound from ocean floor

5 **Mapping the ocean floor**

- Multibeam sonar
  - Employs an array of sound sources and listening devices
  - Obtains a profile of a narrow strip of seafloor

6 **Echo sounder (A) and multibeam sonar (B)**

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8 **Mapping the ocean floor**

- Viewing the ocean floor from space
  - Satellites use radar altimeters to measure subtle differences of the ocean surface
  - Small variations reflect the gravitational pull of features on the seafloor

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10 **View from space (sort of…)**

11 **Mapping the ocean floor**

- Three major provinces of the ocean floor
  - Continental margins
  - Deep-ocean basins
  - Oceanic (mid-ocean) ridges

12 **Major topographic divisions of the north Atlantic Ocean**

13 **Continental margins**

- Passive continental margins
  - Found along most coastal areas that surround the Atlantic ocean
  - Not associated with plate boundaries
  - Experience little volcanism and few earthquakes

14 **Continental margins**

- Features comprising a passive continental margin
  - Continental shelf

    - Flooded extension of the continent
    - Varies greatly in width
    - Gently sloping
    - Contains important mineral deposits
    - Some areas are mantled by extensive glacial deposits
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15 **Continental margins**
- Features comprising a passive continental margin
  - Continental slope
    - Marks the seaward edge of the continental shelf
    - Relatively steep structure
    - Boundary between continental crust and oceanic crust

16 **Continental margins**
- Features comprising a passive continental margin
  - Continental rise
    - Found in regions where trenches are absent
    - Continental slope merges into a more gradual incline – the continental rise
    - Thick accumulation of sediment
    - At the base of the continental slope turbidity currents deposit sediment that forms deep-sea fans

17 **A passive continental margin**

18 **Continental margins**
- Active continental margins
  - Continental slope descends abruptly into a deep-ocean trench
  - Located primarily around the Pacific Ocean
  - Accumulations of deformed sediment and scraps of ocean crust form accretionary wedges

19 **Active continental margin**

20 **Submarine canyons & turbidity currents**
- Submarine canyons
  - Deep, steep-sided valleys cut into the continental slope
  - Some are extensions of river valleys
  - Most appear to have been eroded by turbidity currents

21 **Submarine canyons & turbidity currents**
- *Turbidity currents*
  - Downslope movements of dense, sediment-laden water
  - Deposits are called *turbidites*
  - Turbidites are layered and exhibit graded bedding (decrease in sediment grain size from bottom to top)

22 **Submarine canyons are eroded by turbidity currents**

23 ***Seafloor Spreading and Plate Boundaries***

24 **Features of the deep-ocean basin**
- Deep-ocean trench
  - Long, relatively narrow features
  - Deepest parts of ocean
  - Most are located in the Pacific Ocean
  - Sites where moving lithospheric plates plunge into the mantle
  - Associated with volcanic activity

25 **Earth's major oceanic trenches**

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27 **Features of the deep-ocean basin**
- Abyssal plains
  - Likely the most level places on Earth

- Sites of thick accumulations of sediment
- Found in all oceans

28 **Features of the deep-ocean basin**

- Seamounts
  - Isolated volcanic peaks
  - Many form near oceanic ridges
  - May emerge as an island
  - May sink and form flat-topped seamounts called guyots
  - Vast outpourings of basaltic lavas on the ocean floor create extensive volcanic structures called oceanic plateaus

29 **Anatomy of the oceanic ridge**

- Broad, linear swells along divergent plate boundaries are called oceanic ridges
  - Occupy elevated positions
  - Extensive faulting and earthquakes
  - High heat flow
  - Numerous volcanic structures

30 **Anatomy of the oceanic ridge**

- Oceanic ridge characteristics
  - Longest topographic feature on Earth's surface
    - Over 70,000 km (43,000 miles) in length
    - 20% of Earth's surface
    - Winds through all major oceans
  - Term ridge is misleading – widths of 1000 to 4000 km give the appearance of broad, elongated swells

31 **Anatomy of the oceanic ridge**

- Oceanic ridge characteristics
  - Axis of some ridge segments exhibit deep down-faulted structures called rift valleys
  - Portions of the mid-Atlantic ridge have been studied in considerable detail

32 **Distribution of the oceanic ridge system**

33 **The oceanic ridge system in our backyard**

34 **Origin of oceanic lithosphere**

- Seafloor spreading
  - Concept formulated in the early 1960s by Harry Hess
  - Seafloor spreading occurs along relatively narrow zones, called rift zones, located at the crests of ocean ridges)

35 ***Convection and Tectonics***

36 **Origin of oceanic lithosphere**

- Seafloor spreading
  - As plates move apart, magma wells up into the newly created fractures and generates new slivers of oceanic lithosphere
  - New lithosphere moves from the ridge crest in a conveyor-belt fashion
  - Zones of active rifting are 20 to 30 km wide

37 **Origin of oceanic lithosphere**

- Why are oceanic ridges elevated
  - Primary reason is because newly created oceanic lithosphere is hot and occupies more volume than cooler rocks
  - As the basaltic crust travels away from the ridge crest it is cooled by seawater
  - As the lithosphere moves away it thermally contracts and becomes more dense

38 **Origin of oceanic lithosphere**

- Spreading rates and ridge topography
  - Ridge systems exhibit topographic differences

- Topographic differences are controlled by spreading rates
  - At slow spreading rates (1-5 centimeters per year), a prominent rift valley develops along the ridge crest that is usually 30 to 50 km across and 1500 –3000 meters deep

