1 ***Earth's Evolution Through Time***

***Earth, Chapter 22***

2 ***Chapter 22 – Earth's Evolution Through Geologic Time***

3 **Is Earth Unique?**

- Earth is the only planet in the solar system that can support life.
  - Liquid water
  - Oxygen-rich atmosphere
- Earth seems to be the right planet, in the right location, at the right time

4 **Is Earth Unique?**

- The Right Planet
  - Earth is the right size.
    - Larger planets retain a thick, hostile atmosphere
    - Smaller planets have a thin or nonexistent atmosphere
  - Earth has plate tectonics.
    - Formation of continental crust, highlands, and mountains
    - Without topography, would be covered with a shallow ocean
  - Earth has a molten metallic core.
    - A magnetic field protects Earth from cosmetic rays that would strip away the atmosphere

5 **Is Earth Unique?**

- The Right Location
  - If Earth were 10 percent closer to the Sun
    - Too hot for liquid water
    - Atmosphere like Venus
  - If Earth were 10 percent further from the Sun
    - Too cold for liquid water
  - The Sun is a modest-size star
    - Life span of 10 billion years
      - Larger stars burn out in a few million years
      - Our sun's life span allowed enough time for evolution

6 **Is Earth Unique?**

- The Right Time
  - Atmosphere
    - Current atmosphere developed over time
    - Earth's early atmosphere lacked oxygen
    - Primitive photosynthetic organisms added oxygen to the atmosphere 2.5 billion years ago
  - Mass extinction
    - 65 million years ago, an asteroid struck Earth
      - Killed the non-avian dinosaurs
      - Opened new habitats for mammals that survived

7 **The Geologic Time Scale**

8 **Birth of a Planet**

- The history of Earth began about 13.7 billion years ago with the Big Bang
- From the Big Bang to Heavy Elements
  - Hydrogen and helium formed shortly after the Big Bang
    - Clouds of these gases coalesced into stars
  - Heavier elements are formed in stars
    - Nuclear fusion occurs in the cores of stars
    - A *supernova* event occurs when a star explodes and creates the heaviest elements.

9 **Birth of a Planet**

- From Planetesimals to Protoplanets
  - The solar system formed from a *solar nebula*
    - A solar nebula is a rotating cloud of interstellar dust and gases.
    - Most material condensed in the center of the solar nebula to form the protosun.
    - Remaining debris formed a flattened disk rotating around the protosun.
      - Repeated collisions of debris formed asteroid-sized planetesimals rotating around the protosun.

10 **Birth of a Planet**

- From Planetesimals to Protoplanets
  - Repeated collisions and accretions of the planetesimals formed *protoplanets* and moons
  - Earth's Moon formed from the collision of a Mars-sized object with Earth

11 **The Formation of Earth**

12 ***Big Bang to Planetesimals***

13 **Birth of a Planet**

- Earth's Early Evolution
  - Repeated collisions with planetesimals and the decay of radioactive elements caused Earth's temperature to increase
    - *Hadean* eon
    - Iron and nickel melted and sank to form the metallic core, while less dense material rose to form the mantle and crust
    - Early Earth was covered in a magma ocean

14 **The Hadean**

15 **Origin and Evolution of the Atmosphere and Oceans**

- Earth's Primitive Atmosphere
  - Consisted mainly of hydrogen, helium, methane, ammonia, carbon dioxide, and water vapor
    - Hydrogen and helium escaped into space
    - Enhanced by volcanic outgassing
      - Gases trapped within Earth are released through volcanism
      - Process continues today
  - No free oxygen in the early atmosphere

16 **Outgassing**

17 **Origin and Evolution of the Atmosphere and Oceans**

- Oxygen in the Atmosphere
  - Water vapor condensed into clouds
    - Rain filled Earth's oceans
    - Approximately 3.5 billion years ago, photosynthesizing bacteria began to release oxygen into Earth's oceans
    - Initially, oxygen bonded with dissolved iron in the oceans
      - Formed Banded Iron Formations
        - »Alternating layers of iron-rich rocks and chert
        - »Important reservoir of iron ore

18 **Origin and Evolution of the Atmosphere and Oceans**

- Oxygen in the Atmosphere
  - Eventually, oxygen began to build up in the atmosphere
    - The Great Oxygenation Event occurred 2.5 billion years ago
      - Positive impact on the development of aerobic life-forms
      - Wiped out anaerobic life-forms

