Earthquakes and the Earth's Interior
S=slide

S1 Earthquakes and the Earth's Interior

S2 What is an Earthquake?
"An earthquake is the vibration of Earth produced by the rapid release of energy"

The energy released moves in all directions from the focus (source)

S3 Earthquakes and Faults
'Energy release associated with atomic explosions and volcanic eruptions can produce an earthquake' – rare but seismic waves from these events are recorded
Earthquakes occur along existing faults
Faults are 'locked' until pressure is released in an earthquake

S4 Strike-Slip Faults: Shear
Strike-Slip faults have a sliding (shear) movement like Transform Boundaries

They can be right lateral or left lateral as defined by the motion of the opposite block

S5 Local Faults: Tri-Counties Area
Southern coastal California contains many Earthquake Faults

The red line shows the San Andreas

Ventura County is in the lower right of the map

S6 Reverse Fault: Compression

S7 Normal Faults: Tension

S8 A Type of Normal Fault:
Horst and Graben Systems

S9 Cause of Earthquakes
Work following the 1906 San Francisco earthquake found the horizontal surface displacement of several meters – Pacific Plate moved 4.7 meters (15') northward

Elastic Rebound – rock behaves elastically, it springs back to original shape after the break

S10 Elastic Rebound (Figure from text)

S11 A shows the fault (break in the rock)

In B strain is slowly building in the rock – the rock is bending and storing elastic energy on both sides of the fault

S12 In C the frictional resistance is overcome and the rock breaks (slippage)
In D the rocks return to their original shape (spring back) – the earthquake

S13 Foreshocks and Aftershocks
Foreshocks - small earthquakes that occur before a major earthquake – years to days before

Aftershocks – readjustments of the ground as it returns to the original shape, some can be strong enough to cause further damage

S14 San Andreas Fault
Possibly the most studied fault
Displacements occurs on segments 100 to 200 km long
Each segment behaves differently – some creep, some break often with small quakes, and others store energy over long hundreds of years before breaking (stick slip motion)

S15 Seismology
The study of earthquake waves

Seismograms – records of ground motion (elastic energy)

Body waves – travel through the Earth
- p waves are p primary waves
- s waves are secondary waves

Surface waves – travel along the Earth's surface

S16 Seismograph

S17 Seismogram – record of ground movement, each vertical line is a one minute interval

S18 Locating and Earthquake
Epicenter is the location on the surface directly above the focus
P waves always arrive before the S wave
The greater the time interval between the arrival of the P wave and the S wave the further away the earthquake source
Need information from three or more stations to triangulate

S19 About 95 % of the energy released by earthquakes originates in a few zones
Note the circum-Pacific belt and the zone through the oceans

S20 Measuring the Size of a Quake

Intensity is a measure of the degree of shaking at a given location based on the amount of damage

Magnitude is a calculation using seismic records to estimate the amount of energy released at the source (other techniques are used to calculate as well)

S21 Intensity Scales
Developed to standardize the study of earthquake severity

Based on individual descriptions of the event, secondary effects (landslides and ground rupture)
Modified Mercalli Intensity scale developed using California buildings as its standard but used around the world

S22 Magnitude Scales
Richter Magnitude (1935, Cal Tech) first magnitude scale using seismic records to estimate relative size of quake

Based on the amplitude of the largest seismic wave (p, S, of surface wave) on seismogram

S23 Method to measure magnitude and account for distance from the event using a Wood-Anderson seismograph
Find the amplitude of largest wave and the distance using the difference between P & S then connect a line between them

S24 Richter scale has no upper limit though largest recorded was an 8.9 (equivalent to the detonation of 1 billion tons of TNT)
New and more sensitive instruments can record tremors as small as -2
Logarithmic scale to express magnitude and a 32-fold energy increase
Richter scale originally designed for local events thus M_L

S25 Moment Magnitude
More precise measure (M_W) can be calculated using several techniques
Field studies using the average amount of displacement along the fault, area of rupture surface, and the shear strength of the rock (energy rock can store)
Calculated from very long period seismic waves – better measure for large earthquakes

S26 Moment Magnitude
Gained wide acceptance by seismologists and engineers
-It is the only magnitude scale for estimates of very large quakes
-it is a measure that can be derived mathematically form the rupture surface and displacement and is better at reflecting the energy released
-has two methods of verification

S27 Destruction from a Quake
Damage from seismic vibrations – ground shaking up and down and side to side

The amount of damage depends on; intensity, duration, type of material under the structure, and the design of the structure

