

1 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 cosmic 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 **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

13 **The Hadean**

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

- Earth's Primitive Atmosphere
 - Consisted mainly of hydrogen, helium, methane, ammonia, carbon dioxide, and water vapors
 - 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

15 **Outgassing**

16 **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

17 **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

18 **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

19  **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

20  **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 CO₂ that produced an extreme greenhouse effect, it’s surface temperature is 475°C

21  **White Cliffs of Dover**


22  **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.


23  **Earth’s Early Crust**

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

- Earth’s First Continents
 - Oceanic crust
 - Mostly basalt.
 - Relative density of 3.0 g/cm³.
 - Continental crust
 - Mostly silica-rich rocks (granite).
 - Relative density of 2.7 g/cm³.


25  **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.

26  **Formation of Continental Crust**

27  **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 Archean, 85 percent of modern continental crust had formed.

28  **Isua, Greenland**29  **Cratons**30  **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

31  **Geologic Provinces of North America**32  **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

33  **Rodinia**34  **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.

35  **Gondwana**36  **Formation of Glaciers on Antarctica**37  **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











38  **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.

39  **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

40  **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
- 41  **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.
- 42  **Formation of Pangaea**
- 43  **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
- 44  **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
- 45  **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
- 46  **Appalachian Mountains**
- 47  **Zion**
- 48  **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
- 49  **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
- 50  **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
- 51  **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
- 52  **Mount Shasta**
- 53  **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
- 54  **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.
- 55  **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*.
- 56  **Stromatolites**
- 57  **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
- 58  **Ediacaran Fossil**
- 59  **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

60  **Trilobite**61  **The Ordovician Seas**62  **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.

63  **Evolution of Land Plants**64  **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.

65  **Lobe-Finned Fish to Amphibians**66  **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

67  **Coal-swamp**68  **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

69  **Vertebrate Groups and Divergence**70  **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.

71  **Gymnosperms**72  **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.

73 **Archaeopteryx**74 **Reptiles Returned to the Sea**75 **Allosaurus**76 **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 20°C
 - 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.

77 **Chixulub Crater**78 **Iridium Layer**79 **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

80 **Angiosperms**81 **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.

82 **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.

83 **Marsupials**84 **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.


85  **Laetoli Footprints**

86  **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.

87  **Cave Paintings**

88  **Mammoths**

89  **Evolution of Life on Earth**

90 

End of Chapter 22