19 **Origin and Evolution of the Atmosphere**

**and Oceans**

- Oxygen in the Atmosphere
  - –Eventually, oxygen began to build up in the atmosphere
    - Allowed for the formation of *ozone*
      - –Protected organisms from solar radiation
    - Excessive photosynthesis eventually led to the development of *Snowball Earth*
      - –The entire Earth was covered with glaciers

20 **Origin and Evolution of the Atmosphere and Oceans**

- Evolution of the Oceans
  - –Earth cooled → water vapor condensed → rain fell → water collected in low-lying areas
  - –4 billion years ago, scientists estimate that as much as 90 percent of the current volume of seawater was contained in the developing ocean basins
    - Volcanic eruptions caused rainwater to be slightly acidic
      - –Surface weathering rates increased
        - »Products of chemical weathering increased salinity in the oceans

21 **Origin and Evolution of the Atmosphere and Oceans**

- Evolution of the Oceans
  - –Oceans are reservoirs for carbon dioxide
    - Prevents Earth from a “runaway” greenhouse effect
    - Carbon dioxide is locked up in limestone and hard parts of marine organisms
      - –Venus has an atmosphere composed of 97 percent $CO_2$ that produced an extreme greenhouse effect, it’s surface temperature is 475ºC

22 **White Cliffs of Dover**

23 **Precambrian History: The Formation of Earth’s Continents**

- The Precambrian is divided into:
  - –The Archean eon.
    - “Ancient Age”
  - –The Proterozoic eon.
    - “Early Life”
  - –Knowledge of this time is limited because much of the rock record has been destroyed.

24 **Earth’s Early Crust**

25 ***Rift Pattern on Lava Lake***

26 **Precambrian History: The Formation of Earth’s Continents**

- Earth’s First Continents
  - –Oceanic crust
    - Mostly basalt.
    - Relative density of 3.0 g/cm$^3$.
  - –Continental crust
    - Mostly silica-rich rocks (granite).
    - Relative density of 2.7 g/cm$^3$.

27 **Precambrian History: The Formation of Earth’s Continents**

- Making continental crust
  - –Low-density, silica-rich minerals were distilled from Earth’s mantle through partial melting.
  - –Partial melting of mantle rocks generates low-density, silica-rich materials that buoyantly rise.
    - Crustal fragments formed at volcanic island arcs and hot spots.

28 **Formation of Continental Crust**

29 **Precambrian History: The Formation of Earth’s Continents**

- Earth’s First Continents

- From continental crust to continents
  - Crustal fragments collided and accreted to form larger masses
    - After multiple accretion events, eventually formed large crustal blocks called cratons.
    - A shield is a portion of a modern craton exposed at the surface.
  - By the end of the Archaean, 85 percent of modern continental crust had formed.

30 **Isua, Greenland**

31 **Cratons**

32 **Precambrian History: The Formation of Earth's Continents**

- The Making of North America
  - Piecemeal assembly as a continent
    - Between 3.0 and 2.5 billion years ago
      - Accretion of numerous small crustal units (Superior and Hearne/Rae cratons)
    - About 1.9 billion years ago
      - Collision of crustal provinces (Trans-Hudson mountain belt)
    - During the Mesozoic and Cenozoic eras
      - Several terranes accreted onto the western margin of North America
        - »North American Cordillera

33 **Geologic Provinces of North America**

34 **Precambrian History: The Formation of Earth's Continents**

- Supercontinents of the Precambrian
  - Supercontinents are large landmasses that consist of all, or nearly all, existing continents.
    - Pangaea was the most recent
    - Rodinia preceded it
      - Rodinia formed about 1.1 billion years ago
        - »Split apart 600–800 million years ago

35 **Rodinia**

36 **Precambrian History: The Formation of Earth's Continents**

- Supercontinent cycle
  - The supercontinent cycle is the splitting and reassembling of supercontinents.
      - Impacts Earth's continents
  - Supercontinents, mountain building, and climate.
    - As continents move, ocean circulation patterns change, influencing climate
      - Example: Antarctic glaciation
    - Mountains created by the collision of continents change regional climate
      - Example: Sierra Nevada forests versus the Great Basin desert.

