

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

Earth, 12th Edition, Chapter 13

2  **Chapter 13 – Divergent Boundaries**

3  **An Emerging Picture of the Ocean Floor**

- Mapping the Seafloor
 - From 1872 to 1876, the HMS *Challenger* expedition collected oceanographic data
 - Measured the depth to the seafloor by lowering weighted lines overboard
 - Deepest spot measured is now called the Challenger Deep
 - »10,994 m deep
 - »Measured in 1875

4  **An Emerging Picture of the Ocean Floor**

- Mapping the Seafloor
 - Modern bathymetric techniques
 - The topography (shape) of the ocean floor is called bathymetry
 - Sonar, using sound energy, is now used to measure the depth to the ocean floor
 - Early bathymetric profiles were created using echo sounders, which bounce a sound off an object to determine the distance

5  **Echo Sounder**

6  **An Emerging Picture of the Ocean Floor**

- Mapping the Seafloor
 - Modern bathymetric techniques
 - After World War II the US Navy developed sidescan sonar
 - *Sidescan sonar* images a horizontal region above the seafloor
 - *High-resolution multibeam* instruments send out a fan of sound and record reflections from various receivers to provide a more detailed view of the ocean floor
 - Produced first photograph-like images of seafloor
 - Only about 5% of the seafloor has been mapped in detail

7  **Sidescan and Multibeam Sonar**

8  **An Emerging Picture of the Ocean Floor**

- Mapping the Seafloor
 - Mapping the ocean floor from space
 - Uses satellites equipped with *radar altimeters*
 - Massive underwater structures exert stronger than normal gravitational attraction
 - Water piles up over these features
 - Satellite radar altimeters can detect subtle changes (a few cm) in elevation of the ocean surface

9  **Satellite Altimeter**

10  **An Emerging Picture of the Ocean Floor**

- Provinces of the Ocean Floor
 - Three major areas of the ocean floor based on topography
 - Continental margins
 - Outer margins of the continents and the transition to oceanic crust
 - Deep ocean basins
 - Between the continental margins and the oceanic ridge
 - Oceanic ridges
 - A broad, linear swell at a divergent plate boundary

11  **Major Topographic Divisions of the North Atlantic**

12  **Continental Margins**

- Passive Continental Margins
 - Geologically inactive regions (not associated with plate boundaries)
 - Found along most coastal areas that surround the *Atlantic Ocean*

- Experience little volcanism and few earthquakes
- 13  **Continental Margins**
 - Passive Continental Margins
 - A continental shelf is a gently sloping, flooded portion of the continent
 - Varies greatly in width
 - Gently sloping (average one-tenth of a degree slope)
 - Contains important mineral and oil deposits
 - Some areas contain extensive glacial deposits
 - Some areas contain shelf valleys
 - Important fishing grounds
- 14  **Continental Margins**
 - Passive Continental Margins
 - A continental slope is a steep structure that marks the boundary between the continental and oceanic crust
 - Inclination varies but on average is 5 degrees
 - The slope in some areas is as high as 25 degrees
 - A continental rise is a thick accumulation of sediment from the continental slope
 - These sediments are typically carried by turbidity currents (mixtures of sediment and water) down submarine canyons
 - When a turbidity current emerges onto the relatively flat ocean floor, the sediments spread out in a fan shape called a deep-sea fan
 - The continental rise is composed of multiple deep-sea fans
- 15  **Passive Continental Margin**
- 16  **Continental Margins**
 - Active Continental Margins
 - Where the oceanic lithosphere is being subducted beneath the continent
 - Often associated with deep-ocean trenches
 - Located primarily around the Pacific Ocean
- 17  **Continental Margins**
 - Active Continental Margins
 - Sediments and rocks can be scraped from the descending plate and accumulate on the continental plate as an accretionary wedge
 - Subduction erosion occurs when the subducting plate scrapes the bottom of the overriding plate
 - Effective when the angle of descent is steep
- 18  **Active Continental Margin**
- 19  **Features of the Deep-Ocean Basin**
 - Features include:
 - Deep-ocean trenches
 - Abyssal plains
 - Seamounts and guyots
 - Oceanic plateaus
- 20  **Features of the Deep-Ocean Basin**
 - Deep-Ocean Trench
 - Long narrow creases that represent the deepest part of the seafloor
 - Challenger Deep, in Mariana trench, is the deepest spot in the ocean (10,994 meters below sea level)
 - Surface expression of a subduction zone
 - Associated with volcanic activity
 - Volcanic island arcs
 - Continental volcanic arcs
 - Mostly found in the Pacific Ocean

