1

2 **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

3 **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

4 **Echo Sounder**

5 **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

6 **Sidescan and Multibeam Sonar**

7 **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

8 **Satellite Altimeter**

9 **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

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

11 **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

12 **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

13 **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

14 **Passive Continental Margin**

15 **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

16 **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

17 **Active Continental Margin**

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

- Features include:
  - Deep-ocean trenches
  - Abyssal plains
  - Seamounts and guyots
  - Oceanic plateaus

19 **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

20 **The Challenger Deep**

21 **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

22 **Seismic Reflection Profile of the Ocean Floor**

23 **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

24 **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

25 **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

26 **Distribution of the Oceanic Ridge System**

27 **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

28 **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

29 **Topography of Slow and Fast Spreading Centers**

30 **Topography of Slow and Fast Spreading Centers**

31 **Topography of Slow and Fast Spreading Centers**

32 **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

33 **Ophiolite Complex: Layers of Oceanic Crust**

34 **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

35 **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

36 **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

37 **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

38 **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

39 **East Africa Rift Valley**

40 **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

41 **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*

42 **Formation of an Ocean Basin**

43 **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

44 **Midcontinent Rift**

45 **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

46 **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

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

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

49 **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

50 **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

51 **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

52 **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

53 **The Angle of Plate Subduction Depends on Its Density**

54 **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

55 **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

56 **The Demise of the Farallon Plate**

57 **The Demise of the Farallon Plate**

58

End of Chapter 13