1 EVPP 110 Lecture
Fall 2003, Instructor: Dr. Largen
Physical Environment: Earth Origin, Age & Structure

2

- brief history of universe and earth
- earth in context of our solar system
- age of the earth
- early ideas about physical features of the earth
- nature and origin of rocks
- geologic time/dating the rock & fossil record
- components of the earth system
- structure of the earth

3 Brief History of Universe & Earth

- Origin of the universe
  - unknown for certain
  - actively researched
  - many theories
    - Big Bang theory
    - inflation theory
    - cold dark matter theory
  - theories difficult to test

4 Brief History of Universe & Earth

5 Brief History of Universe & Earth

- Age of the universe
  - unknown for certain
  - actively researched
  - several methods for calculating age of universe
    -
    -
  - age estimates vary
    - range from 8 billion to 14 billion years old

6 Brief History of Universe & Earth
- origin and age of the universe
  - most “popular” origin theory
    - Big Bang Theory
  - most popular age estimate
    - ~ 12 billion years old
- size of universe
  - continually increasing since its creation
    -

7 Brief History of Universe & Earth
- universe is thought to have had a dynamic adolescence
  - from ~12 billion years ago (BYA) to ~7 BYA
    - galaxies, stars and planets of universe were formed, destroyed, re-formed
- steps leading to birth of Earth
  - ~7 BYA
    - red giant star in vicinity of Earth exploded
  - ~4.6 BYA
    - remnants of explosion formed our solar system

8 Earth in context of our solar system

9 Earth in context of our solar system
- After collapse of red giant
  - rotating, dense cloud (solar nebula) remained
    - cloud cooled, condensed and contracted
      - rotating faster
      - forming flattened disk, thinnest at edges
    - contraction continued, rings of material separated from cloud
      - condensed to form planets

10 Earth in context of our solar system
- resulted in 9 planets of our solar system
  - grouped as
    - terrestrial planets
    - Jovian (non-terrestrial) planets
    - Pluto

11 Earth in context of our solar system

- terrestrial planets
  - closest to sun
  - are “earth-like”
    - rocky with metallic centers
      - heavier materials that stayed nearer sun
  - Mercury, Venus, Earth, Mars

12 Earth in context of our solar system
- Jovian (non-terrestrial) planets
  - farther from sun
  - are similar to Jupiter
    - composed mostly of liquids and gases
      - lighter materials that boiled away from areas nearest to the sun
  - Jupiter, Saturn, Uranus, Neptune

13 Earth in context of our solar system
- Pluto
  - anomalous
  - terrestrial but at outer limits of solar system

14 Earth in context of our solar system

15 Earth in context of our solar system
- Earth is unique in our solar system
  - why is the Earth so “special” relative to other planets?
    - temperature
    - presence & composition of atmosphere
    - water
    - continued tectonic activity

16 Age of the Earth

17 Age of the Earth
- ~4.6 billion years old - current estimate
  - age of Earth not always known or agreed upon
- Greek philosophers
  - Earth ageless - no beginning or end to time
- Biblical scholar
  - Bishop Ussher (1664)
    - put age at 5,668 years
      - concluded Earth was formed on October 26, 4004 B.C, based on a literal translation of Bible

18 Early ideas about physical features of the Earth

19 Early ideas about physical features of the Earth
- Throughout much of human history

- believed major physical features of Earth were fixed and unchanging
  - continents, oceans, mountains, valleys were in their “original” location, would always remain in those locations, unchanged

20 Early ideas about physical features of the Earth
- as time passed, knowledge grew
  - generally held belief of an unchanging earth gave way to concept of catastrophism

21 Early ideas about physical features of the Earth
- Catastrophism
  - subscribed to by most natural scientists up through early 19th century
    - proposed that supernatural forces caused catastrophic events that re-shaped the physical landscape
      - earthquakes
      - volcanic eruptions
      - floods

22 Early ideas about physical features of the Earth
- rise of scientific thought and explorations
  - evidence against catastrophism grew

23 Early ideas about physical features of the Earth
- fundamental principles of modern geology were developed
  - principle of superposition
  - principle of original horizontality
  - principle of uniformitarianism

24 Early ideas about physical features of the Earth
- Nicolaus Steno (Danish, 1636-1686)
  - formulated in 1669
    - Principle of Superposition
    - Principle of Original Horizontality
    - Principle of Original Lateral Continuity

25 Early ideas about physical features of the Earth
- principle of superposition
  - in unaltered series of rock layers
    - layers on bottom were deposited first, are oldest
      -
    - oldest at bottom, youngest at top

26 Early ideas about physical features of the Earth
- principle of original horizontality

- strata initially more nearly horizontal than vertical
- any strongly sloped stratum had to have been tilted by external forces after it was formed