37 **Gondwana**

38 **Formation of Glaciers on Antarctica**

39 **Precambrian History: The Formation of Earth's Continents**

- Supercontinents and *sea-level changes*
  - High rate of seafloor spreading
    - Warm oceanic crust displaces seawater
    - Causes sea level to rise
  - Low rate of seafloor spreading
    - Cool oceanic crust sits lower in the ocean basin
    - Causes sea level to fall

40 **Geologic History of the Phanerozoic: The Formation of Earth's Modern Continents**

- Modern Continents
  - Phanerozoic encompasses 542 million years
    - Divided into the *Paleozoic*, *Mesozoic*, and *Cenozoic* eras.
    - Beginning of the Phanerozoic is marked by the appearance of life-forms with hard parts.

–Shells, scales, bones, or teeth.

41 **Geologic History of the Phanerozoic: The Formation of Earth's Modern Continents**

- Paleozoic History
  - At the start of the Paleozoic, North America was a barren lowland
    - Periodically, shallow seas invaded the continents
      - Left behind deposits of limestone, shale, and sandstone

42 **Geologic History of the Phanerozoic: The Formation of Earth's Modern Continents**

- Formation of Pangaea
  - Laurasia was the vast northern continent.
    - Composed of North America, Europe, Siberia, and smaller crustal fragments
    - Tropical landmass that led to the formation of swamps which converted to coal
  - Gondwana was the vast southern continent.
    - Composed of South America, Africa, Australia, Antarctica, and India

43 **Geologic History of the Phanerozoic: The Formation of Earth's Modern Continents**

- Formation of Pangaea
  - Gondwana migrated northward and collided with Laurasia to form Pangaea.
    - Accretion lasted 300 million years and formed several mountain belts
      - Formed the Caledonian, the Appalachian, and the Ural Mountains
  - Pangaea reached its maximum size 250 million years ago.

44 **Formation of Pangaea**

45 **Geologic History of the Phanerozoic: The Formation of Earth's Modern Continents**

- Mesozoic History
  - Changes in sea levels
    - Early in the Mesozoic much of the land was above sea level
    - By the middle Mesozoic, seas invaded western North America
  - Coal formation in western North America
    - By the late Mesozoic, shallow seas encroached on much of western North America
      - Led to the formation of "coal swamps"
      - Cretaceous coal deposits are economically important

46 **Geologic History of the Phanerozoic: The Formation of Earth's Modern Continents**

- Breakup of Pangaea
  - 185 million years ago, a rift developed between North America and Africa
    - Marked the start of the Atlantic Ocean
  - Westward-moving North Atlantic plate began to override the Pacific plate
    - Resulted in a wave of deformation along the western margin of North America

47 **Geologic History of the Phanerozoic: The Formation of Earth's Modern Continents**

- Formation of the North American Cordillera
  - Subduction of the Farallon plate led to 100 million years of volcanic activity
    - Granitic plutons of the Sierra Nevada, Idaho batholith, and British Columbia's Coast Range Batholith
  - Subduction of the Farallon plate also led to the piecemeal addition of crustal fragments
    - Exotic terranes
  - Late Mesozoic *Laramide Orogeny* led to the development of the Rocky Mountains

48 **Appalachian Mountains**

49 **Zion**

50 **Geologic History of the Phanerozoic: The Formation of Earth's Modern Continents**

- Cenozoic History
  - Represents a considerably smaller fraction of geologic time compared to the Mesozoic and Paleozoic eras
    - More is known about this era because the rock formations are more prevalent and widespread

51 **Geologic History of the Phanerozoic: The Formation of Earth's Modern Continents**

- Eastern North America
  - Stable continental margin
    - Abundant marine sedimentation
      - Most extensive development around the Gulf of Mexico
  - Appalachians eroded to a low plain
    - Isostatic adjustment raised the region and rejuvenated its rivers

52 **Geologic History of the Phanerozoic: The Formation of Earth's Modern Continents**

- Western North America
  - Laramide Orogeny was coming to an end
    - Erosional forces lowered the Rocky Mountains and filled basins with sediment
      - Large wedge of sediment created the Great Plains
  - 20 million years ago, broad region from Nevada to Mexico experienced crustal extension
    - Created fault-block mountains and formed the Basin and Range Province

