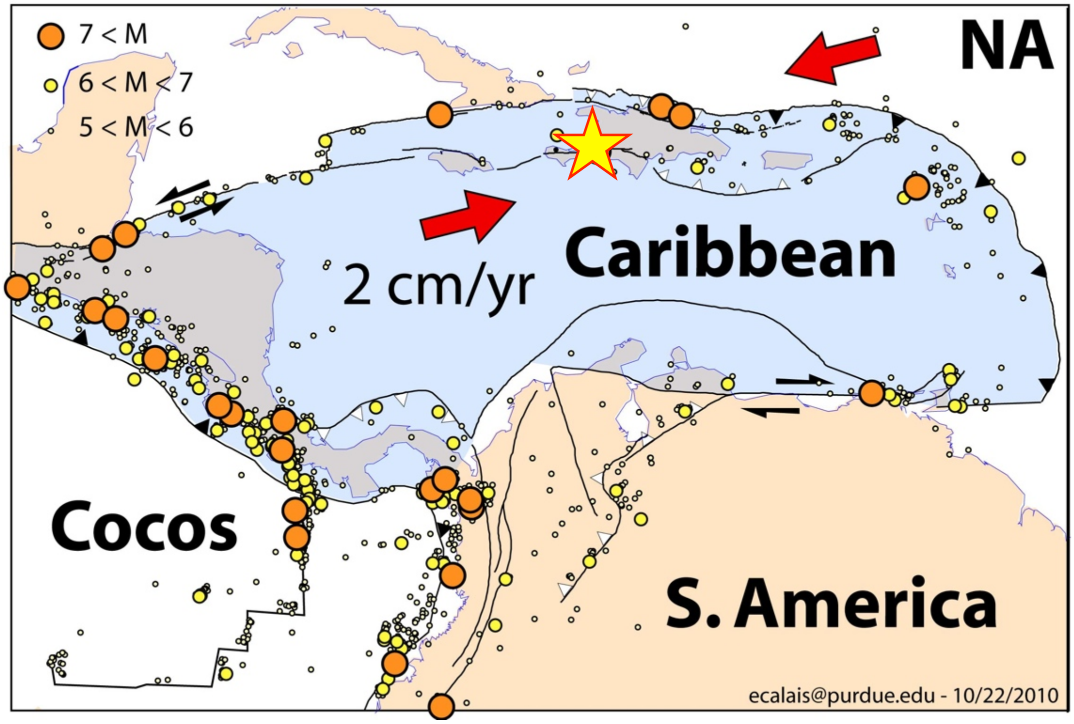
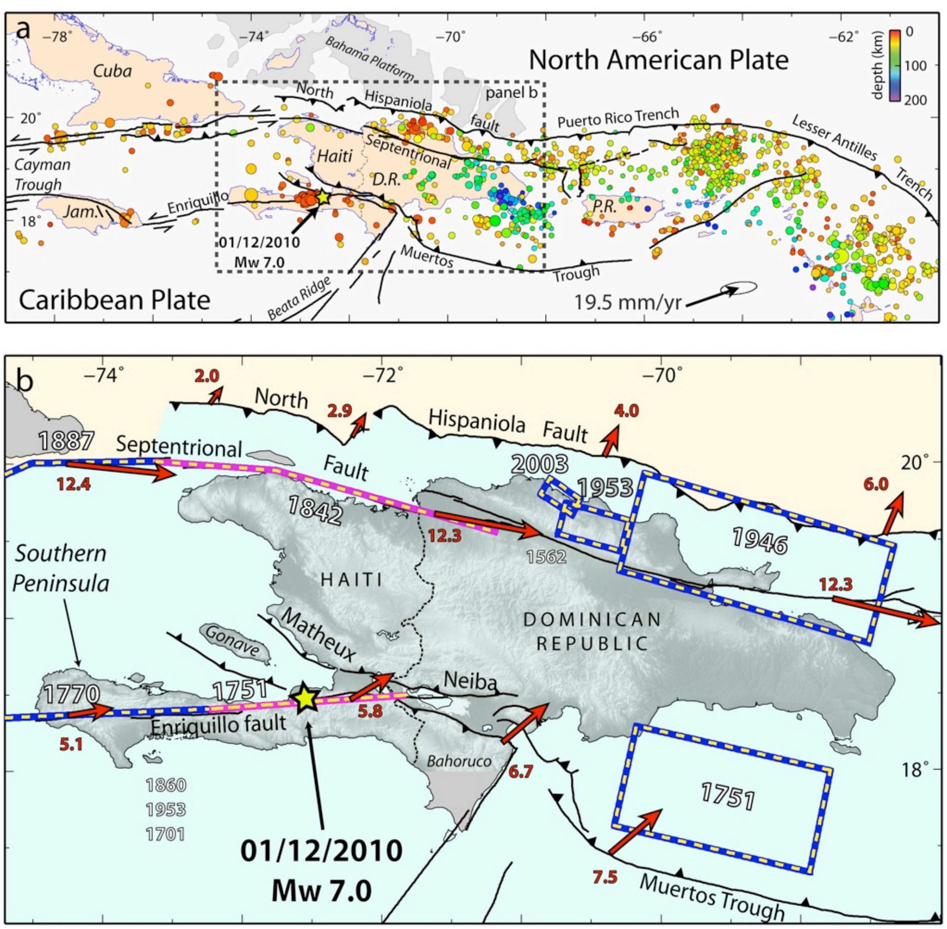
EOSC 562 Earthquakes

