12.001 Introduction to Geology
Spring 2008

Earthquakes

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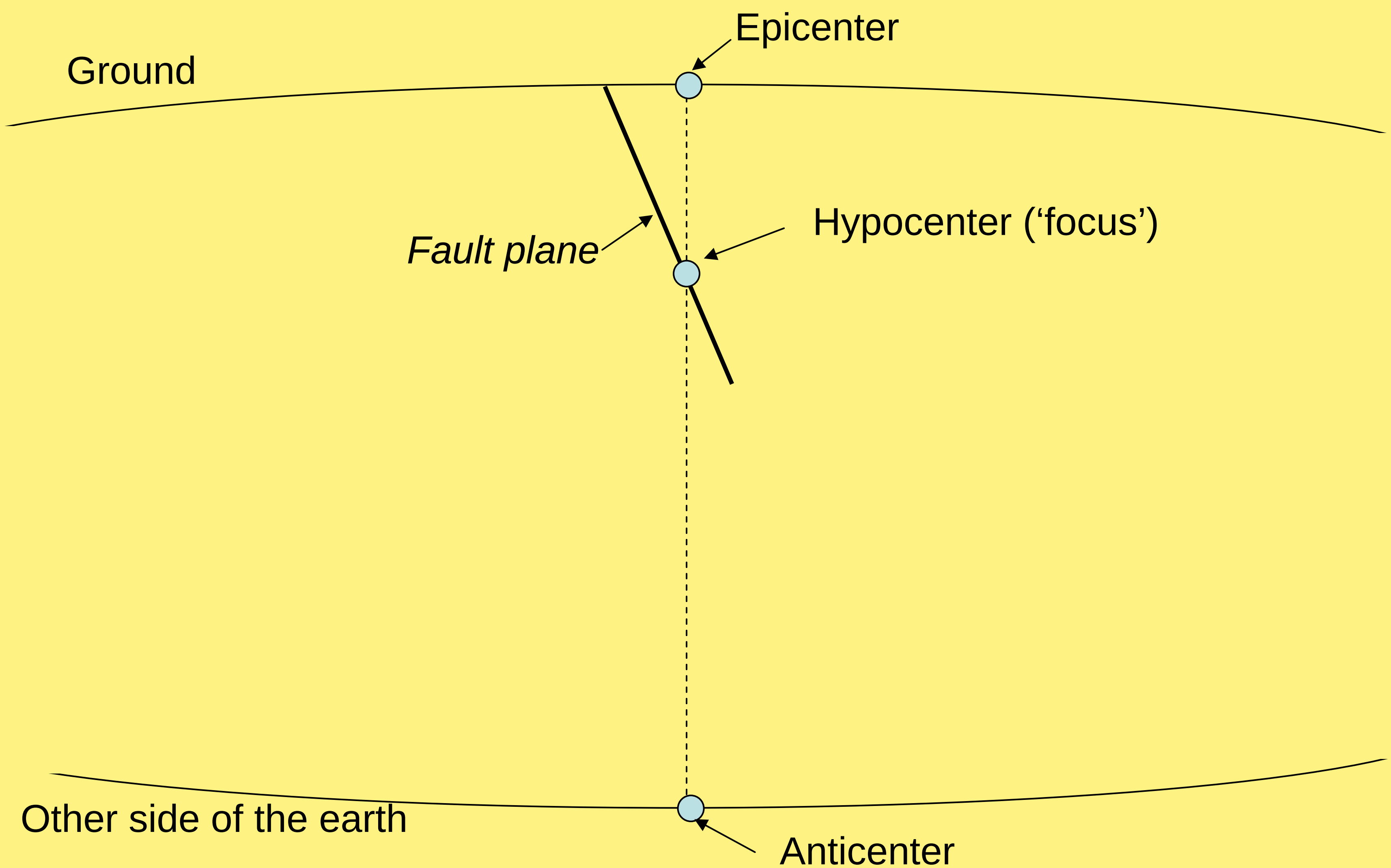
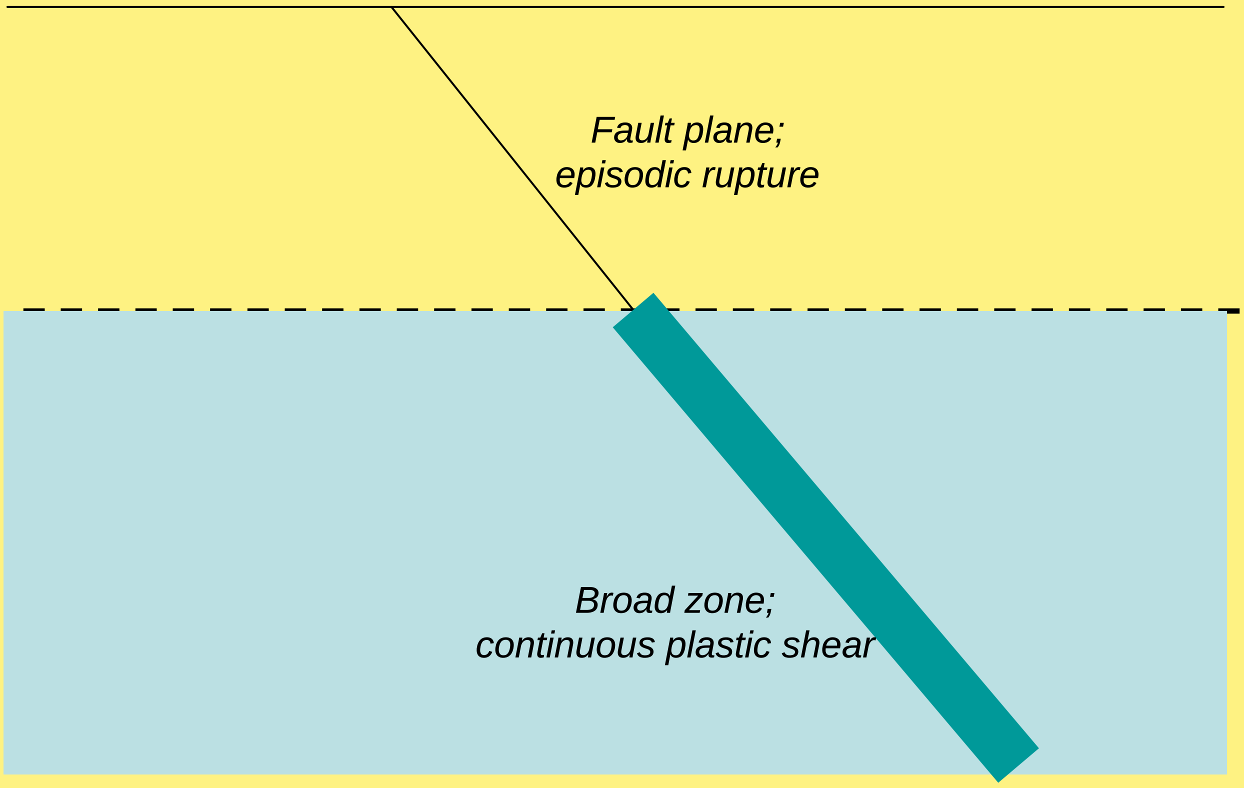
Ratnal, India after the 2001 magnitude 7.7 event

