1 EVPP 110 Lecture
Fall 2003, Instructor: Dr. Largen
Physical Environment: Plate Tectonics, Earthquakes, Volcanoes

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- development of the theory of plate tectonics
- plate tectonics
  - earthquakes
  - volcanoes

3 Plate Tectonics

4 Theory of plate tectonics
- lines of evidence leading to development of current theory
- plate movements
- faulting and volcanism at plate boundaries
  - earthquakes and volcanoes

5 Theory of plate tectonics
- Based on 6 lines of evidence
  - shapes of continents
  - similar distribution of geologic features, fossils, some living species
  - non-uniform distribution of earthquakes and volcanoes
  - sea floor topography, especially the Mid-Atlantic Ridge
  - age of volcanic islands in the Atlantic
  - sea floor magnetism & sea floor spreading

6 Shapes of continents
- Historical perspective
  - throughout most of history
    - physical features of earth believed to be were fixed

7 Shapes of continents
- Historical perspective

- beginning centuries ago
  - noticed outlines of western Africa and eastern South America matched

8 Shapes of continents
- Historical perspective
  - in 1915
    - concept of continental drift was proposed
      - by Alfred Wegener

9 Shape of continents
- Alfred Wegener (German,1880-1930)
  - meterologist
  - wrote The Origin of Continents and Oceans in 1915

10 Shapes of continents
- Wegener's continental drift proposed
  - all large continents of current world were joined together in late Paleozoic Era
    - as single supercontinent, called Pangaea
      - broke apart
        - fragments had drifted about

11

12 Figure: history of continental drift

13 Shapes of continents
- Fit of continental shelves
  - lended further support
    - more striking than fit of continents

14 Shapes of continents
- rejection of continental drift
  - despite mounting evidence
    - Wegener's theory largely rejected
      - due to lack of mechanism for moving the continents

15 Shapes of continents
- Animation of Pangea, continental drift

16 Similar distribution of geologic features, fossils, some living species
- Geologic features
  - cited by Wegener in support of continental drift
    - marine and non-marine rock sequences of same age
    - mountain ranges and glacial deposits match
  - diamond fields of Africa and South America

17 Similar distribution of geologic features, fossils, some living species

- Fossils
  - cited by Wegener in support of continental drift
    - many of same extinct plants and animals in matching locations

18 Similar distribution of geologic features, fossils, some living species

- Fossils
  - Glossopteris fossils
    - plant found on five continents thought to have been joined to form Gondwana
      - former supercontinent formed by southern continents
        - proposed in 1885 by Austrian geologist Edward Suess

19 Similar distribution of geologic features, fossils, some living species

- Fossil plant evidence - Glossopteris
  - extinct group of seed plants that arose during Permian on great southern continent of Gondwana

20 Similar distribution of geologic features, fossils, some living species

- Fossils
  - evidence provided in 1937 by Alexander Du Toit, South Africa geologist
    - found Mesosaurus fossils in same sediment layer in Brazil and in South Africa
      -
  - fossils of a unique trilobite species
    - found only in Boston, Massachusetts and Scotland

21 Similar distribution of geologic features, fossils, some living species

- Living species
  - earthworm genera
    - one genus found only at southern tips of South America and Africa
    - another genus found only in southern India and southern Australia

22 Non-uniform distribution of earthquakes and volcanoes

- earthquakes and volcanoes
  - do not occur uniformly over surface of earth
    - unheard of in some areas
    - routine in other areas

23 Non-uniform distribution of earthquakes and volcanoes

- earthquakes and volcanoes
  - ring of fire
    - around Pacific Rim

24 Figure: Crustal plate boundaries

25 Sea floor topography

- historical perspective
  - prior to advent of technology that enabled its exploration
    - ocean floor was thought to be
      - feature-less plain
        - called the abyssal plain

26 Sea floor topography

- historical perspective
  - declassification of sonar
    - helped document presence
      - mid-ocean ridges

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28 Sea floor topography

- Mid-Atlantic Ridge
  - under water mountain range
    - longest mountain range on earth
  - runs down middle of Atlantic Ocean
    - roughly equidistant between continents