21  **The Challenger Deep**22  **Features of the Deep-Ocean Basin**

- Abyssal Plains
 - Flat features of the ocean floor
 - Likely the most level places on Earth
 - Sites of thick accumulations of sediment
 - Fine sediments from turbidity currents
 - Minerals precipitated from seawater
 - Shells of marine plankton
 - Found in all oceans
 - Most extensive in the Atlantic Ocean

23  **Seismic Reflection Profile of the Ocean Floor**24  **Features of the Deep-Ocean Basin**

- Volcanic Structures on the Ocean Floor
 - Seamounts and volcanic islands
 - Submarine volcanoes are called seamounts
 - Over a million seamounts exist
 - Found in all ocean floors but most common in the Pacific
 - Many form near oceanic ridges or over a hot spot
 - A seamount may grow large enough to emerge as a volcanic island
 - Examples include Easter Island, Tahiti, Bora Bora, and the Galapagos Islands

25  **Features of the Deep-Ocean Basin**

- Volcanic Structures on the Ocean Floor
 - Guyots
 - Submerged, flat-topped seamounts
 - After the volcano is extinct, it eventually erodes to sea level where waves flatten the top of the structure
 - As plates carry the structure away, it eventually sinks into the ocean
 - Oceanic plateaus
 - Vast outpourings of basaltic lavas on the ocean floor
 - Resemble continental flood basalts

26  **Anatomy of the Oceanic Ridge**

- An oceanic ridge, or mid-ocean ridge, or rise is a broad, linear swell along a divergent plate boundary
 - The longest topographic feature on Earth
 - Width varies from 1000 to 4000 km
 - Occupy elevated positions
 - Segments are offset by transform faults
 - Extensive faulting and earthquakes
 - A rift valley (a deep, down-faulted structure) exists on the axis of most ridges
 - Range in width from 30 to 50 km and can have walls towering 500–2500 m above the valley floor

27  **Distribution of the Oceanic Ridge System**28  **Oceanic Ridges and Seafloor Spreading**

- Seafloor Spreading
 - This concept was formulated in the early 1960s by Harry Hess
 - Seafloor spreading occurs along the crests of oceanic ridges
 - Newly formed melt (from decompression melting of the mantle) slowly rises toward the surface
 - Consistent chemical composition
 - Most melt solidifies in the lower crust, but some escapes to the sea floor and erupts as lava

- 29  **Oceanic Ridges and Seafloor Spreading**
- Ocean Ridge Topography
 - Newly created lithosphere is hot and less dense than surrounding rocks
 - As the newly formed crust moves away from the spreading center, it cools and increases in density
 - Oceanic ridges with slow spreading rates have *well-developed rift valleys* and rugged topography
 - Oceanic ridges with intermediate spreading rates have *subdued rift valleys* and topography
 - Oceanic ridges with fast spreading rates generally *do not have a rift valley* and have a shallow profile
- 30  **Topography of Slow and Fast Spreading Centers**
- 31  **Topography of Slow and Fast Spreading Centers**
- 32  **Topography of Slow and Fast Spreading Centers**
- 33  **The Nature of Oceanic Crust**
- Ocean Crust in Four Layers
 - The sequence of four layers composing the oceanic crust is called an ophiolite complex
 - Layer 1
 - consists of deep sea sediments and sedimentary rocks
 - Layer 2
 - consists of *pillow lavas*
 - Layer 3
 - consists of numerous interconnected dikes called a *sheeted dike complex*
 - Layer 4
 - consists of gabbro
- 34  **Ophiolite Complex: Layers of Oceanic Crust**
- 35  **The Nature of Oceanic Crust**
- How Does Oceanic Crust Form?
 - Basaltic magma originates from partially melted mantle peridotite
 - The magma rises through the upper mantle in tiny cracks until it reaches a lens-shaped magma chamber beneath the ridge crest
 - As the pressure in the chamber increases, the rock about the chamber periodically fractures
- 36  **The Nature of Oceanic Crust**
- How Does Oceanic Crust Form?
 - Magma ascends through these fractures, cools, and solidifies to form a sheeted dike complex
 - 10–20 percent of the magma reaches the seafloor, where it quickly solidifies, forming large tube-shaped protuberances known as pillow basalts
- 37  **The Nature of Oceanic Crust**
- Interactions Between Seawater and Oceanic Crust
 - Permeable and highly fractured crust allows seawater to penetrate the crust by 2–3 km
 - Seawater is heated as it circulates through the crust, altering the basalt by *hydrothermal metamorphism*
 - Hot groundwater dissolves ions of various metals from the rock and precipitates them on the seafloor as particle-filled clouds called black smokers
- 38  **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
 - (an elongated depression where the lithosphere is stretched and thinned)
 - When the lithosphere is thick and cold, rifts are narrow
 - Examples include the East African Rift, the Rio Grande Rift, the Baikal Rift, and the