27 Early ideas about physical features of the Earth

28 Early ideas about physical features of the Earth

- principle of original lateral continuity
  - holds that
    - strata originally are unbroken, flat expanses
    - original continuity of a stratum can be broken by erosion
      - as when a river cuts downward to form a valley
  -

29 Early ideas about physical features of the Earth

- James Hutton (Scottish, 1726-1797)
  - formulated in1785 the
    - principle of uniformitarianism

30 Early ideas about physical features of the Earth

- Principle of uniformitarianism
  - holds that geologic processes happening today operated in a similar fashion in past
    - provide guidance in studying earth's history
  - fundamental to modern science of geology
  - laws of nature have not changed over time, were same in past as now

31 Early ideas about physical features of the Earth

- Principle of uniformitarianism
  - its application is sometimes called "actualism"
    - example; when ripples seen on ancient rock composed of hardened sand (sandstone)
      - can assume they developed in same way that ripples develop today
        - under influence of certain kinds of water movement or wind

32 Early ideas about physical features of the Earth

- Principle of uniformitarianism
  - James Hutton
    - believed that rocks of past formed as a result of same processes that were currently operating
      - such as
        - volcanic activity
        - accumulation of grains of sand and clay under the influence of gravity

33 Early ideas about physical features of the Earth

34 Nature and Origin of Rocks

35 Nature and Origin of Rocks
- rock
  - consist of interlocking or bonded grains of matter
    - typically composed of single minerals
  - most formed of two or more minerals
- mineral
  - naturally occurring inorganic solid element or compound with
    - particular chemical composition (or range of compositions)
    - characteristic internal structure

36 Nature and Origin of Rocks
- kinds of rocks
  - three basic types recognized, based on modes of origin
    - igneous
    - sedimentary
    - metamorphic

37 Nature and Origin of Rocks
- igneous rocks
  - form by cooling of molten material to point at which it hardens
    - molten material (magma) comes from within earth
    - reaches surface through cracks, fissures in crust
    - cools and hardens
  - composed of bonded grains
    - each consisting of a particular mineral

38 Nature and Origin of Rocks
- sedimentary rock
  - form by
    - accumulation of grains of sediment in a variety of settings
    - bonding together of grains to form solid sedimentary rock

39 Nature and Origin of Rocks
- metamorphic rock
  - forms by alteration of rocks within earth under conditions of great temperature and pressure (without melting them)

40 Geologic Time
&
Dating the Rock & Fossil Record

41 Geologic Time & Dating the Rock/Fossil Record
- geologic time

- expressed in two ways
  - relative time (relative age)
  - absolute time (absolute age)

42 Geologic Time & Dating the Rock/Fossil Record
- relative time (relative age)
  - determined by relative position of sedimentary rocks to each other
  - can be used to answer a question like, “Which is younger?”
  - utilizes comparison of different geologic formations to determine which is oldest, next oldest, etc.

43 Geologic Time & Dating the Rock/Fossil Record
- relative time (relative age)
  - governed by concepts such as
    - principle of superposition
      - looked at earlier
    - principle of intrusive relationships
    - principle of cross-cutting relationships
    - principle of inclusions
    - principle of faunal succession
    - unconformities
    - geologic correlation

44 Geologic Time & Dating the Rock/Fossil Record
- Principle of intrusive relationships
  - intrusive igneous rock is always younger than rock it invades
    - feature such as a dike that cuts formations is younger than formations it cuts
    - dike
      - molten magma that cuts upward through sedimentary or metamorphic rocks

45 Geologic Time & Dating the Rock/Fossil Record
-

46 Geologic Time & Dating the Rock/Fossil Record
- Principle of cross-cutting relationships
  - break or fault in formation is always younger than formation itself
    - fault that offsets beds is younger than beds it offsets

47 Geologic Time & Dating the Rock/Fossil Record

48 Geologic Time & Dating the Rock/Fossil Record
- Principle of inclusions
  - when fragments of one body of rock are found in a second body of rock
    - second body is always younger than first

49 Geologic Time & Dating the Rock/Fossil Record
- Principle of inclusions
  - rock fragments in this conglomerate are older than conglomerate itself

50 Geologic Time & Dating the Rock/Fossil Record
- Principle of faunal succession
  - proposed by William Smith (1769-1839)
  - states that over time, organisms on earth have changed in a definite order that is reflected in fossil record
  - rocks with recently evolved life forms are younger than those with older life forms

51 Geologic Time & Dating the Rock/Fossil Record
- unconformities
  - gaps in rock record
  - surface between group of sedimentary strata and rocks beneath those strata
  - mark boundaries between rocks of different ages
  - may result from
    - non-deposition (a hiatus)
    - deposition followed by erosion