29 Age of volcanic islands in Atlantic

- age of islands in Atlantic Ocean
  - increase the farther they are to either side of Mid-Atlantic Ridge

30 Sea floor magnetism & spreading

- Earth's magnetic field
  - strong
  - dipolar

31 Sea floor magnetism & spreading

- Earth's magnetic polarity
  - present north magnetic pole is located near the north geographic pole
  - south magnetic pole is located near the south geographic pole

32 Sea floor magnetism & spreading

- Interest in continental drift
  - revived during 1950s
    - result of paleomegnetism studies
  - paleomagnetism
    - remnant magnetism in ancient rocks
    - records direction of Earth's magnetic poles at time of rock's formation
      - magnetic iron-bearing minerals (usually magnetite) align themselves with

Earth’s magnetic field, “freeze” in place
- recording direction and strength

33 Sea floor magnetism & spreading

- Magnetic reversals
  - in geologic past
    - earth’s magnetic field has reversed, 180 degrees opposite of present
    - reversals are recorded in rock

34 Sea floor magnetism & spreading

- magnetic anomalies
  - average regional magnetic field of earth
    - magnetic field at a point
- can be measured, values displayed graphically

35 Sea floor magnetism & spreading

- magnetic stripes
  - discovered during oceanographic research in 1960s
    - resulted from plotting magnetic anomalies measured on ocean floor
      - produced pattern of “stripes”
        - first seen in Atlantic, later in Pacific
  - striping patterns were symmetrical about mid ocean ridges

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37 Sea floor magnetism & spreading

- magnetic stiping
  - led to development of
    - theory of sea floor spreading
      - proposed in 1962 by Harry Hess, Princeton University
      - helps accounts for continental movement

38 Sea floor magnetism & spreading

- sea floor spreading
  - sea floor separates at mid-oceanic ridges
    - new crust forms by upwelling magma
      - as it cools
      - newly formed crust moves laterally away from ridge over time

39 Sea floor magnetism & spreading

- during sea-floor spreading
  - magnetic field of the rock is fixed, in alignment with the earth’s field, at time rock cools
    - after a polarity reversal
      - it will be aligned against (opposite) earth’s field

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41 Sea floor magnetism & spreading

- sea-floor spreading
  - mechanism to drive this system
    - thermal convection cells in mantle
      - hot magma rises from mantle
        - intrudes into fractures along mid ocean ridges, forming new crust
    - cold crust is subducted back into mantle at deep-sea trenches
      - where it is heated and recycled, completing cell

42 Sea floor magnetism & spreading

- Mechanism
  - convection cells in mantle
  - example
    - heat beaker
    - water expands and rises
    - it spreads and cools at the top
    - cool water sinks

43 Sea floor magnetism & spreading

- sea-floor spreading
  - consequence
    - ocean basins are geologically young features
      - continental fossils are at least 3.5 billion years old
      - oldest marine fossils are about 180 million years
      - there is relatively little sediment

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45

46 Plate tectonics

47 Plate tectonics

- Plates
- types of plate boundaries

48 Plate tectonics

- Plates
  - consist of lithosphere (oceanic and continental crust) and underlying mantle
  - vary in thickness
    - up to ~250km thick
      - upper mantle + continental crust
    - up to ~100km thick
      - upper mantle + oceanic crust

49 Plate tectonics

- Plates
  - lithosphere overlies hotter and weaker semi-plastic asthenosphere
    - heat transfer system in asthenosphere causes overlying plates to move
  - as plates move over asthenosphere
    - they separate
      - mostly at mid ocean ridges
    - collide and are subducted back into mantle
      - in areas such as ocean trenches

50 Plate tectonics

- Plate movements
  - plates move slowly (up to 15 cm/yr)
  - may collide, move apart, or slide past each other
  - friction during plate movement often generates earthquakes

51 Plate tectonics

- Plate boundary types
  - divergent plate boundaries
  - convergent plate boundaries
  - transform faults