Rhine Valley

- When the lithosphere is thin and hot, the rift can be very wide
 - Examples include the Basin and Range in the western United States

39 **Continental Rifting—The Birth of a New Ocean Basin**

- East African Rift
 - Continental rift extending through eastern Africa
 - Consists of several interconnected rift valleys
 - *Normal faulting* led to grabens (down-faulted blocks)
 - Area has expensive basaltic flows and volcanic cones

40 **East Africa Rift Valley**

41 **Continental Rifting—The Birth of a New Ocean Basin**

- Red Sea
 - Formed when the Arabian Peninsula rifted from Africa beginning about 30 million years ago
 - Fault scarps surrounding the Red Sea are similar to structures seen in the East African Rift
 - If spreading continues, the Red Sea will grow wider and develop an elongated mid-ocean ridge

42 **Continental Rifting—The Birth of a New Ocean Basin**

- Atlantic Ocean
 - After tens of millions of years, the Red Sea will develop into a feature similar to the Atlantic Ocean
 - As new oceanic crust was added to the diverging plates, the rifted margins moved further from the region of upwelling
 - These margins cooled and subsided below sea level
 - Eventually become *passive continental margins*

43 **Formation of an Ocean Basin**

44 **Continental Rifting—The Birth of a New Ocean Basin**

- Failed rifting
 - A failed rift valley extends from Lake Superior into Kansas
 - Formerly active rift valley is filled with basalt and clastic sedimentary rocks
 - Why rifts fail or succeed is not fully understood

45 **Midcontinent Rift**

46 **Continental Rifting—The Birth of a New Ocean Basin**

- Mechanisms for Continental Rifting
 - The supercontinent cycle is the formation and dispersal of supercontinents
 - At least two supercontinents have existed in the geologic past
 - Pangaea—most recent
 - Rodinia
 - Involves major changes in the direction and nature of the forces that drive plate motion

47 **Continental Rifting—The Birth of a New Ocean Basin**

- Mechanisms for Continental Rifting
 - *Mantle plumes* and *hot spots*
 - Regions of hotter than normal mantle rise, experience decompression melting, create basalts that triggers hot-spot volcanism on the surface
 - *Mantle plumes* concentrate under the thick continental crust, which traps heat in the mantle
 - Hot mantle plumes eventually cause the overlying crust to dome and weaken
 - *Decompression melting* can trigger *hot spot volcanism*
 - » Flood basalts can precede a rifting event

48 **The Possible Role of Mantle Plumes in the Breakup of Pangaea**

49 **The Possible Role of Mantle Plumes in the Breakup of Pangaea**

- 50  **Continental Rifting—The Birth of a New Ocean Basin**
- Mantle plumes and hot spots
 - Doming of the crust can produce three rifts that join in the area above the rising mantle plume called a triple junction
 - Continental rift usually occurs along two of the arms
 - » The third arm becomes a failed rift
 - *Mantle plumes do not always lead to rifting*
 - Example: Columbia River Basalts in the Pacific Northwest
- 51  **Continental Rifting—The Birth of a New Ocean Basin**
- Mechanisms for Continental Rifting
 - Role of tensional stress
 - When the crust is thin and hot, small stresses are sufficient to initiate spreading
 - Example: Basin and Range region
 - Slab pull from subducting plates can create sufficient tensional stress to initiate rifting
- 52  **Destruction of Oceanic Lithosphere**
- Why Oceanic Lithosphere Subducts
 - Subduction is complex
 - Fate of oceanic crust is still debated
 - Pile up at the boundary between the upper and lower mantle
 - Subduct to the core–mantle boundary
 - Overall density must be greater than underlying asthenosphere in order to undergo subduction
- 53  **Destruction of Oceanic Lithosphere**
- Spontaneous subduction
 - Very old, thick, dense lithosphere sinks to the mantle by its own weight
 - Results in descending angles of nearly 90 degrees
 - Example: Mariana trench
 - Lithospheric mantle is what drives subduction
- 54  **The Angle of Plate Subduction Depends on Its Density**
- 55  **Destruction of Oceanic Lithosphere**
- Forced subduction
 - Younger, less dense lithosphere is forced beneath the overlying plate by compressional forces
 - Results in frequent earthquakes
 - Can fold and thicken upper plate
 - Descends at shallow angles
 - Example: Peru–Chile trench
- 56  **Destruction of Oceanic Lithosphere**
- Subducting Plates: the Demise of Ocean Basins
 - If a plate subducts faster than it is produced at a spreading center, the plate will get smaller until it completely subducts
 - Example: Farallon Plate and replacement of subduction zone with San Andreas transform boundary
- 57  **The Demise of the Farallon Plate**
- 58  **The Demise of the Farallon Plate**
- 59  **Stay tuned for more on plate tectonics...**