52 Geologic Time & Dating the Rock/Fossil Record
- unconformities
  - angular unconformity
    - separates tilted beds from flat lying beds
  - disconformity
    - separates beds; upper beds rest on erosion surface that developed after lower beds were deposited
  - nonconformity
    - separates flat-lying beds from igneous or metamorphic rock

53 Geologic Time & Dating the Rock/Fossil Record

54 Geologic Time & Dating the Rock/Fossil Record
- Disconformity
  - erosional disconformity separates earlier folding in the lower half from folding (above) after later ash flows were deposited(outcrop of volcanic ash, Japan)

55 Geologic Time & Dating the Rock/Fossil Record
- Unconformity
  - boundary between unlayered igneous or metamorphic rocks, and overlying sequential sedimentary rocks
  - lower rocks show evidence of erosion before deposition of sedimentary rocks

56 Geologic Time & Dating the Rock/Fossil Record
- geologic correlation
  - seeks to establish age relationships between distant sequences of rock
    - often through use of fossil assemblages, or index fossils
  - a key bed, a distinctive stratum that appears at several localities, may also be

used

57 Geologic Time & Dating the Rock/Fossil Record
- Index fossils
  - organisms with specific characteristics:
    - short lived (geologically)
    - widespread occurrence
    - readily recognized

58 Geologic Time & Dating the Rock/Fossil Record
- absolute time (absolute age)
  - absolute ages are expressed in years, or millions or billions of years, before present
  - usually determined using radiometric dating

59 Geologic Time & Dating the Rock/Fossil Record
- Radioactivity and absolute ages
  - radioactive elements and products of their radioactive decay can be used to measure ages of rocks

60 Geologic Time & Dating the Rock/Fossil Record
- radioactive isotopes
  - decay spontaneously, changing into atoms of another element
    - each at own nearly constant rate
      - age of rock determined by measuring amounts of parent and daughter isotope that remain in rock
- parent isotope
  - isotope that undergoes decay
- daughter isotope
  - product of parent isotope's decay

61 Geologic Time & Dating the Rock/Fossil Record
- radioactive decay
  - atoms change to those of another element by releasing subatomic particles and energy
  - follows an exponential decay law

62 Geologic Time & Dating the Rock/Fossil Record
- exponential decay law
  - no matter how much of parent element is present when decay begins
    - after certain amount of time, half that amount will survive
      - after another interval of same duration, half of surviving amount will survive
      - and so on, and so on….
        - characteristic interval is known as half life

63 Geologic Time & Dating the Rock/Fossil Record
- half life
  - time necessary for half of original atoms of parent isotope to decay into daughter isotope

64 Radioactive Decay

65 Geologic Time & Dating the Rock/Fossil Record

- Radiometric dating
  - requires a parent isotope that undergoes radioactive decays to yield a daughter isotope at a known rate
    - Example:
      - $^{14}C \rightarrow {}^{14}N$
      - called radiocarbon dating
      - half-life of ^{14}C is 5730 years (relatively short)
      - can only be used for dating materials less than 70,000 years old

66 Half Lives of Some Radiometric Isotopes

67 Geologic Time & Dating the Rock/Fossil Record

- Geologic time
- Eons
  - largest divisions of time, beginning with the Archean (4.6 to 3.8 billion years ago)
  - Eras (subdivisions of eons)
    - defined by dominant life forms
    - Periods (divisions of eras)
      - based on smaller scale changes
      - Epochs (divisions of periods)
        - based on detailed, smaller scale changes

68 Geologic Time Scale

- Archean Eon (4.6bya-2.5bya)
- Proterozoic Eon (2.5bya-543mya)
- Phanerozoic Eon (543mya-present) “interval of well-displayed life”
  - Paleozoic Era (543mya-251mya) “old life”
    - 8 periods; Cambrian, Ordovician, Silurian, Devonian, Mississippian, Pennsylvania, Permian
  - Mesozoic Era (251mya-65mya) “middle life”
    - 3 periods; Triassic, Jurassic, Cretaceous
  - Cenozoic Era (65mya-present) “modern life”
    - Paleogene Period (65mya-24mya)
      - 3 epochs; Paleocene, Eocene, Oligocene
    - Neogene Period (24mya-present)
      - 4 epochs; Miocene, Pliocene, Pleistocene, Holocene

69 Geologic Time

70 Paleozoic Era (543mya-251mya)

- Trilobite fossil, early Paleozoic era

71 Mesozoic Era (251mya-65mya)

- “age of the dinosaurs”
-

72 Cenozoic Era (65mya-present)
- “age of mammals”

73 Components of the Earth System - or “Ecosphere”

74 Components of the Earth System

75 Components of the Earth System
- Ecosphere
  - entire earth system
  - includes all other spheres
- Lithosphere
  - solid earth, including earth’s crust & part of upper mantle
- Hydrosphere
  - liquid envelope of water which surrounds our planet
- Atmosphere
  - layer of gas (air) which surrounds our planet
- Biosphere
  - living organisms which inhabit all of above spheres.