52 Plate tectonics

- Plate boundary types
  - divergent plate boundaries
    - plates move apart in opposite directions
    - crust is extended, thinned, and fractured as magma arises to surface
    - two types
      - oceanic
      - continental

53 Plate tectonics

- Plate boundary types
  - divergent plate boundaries
    - oceanic
      - produce mid-ocean ridges
        - ex., Mid-Atlantic Ridge
    - continental
      - produce rift valleys
        - ex., East African Rift Valley

54 Plate tectonics

- Plate boundary types
  - convergent plate boundaries
    - older crust is destroyed and recycled
    - two plates collide
      - leading edge of one plate descends beneath margin of other via
        - subduction

55 Plate tectonics

- Plate boundary types
  - convergent plate boundaries
    - subduction
      - key is density of rock types involved
        - density = mass/unit volume
      - more dense plate will be subducted downward (sink) under less dense plate
        - density differences as small as 1% are enough to cause subduction

56 Plate tectonics

- Plate boundary types
  - convergent plate boundaries
    - subduction
      - subducting plate moves downward into the asthenosphere
        - is heated and is incorporated into mantle
      - results in regional seismic and volcanic activity
    - trench usually forms at boundary between two converging plates

57 Plate tectonics

- Plate boundary types
  - convergent plate boundaries
    - characterized by
      - defromation
      - volcanism
      - mountain building
      - metamorphism
      - seismicity
      - important mineral deposits

58 Plate tectonics

- Plate boundary types
  - convergent plate boundaries
    - three types
      - oceanic-oceanic
      - oceanic-continental

        - continental-continental

59 Plate tectonics
- Plate boundary types
  - convergent plate boundaries
    - oceanic-oceanic
      - two oceanic plates converge
      - subducted plate bend downward to form outer wall of an oceanic trench
        - leads to formation of a volcanic island arc

60 Plate tectonics
- oceanic trench
  - subducted plate
    - bends downward
    - drags part of surface with it
    - forms outer wall of trench
  - marks top of subduction zones

61 Plate tectonics
- Volcanic island arc
  - subducted plate descends into mantle
    - is heated and partially melted
    - produces magma that is less dense than mantle rocks
      - less dense magma rises to surface
        - forming a curved (plane intersecting sphere) chain of volcanic islands called a volcanic island arc
  - examples
    - Japan, the Philippines, and Indonesia are examples

62 Plate tectonics
- Plate boundary types
  - convergent plate boundaries
    - oceanic-continental
      - oceanic and continental plate converge (collide)
      - denser (3.28 g/cm^3) oceanic plate is subducted under less dense (3.0 g/cm^3) continental plate
        - forms outer wall of oceanic trench
        - leads to formation of a volcanic mountain chain

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64 Plate tectonics
- Volcanic mountain chain

- subducted oceanic plate descends into mantle
  - is heated and partially melted
  - produces magma that is less dense than mantle rocks
    - less dense magma rises to surface inland of the coast
      - forming a chain of volcanic mountains
- examples
  - Andes Mountains (South America)
  - Cascade Mountains (North America)

65 Plate tectonics

- Plate boundary types
  - convergent plate boundaries
    - continental-continental
      - two continental plates converge
      - both plates are of roughly equal density
        - neither plate can be subducted
        - one plate mayslide partly under the other
        - leads to formation of interior mountain belts and seismic activity

66 Plate tectonics

- Plate boundary types
  - transform plate boundaries
    - two plates move past one another in opposite directions
      - along fractures known as transform faults
      - majority are in ocean crust
        - may along extend into continents
    - associated with seismic activity
    - example
      - San Andreas fault
        - separates Pacific plate from North American plate

67 Figure: San Andreas fault

68

69

70

71 Earthquakes

72 Earthquakes

- definition
- cause
- features

        - fault
        - focus
        - epicenter
    - measurement and rating
    - primary effects
    - secondary effects

73 Earthquake- definition & cause

- sudden motion or trembling in Earth along an existing fault
    - caused by abrupt release of slowly accumulated strain
        - strain
            - change in shape or volume of a body as a result of stress