S28 Diagram showing the types of ground movement

S29 Displacement (offset) by 1906 San Francisco Earthquake
Near Point Reyes in 1906 the maximum fault offset was estimated from 15 to 21+ feet (in about 40 seconds)
Fires raged & created 95% of damage

S30 Destruction from a Quake
Amplification of seismic waves
soft sediments generally amplify the vibrations more than solid bedrock
Liquefaction – unconsolidated material saturated with water turns to a mobile fluid that cannot support structures
Tsunami or seismic sea wave can be generated by vertical displacement along a fault on the ocean floor or a landslide

S31 Liquifaction
Mud volcanoes from the Loma Prieta earthquake – geyser of sand and water shot from the ground

S32 Tsunami - Once formed they resemble ripples in a pond but move across the ocean at speeds between 500 and 950 km/hr (300-600 miles/hr). A boat on the open ocean may not detect them because the height is generally less than 1 m and the wavelength ranges from 100 to 700 km (62-435miles)
When the wave approaches shore it slows and the water piles up to heights that can exceed 30 m (100 ft)

S33 Tsunami travel times in the Pacific Ocean
(figure from text)

S34 Landslides and Ground Subsidence – triggered by vibrations from an earthquake
Clay layer was weakened and slump occurred (mass wasting)

S35 Earthquakes East of the Rockies
Six major earthquakes since Colonial times
Three with magnitudes of 7.5, 7.3, and 7.8 in the Mississippi River Valley of Missouri – New Madrid – Dec. 1811 –Feb. 1812 felt in Virginia and Boston
1909 – Illinois, 1931 – Texas
1886 – Charleston, South Carolina – greatest historical quake – lasted one minute

S36 Earthquake Predictions
Short-range predictions – warning of location and magnitude of large earthquake over narrow time range (hrs to days), including precursors to forthcoming quakes – measures uplift, subsidence, and strain in rocks
Must have small range of uncertainty for location and magnitude few failures and false alarms

S37 Earthquake Predictions
Long-range predictions – probability of earthquake of certain magnitude occurring in 30 to 100 years or more
Good for updating building code
Based on idea that earthquakes occur in cycles – once quake is over the strain starts building in the rock until the next failure

S38 Note 30% in Santa Cruz area – Loma Prieta occurred in 1989, 90% in Parkfield area – 2004 a magnitude 6 earthquake

S39 The probability of a magnitude 6.7 or larger earthquake over the next 30 years striking the greater Los Angeles area is 67%, and in the San Francisco Bay Area it is 63%.

For the entire California region, the fault with the highest probability of generating at least one magnitude 6.7 quake or larger is the southern San Andreas (59% in the next 30 years).

For northern California, the most likely source of such earthquakes is the Hayward-Rodgers Creek Fault (31% in the next 30 years).

S40 Seismic Waves and the Earth's Interior
Can't dig our way into the interior of the Earth (best to date is 1/500th of the way to the center)
Many earthquakes are large enough that seismic waves travel all the way through and are recorded on the other side

S41 Seismic waves usually do not travel along a straight path

S42 Seismic waves are reflected, refracted, and diffracted as they travel through the Earth
Reflect off boundaries between different layers
Refract – bend – going from layer to another
Diffract around obstacles encountered

S43 Profile or cross section showing a seismic wave crossing the boundary into and out of the mantle compared to one that does not cross the boundary

S44 Seismic wave velocity generally increases with depth

Seismic waves travel faster when rock is stiffer of less compressible – hot rock is less stiff than cold rock – waves travel slower
Seismic waves travel at different speeds through different material
Seismic waves can be used to tell composition and temperature

S45 Formation of Layered Structure
Accumulation of material to form Earth added heat and radioactive decay added to the heat – iron and nickel melt
Hot dense material sank to the core and buoyant melted rock rose toward the surface – formed the crust

S46 Internal Structure
Divisions based on physical properties – solid or liquid and weak or strong
Crust – thin outer skin –
    continental crust (granitic, density 2.7g/cm^3, thick – 35-40 km)
    oceanic crust (basalt, density 3.0 g/cm^3 and thin – 7 km)

S47 Internal Structure
Mantle– 82 % of Earth's volume – upper mantle is composed of peridotite
    lithosphere – crust and upper mantle, cool outer shell
    asthenosphere – some melting, weak zone, mechanically detached from lithosphere
    lower mantle 660 km to 2900 km (top of core) pressure strengthens the rock but can flow

S48 Internal Structure
Core – nickel-iron alloy with some oxygen, silicon, and sulfur
    density 11 g/cm^3
    outer core is liquid – movement causes magnetic field
    inner core is solid due to immense pressure