39 ***<u>Forming a Divergent Boundary</u>***

40 **Origin of oceanic lithosphere**

- Spreading rates and ridge topography
  - Topographic differences are controlled by spreading rates
    - At intermediate spreading rates (5-9 centimeters per year), rift valleys that develop are shallow and less than 200 meters deep
    - At spreading rates greater than 9 centimeters per year no median rift valley develops and these areas are usually narrow and extensively faulted

41 **Slow spreading oceanic ridge**

42 **Fast spreading oceanic ridge**

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44 **Structure of the oceanic crust**

- Four distinct layers
  - Layer 1 – sequence of unconsolidated sediments
  - Layer 2– consisting of pillow lavas
  - Layer 3 – numerous interconnected dikes called sheet dikes
  - Layer 4 – gabbro
- sequence of rocks called an ophiolite complex

45 **Structure of the oceanic crust**

- Formation of oceanic crust
  - Basaltic magma originates from partially melted mantle peridotite
  - Molten rock injected into fractures above the magma chambers creates the sheeted dike complex
  - The submarine lava flows chill quickly and the congealed margin is forced forward to produce large tube-shaped protuberances known as pillow basalts

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48 **Structure of the oceanic crust**

- Interactions between seawater and oceanic crust
  - Seawater circulates downward through the highly fractured crust
  - Basaltic rock is altered by hydrothermal metamorphism
  - Hydrothermal fluids dissolve ions of various metals and precipitate them on the seafloor as particle-filled clouds called black smokers

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50 **Continental rifting: The birth of a new ocean basin**

- Evolution of an ocean basin
  - A new ocean basin begins with the formation of a continental rift
    - Splits landmasses into two or more smaller segments
    - Examples include the East African Rift, Baikal rift, the Rhine Valley, Rio Grand Rift, and the Basin and Range
  - The Red Sea is an example of a rift valley that has lengthened and deepened in a narrow linear sea

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53 **Continental rifting: The birth of a new ocean basin**

- Evolution of an ocean basin
  - If spreading continues the Red Sea will grow wider and develop an oceanic ridge similar

to the Atlantic Ocean
- Not all rift valleys develop into full-fledged spreading centers (e.g., a failed rift running through the central United States from Lake Superior to Kansas)

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56 **Continental rifting: The birth of a new ocean basin**

- Mechanisms for continental rifting
  - Two mechanisms have been proposed
  - Mantle plumes and hotspots
    - Regions of hotter than normal mantle cause decompression melting that results in a volcanic region called a hotspot
    - Hot mantle plumes may cause the overlying crust to dome and weaken
    - Lifting and stretching of the crust results in a continental rift similar to the East African Rift

57 **Continental rifting: The birth of a new ocean basin**

- Mechanisms for continental rifting
  - Slab pull and slab suction
    - Subduction of old oceanic lithosphere may pull a continent attached to a subducting slab and create a rift
    - Another possible force might result from sinking of a cold slab causing the trench to retreat or roll back due to flow in the asthenosphere – this is known as slab suction

58 **Destruction of oceanic lithosphere**

- Why oceanic lithosphere subducts
  - Oceanic lithosphere subducts because its overall density is greater than the underlying mantle
  - Subduction of older, colder lithosphere results in descending angles of nearly 90º

59 **Destruction of oceanic lithosphere**

- Why oceanic lithosphere subducts
  - Younger, warmer oceanic lithosphere is more buoyant and angles of descent are small
    - The lithospheric slab moves horizontally beneath a block of continental lithosphere
    - This phenomenon is called buoyant subduction
  - Subduction may be prevented or modified when oceanic crust is unusually thick because of seamounts

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61 **Destruction of oceanic lithosphere**

- Subducting plates: The demise of an ocean basin
    - Plate movements have been reconstructed for the past 200 million years using magnetic stripes on the ocean floor
    - Research indicates that parts, or even entire oceanic basins, have been destroyed along subduction zones

62 **Destruction of oceanic lithosphere**

- Subducting plates: The demise of an ocean basin
    - The Farallon plate once occupied much of the eastern Pacific basin
      - Beginning 180 million years ago the Farallon plate was subducting beneath the Americas faster than it was being generated
      - The plate got continually smaller and now only fragments of the original plate remain as the Juan de Fuca, Cocos, and Nazca plates

63 **Demise of the Farallon plate**

64 **Opening and closing basins: The supercontinent cycle**

- Rifting and dispersal of one supercontinent is followed by a long period as fragments are reassembled = supercontinent cycle
- Before Pangaea
  - An earlier documented supercontinent, Rodinia, formed about one billion years ago

65 **Opening and closing basins: The supercontinent cycle**

- Before Pangaea
  - Rodinia split apart between 750 and 550 million years ago
  - Some fragments eventually formed Gondwana while others became continental landmasses in the Northern Hemisphere
  - Most of these landmasses were reassembled into Pangaea

66 **Opening and closing basins: The supercontinent cycle**

- Plate tectonics into the future
  - Geologists have extrapolated present-day plate movements into the future
  - 50 million years from now it is projected that
    - The Baja Peninsula and a portion of southern California will slide northward past the North American plate

67 **Opening and closing basins: The supercontinent cycle**

- Plate tectonics into the future
  - 50 million years from now it is projected that
    - Africa will collide with Eurasia closing the Mediterranean and initiating mountain building
    - Australia will be astride the equator on a collision course with Asia

68 **A possible view of the world in 50 million years**

69 **Stay tuned for more on plate tectonics...**