74 Earthquake- features

- fault
- focus
- epicenter
- foreshocks
- aftershocks

75 Earthquake- features

- fault
    - fracture in rock of earth’s crust
        - along which bodies of rock move past each other
        - results from stress in earth’s crust

76 Earthquake- features

- focus
    - initial rupture point of an earthquake
        - where strain energy is first converted to elastic wave energy
    - point within Earth which is center of an earthquake

77 Earthquake- features

- Depth of focus
    - earthquakes can be classified by
        - depth of focus below the surface
            - shallow
                - 0-70 kilometers
            - intermediate
                - 70-300 kilometers
            - deep
                - 300-700 kilometers

78 Earthquake- features

- epicenter

    - point on Earth's surface directly above focus of an earthquake

79 Earthquake- features
- foreshocks
  - shock waves
    - released from seconds to weeks before main shock
- aftershocks
  - shock waves
    - follow main shock of an earthquake for up to several months
    - often decreasing in frequency and magnitude over time

80 Earthquake- measurement
- device
- scales

81 Earthquake- measurement
- device
  - seismograph
    - instrument that detects, magnifies, and records vibrations of Earth, especially earthquakes
    - resulting record is a seismogram

82 Earthquake- measurement
- Seismogram example
  - shows earthquake
    - three different traces represent vibrations in different directions

83 Earthquake- measurement
- Scales
  - attempt to measure severity of earthquake
    - do not directly measure amount of energy released
      - imply it
  - examples
    - Richter scale
    - Mercalli scale

84 Earthquake- measurement
- Richter scale
  - measures vibrational amplitude of earth's movement in response to seismic waves
  - does NOT measure energy released
  - produces numerical scale of earthquake magnitude
    - as indicated by amplitude (size) of earth's vibrations

85 Earthquake- measurement
- Richter scale
  - devised in 1935 by the seismologist C.F. Richter

- local quake magnitude
  - logarithm, to base 10, of amplitude in microns of largest trace deflection that would be observed on a standard seismograph at a distance of 100 km from epicenter

86 Earthquake- measurement

- Richter scale
  - generalized severity rating
    - insignificant
      - < 4.0 on Richter scale
    - minor
      - 4.0 - 4.9 on Richter scale
    - damaging
      - 5.0 - 5.9 on Richter scale
    - destructive
      - 6.0 - 6.9 on Richter scale
    - major
      - 7.0 - 7.9 on Richter scale
    - great
      - ≥ 8.0 on Richter scale

87 Earthquake- measurement

- Richter scale
  - great
      - ≥ 8.0 on Richter scale
      - releases equivalent of 1 billion tons of TNT or more, over a period of 1-2 minutes
      - most intense energy release per unit time of any natural event
  - there is no upper limit
    - Chile, 1960, largest observed to data = 9.5 on Richter scale
    - San Francisco, 1906 = 7.9 on Richter scale

88 Earthquake- measurement

- Mercalli scale
  - does NOT measure energy released
  - arbitrary scale of earthquake intensity
  - ranges from
    - I (detectable only instrumentally) to
    - XII (causing almost total destruction)

- based on
  - human perception of earthquake
  - damage observed after earthquake

89 Average annual number of earthquakes by magnitude

90 Earthquake - Effects

- Earthquakes
  - can cause damage in a number of ways
  - primary effects
  - secondary effects

91 Earthquakes - Primary Effects

- Primary effects
  - direct effects from movement of earth on
    - people
    - buildings
    - bridges
    - overpasses
    - dams
    - pipelines
  - movements include
    - shaking
    - possible permanent vertical or horizontal displacement of ground

92 Earthquakes - Secondary Effects

- Secondary effects
  - indirect effects on movement of earth
  - include
    - tsunami
    - seiche
    - landslide
    - liquefaction
    - fire
    - disease

93 Earthquakes - Secondary Effects

- Tsunami
  - large, water waves produced by any large-scale, short-duration disturbance of ocean floor
    - also called “tidal waves”
      - misnomer - nothing to do with tides
  - caused
    - principally, by shallow submarine earthquake