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65 **Geologic History of the Phanerozoic: The Formation of Earth's Modern Continents**

- Western North America
  - Entire western interior uplifted
    - Re-elevated the Rocky Mountains and rejuvenated many western rivers
      - Many spectacular gorges, such as the Grand Canyon, were created
  - Volcanic activity was common
    - Basaltic plateaus formed in Washington, Oregon, and Idaho
  - Last 2.6 million years dominated by glacial/interglacial cycles

66 **Mount Shasta**

67 **Earth's First Life**

- The oldest fossils are 3.5 billion years old microscopic fossils (similar to cyanobacteria) found in chert deposits
  - Chemical traces suggest life may have existed 3.8 billion years ago

68 **Earth's First Life**

- Origin of Life
  - Amino acids are essential molecules for proteins
  - Many hypotheses for the formation of amino acids
    - Synthesized from ultraviolet light.
    - Synthesized from a lightning strike.
    - Brought to Earth from asteroids.
    - Developed in hydrothermal vents or hot springs.

69 ***Life through time***

70 **Earth's First Life**

- Origin of Life
  - Earth's first life: prokaryotes
    - First known organisms were single-celled bacteria, *prokaryotes*, which lacked a nucleus.

- Early prokaryotes were anaerobic
- Later prokaryotes used solar energy to synthesize organic compounds, thus producing their own food
  - Photosynthetic cyanobacteria-like prokaryotes lived in layered mats on top of mounds called *stromatolites*.

71 **Stromatolites**

72 ***Precambrian Stromatolites***

73 ***Modern Stromatolites***

74 **Earth's First Life**

- Origin of Life
  - Evolution of eukaryotes
    - *Eukaryote* cells contain a nucleus
      - More advanced than prokaryotes
      - All plants and animals are eukaryotes
    - Multicelled organisms did not evolve until 1.2 billion years ago
      - First primitive marine animals did not evolve until 600 million years ago

75 **Ediacaran Fossil**

76 **Paleozoic Era: Life Explodes**

- The Paleozoic starts with the Cambrian Period
  - Spectacular variety of life-forms
    - All major invertebrate groups first appear in the Cambrian.
    - Expansion in biodiversity is coined the *Cambrian Explosion*.
- Early Paleozoic Life-Forms
  - The Cambrian period was the golden age of trilobites
  - The Ordovician period marked the appearance of abundant cephalopods
    - Highly developed mollusks
  - Early diversification driven by the emergence of predators

77 **Trilobite**

78 ***Trilobite – early ocean dweller***

79 ***Ammonites***

80 **The Ordovician Seas**

81 **Paleozoic Era: Life Explodes**

- Early Paleozoic Life-Forms
  - First land plants evolved 400 million years ago
    - Evolved to adapt to living on land.
    - Many difficulties to overcome:
      - Obtaining water.
      - Staying upright against gravity and winds.

82 **Evolution of Land Plants**

83 **Paleozoic Era: Life Explodes**

- Vertebrates Move to Land
  - Lobe-finned fishes adapted to land and became the first amphibians
    - Used fins to move from one pond to another.
  - Amphibians are not fully adapted to life out of the water
    - Born in the water with gills and a tail.
    - Air-breathing adults with legs.

84 **Lobe-Finned Fish to Amphibians**

85 **Paleozoic Era: Life Explodes**

- Reptiles: The First True Terrestrial Vertebrates
  - Reptiles were better adapted to live on land
    - "waterproof" skin
    - Shell-covered eggs

– These "private aquariums" eliminate the need to reproduce in the water

86 **Coal-swamp**

87 ***The Great Dying: 250 Ma***

88 ***Figure 22.B (left)***

89 ***Figure 22.B (right)***

90 **Paleozoic Era: Life Explodes**

- The Great Permian Extinction
  - The most significant mass extinction over the past 500 million years.
    - 70 percent of land-dwelling species went extinct.
    - 96 percent of marine organisms went extinct.
  - Ultimately created more diverse biological communities
  - Several causes
    - Volcanic activity
    - Asteroid impact

91 **Vertebrate Groups and Divergence**

92 **Mesozoic Era: Age of the Dinosaurs**

- Gymnosperms: The Dominant Mesozoic Trees
  - *Gymnosperms* (cycads, conifers, and ginkgoes) became the dominant trees of the Mesozoic.
    - Did not need freestanding water for fertilization
  - Fossil gymnosperms in Arizona's Petrified National Park.