76 Earth’s Structure

77 Earth’s Structure
- “Layman’s” description
  - hot, dense, solid inner iron core
  - hot, dense, molten iron outer core
  - thick, rocky mantle
  - thin, rocky crust
- formally described two ways
  - chemical-based description
  - mechanical-based

78 Earth’s Structure
- chemical-based description
  - Crust
  - Mantle
  - Core

79 Earth’s Structure
- chemical-based description
  - crust
    - outermost layer or shell
    - represents <0.1% of Earth's total volume
    - total depth is ~100km
    - floats on upper mantle
    - broken into 16 plates

80 Earth's Structure
- chemical-based description
  - crust
    - nine elements compose ~99% of mass
      - oxygen = 45%
      - silicon = 27%
      - aluminum = 8%
      - iron = 5.8%
      - calcium = 5.1%
      - magnesium = 2.8%
      - sodium = 2.3%

81 Earth's Structure
- chemical-based description
  - crust
    - divided into
      - continental
        - 30-60km thick
        - composed of Al, Ca, K-rich silicate ("granite")
        - density ~2.8 g/cm^3
      - oceanic
        - 6-10km thick
        - Fe, Mg-rich silicate ("basalt")
        - density ~3.0 g/cm^3

82 Earth's Structure
- chemical-based description
  - mantle
    - zone below crust & above core
    - ~3000km thick
    - consists of soft rock, mostly Fe, Mg-rich silicates
    - density ~3.2-5.0 g/cm^3
    - constitutes ~ 67% of Earth's mass
    - divided into
      - upper mantle
      - transition zone
      - lower mantle

83 Earth's Structure
- chemical-based description
  - core
    - central zone
    - ~3000km thick

- composed of metallic iron
  - no silicate
- density ~10 g/cm^3
- divided into
  - inner core
  - transition zone
  - outer core

84 Earth's Structure

85 Earth's Structure

- Mechanical-based description
  - Lithosphere
  - Asthenosphere
  - Mesosphere
  - Outer Core
  - Inner Core

86 Earth's Structure

- Mechanical-based description
  - lithosphere
    - solid portion of Earth
      - compared with non-solid atmosphere & hydrosphere
    - includes crust & part of upper mantle
    - ~100 km thick
    - rigid
    - very strong, rigid
    - cool

87 Earth's Structure

- mechanical-based description
  - asthenosphere
    - layer or shell below lithosphere
    - plastic - but solid
    - very weak
    - hot
    - ~200km thick
    - part of upper mantle

88 Earth's Structure

- mechanical-based description
  - mesosphere
    - layer or shell below asthenosphere
    - plastic

- weak, but stronger than asthenosphere
- hot
- ~2600km thick
- remainder of mantle

89 Earth's Structure
- Mechanical-based description
  - outer core
    - molten
      - iron, nickel, dissolved sulfur and oxygen
    - constitutes ~30% of Earth's mass
    - ~2200km thick
    - convection currents in this region generate Earth's magnetic field

90 Earth's Structure
- mechanical-based description
  - inner core
    - solid
      - mostly iron, some nickel
    - ~1400km thick
    - constitutes ~2% of Earth's mass
    - floats in middle of molten outer core
    - pressure reaches ~3 million atmospheres
    - temperatures range from 4000-5000°C

91 Earth's Structure

92 Structure of the Earth

93 Earth's Structure
- Interior of earth
  - hot and dense
    - weight of upper layers presses on interior
      - extreme compression leads to extreme heating
    -
  - since metals are heavy and rocks are light
    - heavy metals sink to center (iron and nickel)
    - lighter minerals float to surface (silicates)

94 Earth's Structure
- Interior of earth
  - temperature
    - increases nonlinearly with depth
  - pressure
    - increases linearly with depth

- density
  - increases with depth
- combination of temperature and pressure determines when materials in Earth will be molten versus solid
  - affects production of convection process in asthenosphere

95 Earth's Structure

- isostasy
  - condition of equilibrium (comparable to floating) of units of lithosphere above asthenosphere
  - Crustal loading (as by ice, water, sediments, or volcanic flows)
    - leads to isostatic depression or downwarping
  - Crustal unloading (as by erosion, or melting of ice)
    - leads to isostatic uplift or upwarping

96 The End