        - also by submarine earth movement, subsidence, or volcanic eruption

94 Earthquakes - Secondary Effects

- Tsunami
    - can severely damage coastal areas
    - can travel up to ~950 km/h (~590m/h)

95 Earthquakes - Secondary Effects

- seiche
    - wave oscillation of surface of water in an enclosed or semi-enclosed basin (as a lake, bay, or harbor)

96 Earthquakes - Secondary Effects

- landslide
    - mass movement of rock and sediment on unstable slopes
    - can be triggered by earthquakes
    - occurrence and severity can be increased
        - after fire removes vegetation, or clear-cutting of forests

97 Earthquakes - Secondary Effects

- liquefaction
    - process of changing soil and unconsolidated sediments into a water mixture after an earthquake
        - young, water-saturated, well-sorted, fine grain sands and silts behave as viscous fluids rather than solids
    - can lead to ground failure and foundation failure
        - ground slides under building foundation

98 Earthquakes - Secondary Effects

- Fire
    - often does more damage than earthquake itself
    - results from
        - ruptured, spilled underground or above ground pipelines or tanks
        - lack of water due to water lines break s
        - inability to access fire due to blocked streets
        - downed electrical lines
            - may spark, setting off fires
            - may prohibit communication requesting fire-related assistance

99 Earthquakes - Secondary Effects

- disease
    - resulting from
        - poor sanitation
            - broken sewer and water lines
        - contaminated drinking water
            - broken water lines
        - increases in populations of disease vectors
            - such as mosquitoes

100 Volcanoes and Volcanism

101 Volcanoes

- definition
- cause
- form
- locations
- types of releases
- effects
- example

102 Volcanoes - definition

- Volcano
  - definition
    - vent in crust of Earth through which magma reaches surface
      - lava = magma that reaches surface

103 Volcanoes - causes

- Volcano
  - causes
    - diverging plate boundaries
      - allow magma from mantle to penetrate crust
    - converging plate boundaries
      - subducted (sinking) crust melts to form magma which rises and penetrates plate and reaches surface

104 Volcanoes - form

- Volcano
  - form
    - varied
      - usually conical
        - results from ejected material

105 Volcanoes - locations

- Volcano
  - locations

        - tend to occur in belts associated with locations of plate boundaries
    - "ring of fire"
        - ring of volcanoes around Pacific Rim

106 Volcanoes - types of releases

- Volcano
    - types of releases
        - ejecta
        - liquid lava
        - gases

107 Volcanoes - types of releases

- Volcano
    - types of releases
        - ejecta
            - debris ranging from large chunks of lava rock to ash (may be glowing hot)

108 Volcanoes - types of releases

- Volcano
    - types of releases
        - liquid lava
            - molten rock (magma) that has reached surface
            - may be spewed, or released slowly

109 Volcanoes - types of releases

- Volcano
    - types of releases
        - gases
            - water vapor, carbon dioxide, sulfur dioxide

110

111

112 Volcanoes - effects

- lava flows
- ash deposition
- mud slides
- "blast" zones
- toxic gas
- seismic sea waves
- atmospheric dust

113 Volcanoes - effects

- effect on climate
    - atmospheric dust
        - blocks great deal of sun's energy from reaching earth's surface
            - cools climate until particles sink to surface

114 Krakatau Volcano

- located in Sunda strait between islands of Java and Sumatra
- eruption occurred 8/26-28/1883
  - series of violent explosions
  - audible across 10% of Earth's surface
  - displaced 20 cubic km (5 cubic miles) of lava, rock, ash
  - produced seismic sea waves
    - destroyed 165 coastal villages, killing ~36,000

115 Krakatau Volcano

- after eruptions
  - ~1/3 of original volume of island remained above sea level
  - volcanic ash (dust) in atmosphere caused
    - deep red sunsets, globally, for years
    - average global temperatures reduction of 1-2 degrees C
      - didn't return to normal for ~5 years

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117 Krakatau Volcano

118 The end