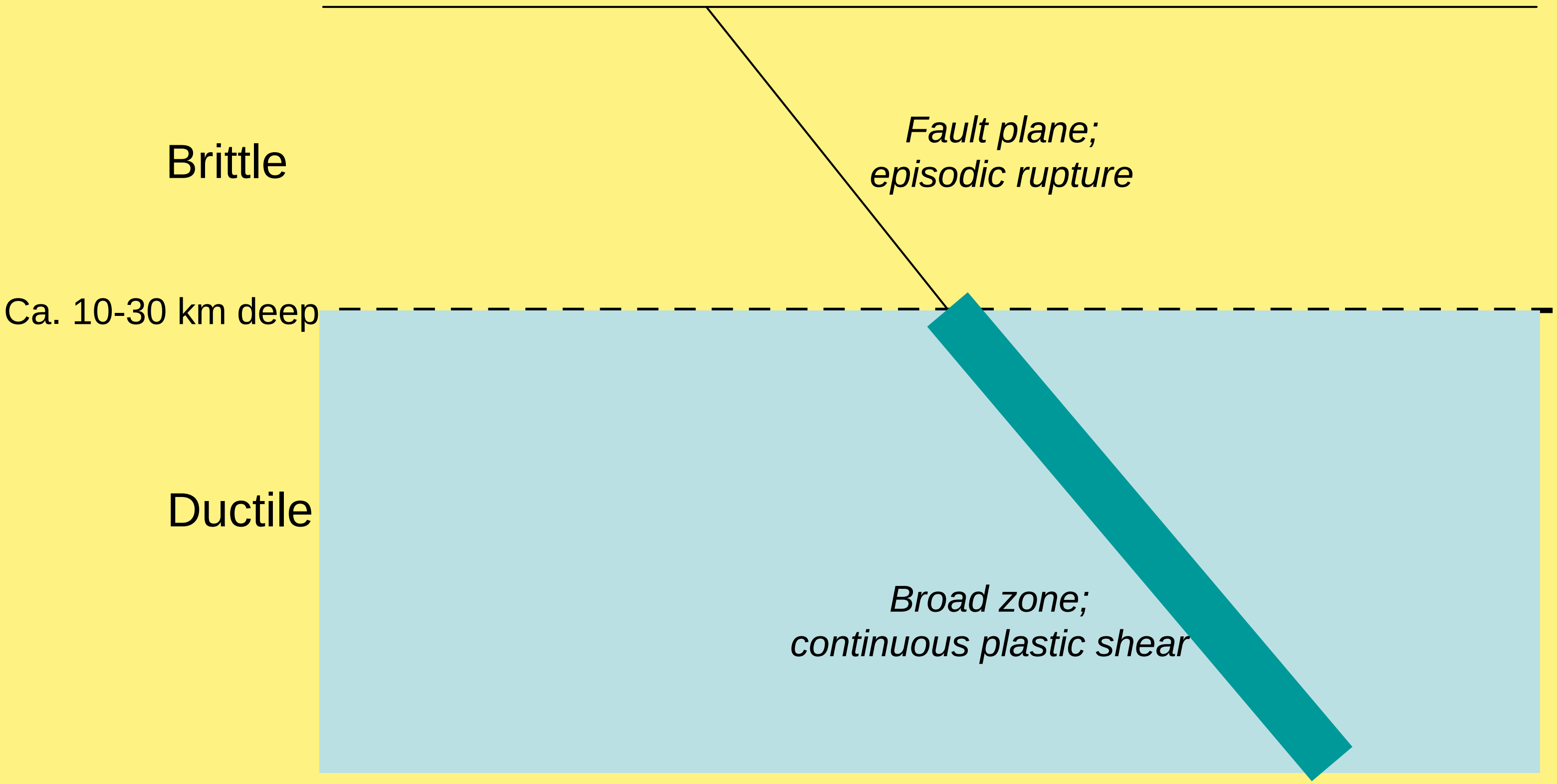
Earthquake nomenclature



Faults at depth



Faults at depth



Body waves

Two types of body waves.

P-waves =
Primary Waves =
first arrival

S-waves =
Secondary Waves =
second arrival

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P- and S-wave analogs

P-waves: **P**ressure, **P**rimary

Analogous to sound

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S-waves: **S**hear, **S**econdary

Analogous to light

Surface wave analogues

Rayleigh wave (analogous to ocean surface)

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Love wave (analogous to a snake or shaken rope)

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Surface wave analog II: Rayleigh waves

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A particle of water (or a boat) at the surface moves in a circular pattern, but stays at the same location.

At greater depth, the water particles also move in circles, but the circles are smaller.

Normal modes (natural or harmonic oscillations)

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Spheroidal (radial motion)

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Toroidal (torsional, shearing motion)

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On earth, periods are
ca. tens of minutes

Differing wave speeds

Granite (and Average Continental Crust)

6.0 km/sec

2.5 km/sec

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3.5 km/sec

3.0 km/sec

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Differences in density and other physical properties affect the velocity of seismic waves.

Seismic wave speed

- Surface and normal modes have complex velocity dependencies

- **Body waves are simpler (and more important for studying earth's interior)**

Velocity is proportional to: $\dfrac{\text{elastic modulus (stiffness)}}{\text{density (momentum)}}$

Elastic modulus = $\dfrac{\text{stress}}{\text{strain}}$

stress — $F/m^2 = kg/s^2m$

strain — Unitless; e.g., $^{\partial \text{Volume}}/_{\text{Volume}}$

Two elastic moduli:

- Bulk modulus (κ): isotropic compression; springiness of bonds
- Shear modulus (μ): resistance to change in shape

Seismic wave speed II

General relation: $V = (\text{modulus}/\rho)^{0.5}$

$$V_P = ([\kappa + 4/3\mu]/\rho)^{0.5}$$

$$V_S = (\mu/\rho)^{0.5}$$

- Which is faster, P or S?
- Since $\mu = 0$ in fluids, what happens to waves in the outer core?