93 **Gymnosperms**

94 **Mesozoic Era: Age of the Dinosaurs**

- Reptiles Dominate the Land, Sea, and Sky
  - First reptiles were small, but they evolved rapidly
    - Dinosaurs evolved into large and small organisms, herbivorous and carnivorous organisms.
    - Pterosaurs had membranous wings that allowed for rudimentary flight.
    - Ancestors to modern birds (like Archaeopteryx) had feathered wings and reptilian characteristics.
    - Other reptiles returned to the sea.
  - Reptiles were the dominant terrestrial organism in the Mesozoic
    - Many went extinct at the end of the Mesozoic.

95 ***Triassic-age Petrified Log***

96 **Archaeopteryx**

97 **Reptiles Returned to the Sea**

98 ***Mesozoic Crocodile***

99 ***Tyrannosaurus***

100 ***Pteranodon, a flying reptile (?)***

101 **Allosaurus**

102 **End of the Mesozoic Era**

- What could have triggered the extinction of one of the most successful groups of land animals?
- Researchers suggest a "one–two punch"
  - Climate data indicates that average temperature increased by more than 20ºC
  - Coincided with massive basaltic eruptions that produced the Deccan Plateau
  - 66 million years ago our planet was struck by a stony meteorite
    - Evidence in the form of sediment containing a high level of the element *iridium*, rare in Earth's crust but found in high proportions in stony meteorites.

103 ***"Night comes to the Cretaceous", 65 Ma***

104 **Chicxulub Crater**

105 **Iridium Layer**

106 **Cenozoic Era: Age of Mammals**
- In the Cenozoic, mammals replaced the reptiles as the dominant land animals
- *Angiosperms* (flowering plants with seeds) replaced gymnosperms as the dominant plants
  - Strongly influenced the evolution of birds and mammals

107 **Angiosperms**

108 **Cenozoic Era: Age of Mammals**
- From Reptiles to Mammals
  - Earliest mammals coexisted with dinosaurs in the Mesozoic.
    - Small, nocturnal, rodent-like creatures.
  - Mammals are distinct from reptiles.
    - Give birth to live young.
    - Have mammary glands.
    - Warm-blooded
      - Can occupy more diverse habitats than cold-blooded creatures.
  - Cenozoic mammals diversified rapidly.

109 ***Extinct Cenozoic Animals***

110 **Cenozoic Era: Age of Mammals**
- Marsupial and Placental Mammals
  - Marsupials are born at an early stage of development.
    - After birth, the juveniles enter the mother's pouch to complete development
  - Placentals are born later in development.
    - Young are comparatively mature
  - Today, marsupials are found primarily in Australia, where they took a separate evolutionary path largely isolated from placental mammals.

111 **Marsupials**

112 **Cenozoic Era: Age of Mammals**
- Humans: Mammals with Large Brains and Bipedal Locomotion
  - Several populations of anthropoids diverged 7 or 8 million years ago in Africa.
    - One line produced modern apes, one line produced several varieties of human ancestors.
    - Good fossil evidence in sedimentary basins in Africa.
  - *Australopithecus* shows skeletal characteristics of both apelike ancestors and modern humans.
    - Upright posture and bipedal locomotion.
      - Correlates with leaving forest habitat and moving to open grasslands.
  - Many species of the genus *Homo*.
    - Examples: *Homo habilis* and *Homo erectus*.
    - *Homo sapiens* originated in Africa 200,000 years ago.

113 **Laetoli Footprints**

114 **Cenozoic Era: Age of Mammals**
- Large Mammal Extinction
  - Many mammals diversified into very large organisms.
    - Examples: 5-meter-tall hornless rhinoceros, mastodons, mammoths.
  - Most large mammals went extinct in the Pleistocene.
    - Because these large animals survived several major glacial advances and interglacial periods, it is difficult to ascribe extinctions.
    - Early humans may have contributed to their demise through hunting practices.

115 **Cave Paintings**

116 **Mammoths**

117 **Evolution of Life on Earth**

118 ***End of Chapter***