Seismic wave speed III

General relation: $V = (\text{modulus}/\rho)^{0.5}$

$$V_P = ([\kappa + 4/3\mu]/\rho)^{0.5}$$

$$V_S = (\mu/\rho)^{0.5}$$

- For finite κ and μ, V_P must be faster than V_S
- $\mu = 0$ in fluids, so V_P drops sharply and V_S goes to 0 when waves hit a solid/fluid boundary

Waves are refracted and reflected from boundaries

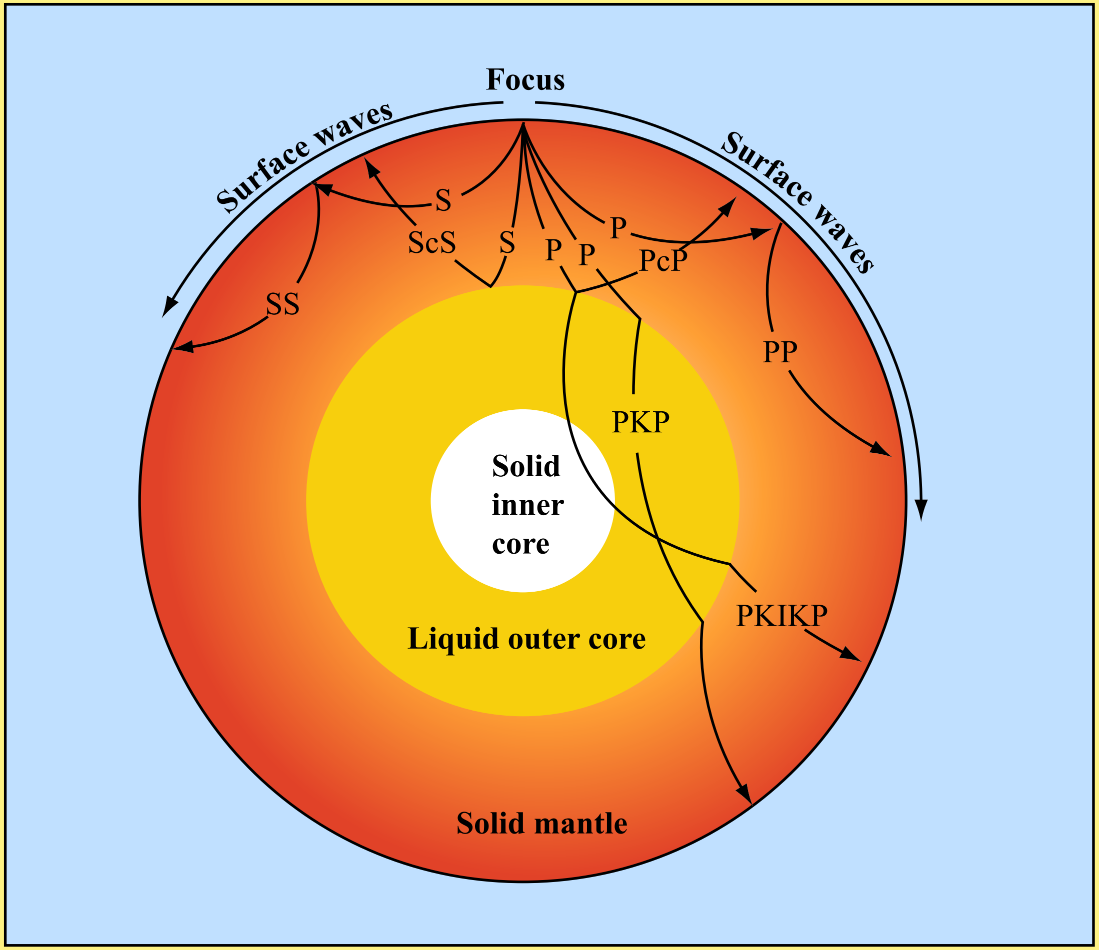

Figure by MIT OpenCourseWare.

Moment magnitude (total energy release)

Moment = Slip x Area x Elastic modulus

N·m — m — m^2 — $kg/s^2 \cdot m$

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Earthquake frequency and intensity

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Fig. 8.16ab

W. W. Norton. Modified from Dolgoff, 1996

Top 20 earthquakes of all time (USGS)

1960 05 22 - Chile - M 9.5
1964 03 28 - Prince William Sound, Alaska - M 9.2
2004 12 26 - Sumatra-Andaman Islands - M 9.1
1952 11 04 - Kamchatka - M 9.0
1700 01 26 - Cascadia Subduction Zone - M 9.0
1906 01 31 - Off the Coast of Ecuador - M 8.8
1965 02 04 - Rat Islands, Alaska - M 8.7
1755 11 01 - Lisbon, Portugal - M 8.7
2005 03 28 - Northern Sumatra, Indonesia - M 8.6
1957 03 09 - Andreanof Islands, Alaska - M 8.6
1950 08 15 - Assam - Tibet - M 8.6
1963 10 13 - Kuril Islands - M 8.5
1938 02 01 - Banda Sea, Indonesia - M 8.5
1923 02 03 - Kamchatka - M 8.5
1896 06 15 - Sanriku, Japan - M 8.5
2001 06 23 - Near the Coast of Peru - M 8.4
1933 03 02 - Sanriku, Japan - M 8.4
1905 07 09 - Mongolia - M 8.4
2006 11 15 - Kuril Islands - M 8.3
2003 09 25 - Hokkaido, Japan Region - M 8.3

The Mercalli Intensity scale

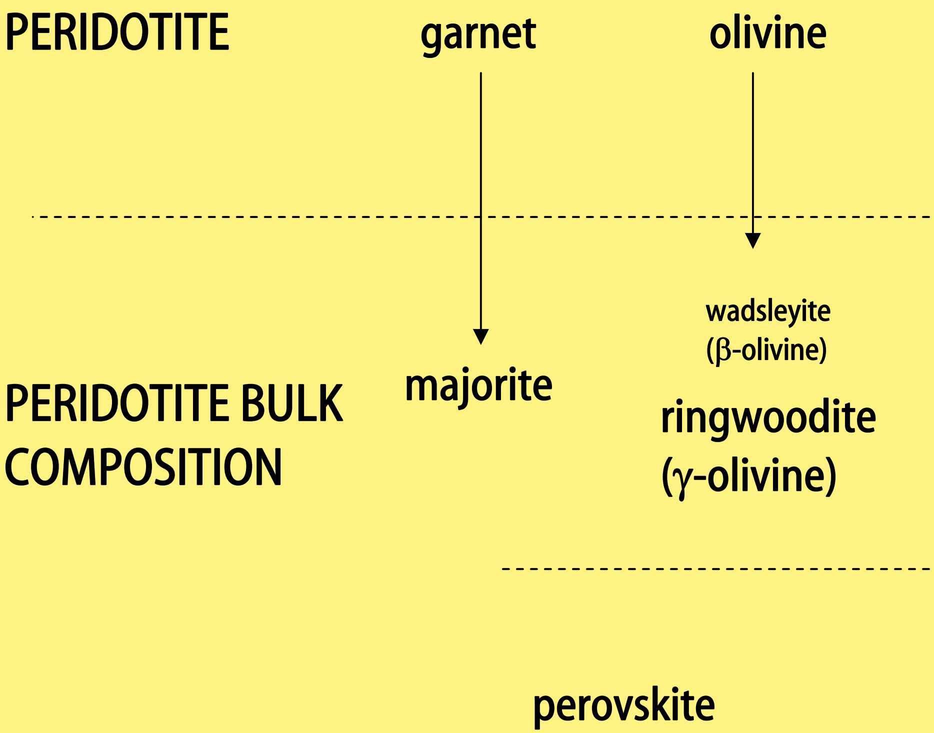
(earthquake intensities for people who don't like numbers and are easily scared)
(or for earthquakes that occurred before seimograph measurement)

Intensity Level	Description
I	Not felt.
II	Felt only by a few people at rest. Suspended objects may swing.
III	Felt noticeably indoors. Many people do not recognize it as an earthquake. Parked cars may rock slightly.
IV	Felt indoors by many, outdoors by few. Dishes, windows, doors rattle. Parked cars rock noticeably.
V	Felt by most; many awakened. Some dishes, windows broken. Unstable objects overturned.
VI	Felt by all. Some heavy furniture moves. Damage slight.
VII	Slight to moderate damage in well-built structures; considerable damage in poorly built structures; some chimney broken.
VIII	Considerable damage in well-built structures. Damage great in poorly built structures. Fall of chimneys, factory stacks, columns, monuments, walls.
IX	Damage great in well-built structures, with partial collapse. Buildings shifted off foundations.
X	Some well-built wooden structures destroyed; most masonry and frame structures destroyed. Rails bent.
XI	Few if many masonry structures remain standing. Bridges destroyed. Rails bent greatly.
XII	Damage total. Lines of sight and level are distorted. Objects thrown into the air.

Figure by MIT OpenCourseWare.

Board

Olivine and pyroxene polymorphs in the mantle change seismic velocity



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