- course outline and policies
- my absences / Jan 13 or 14 seminar instead
- First intro lecture and (hopefully) discussion
- reading for next time

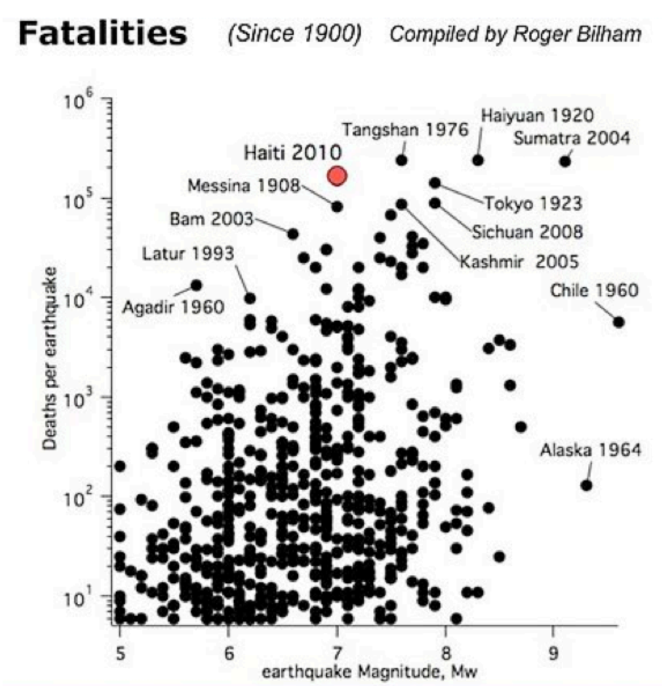
January 12, 2010
M 7 Haiti Earthquake:
<u>one year ago today</u>

Haiti is along the boundary between the Caribbean Plate and the North American Plate





From Calais et al., Nature Geoscience, 2011



Fatalities
(Since 1900)
Compiled by Roger Bilham
Haiti 2010
Tangshan 1976
Haiyuan 1920
Sumatra 2004
Messina 1908
Tokyo 1923
Bam 2003
Sichuan 2008
Latur 1993
Kashmir 2005
Agadir 1960
Chile 1960
Alaska 1964
Deaths per earthquake
earthquake Magnitude, Mw

Categories of faults, geometric description and symbols

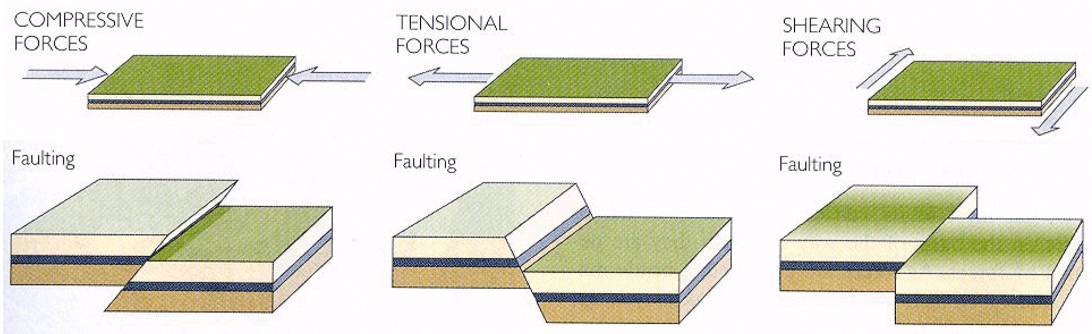
Plate boundaries and earthquakes

Geology of faults (descriptive)

Stress, strain, and faulting (mostly definitions)

Mercalli Intensity

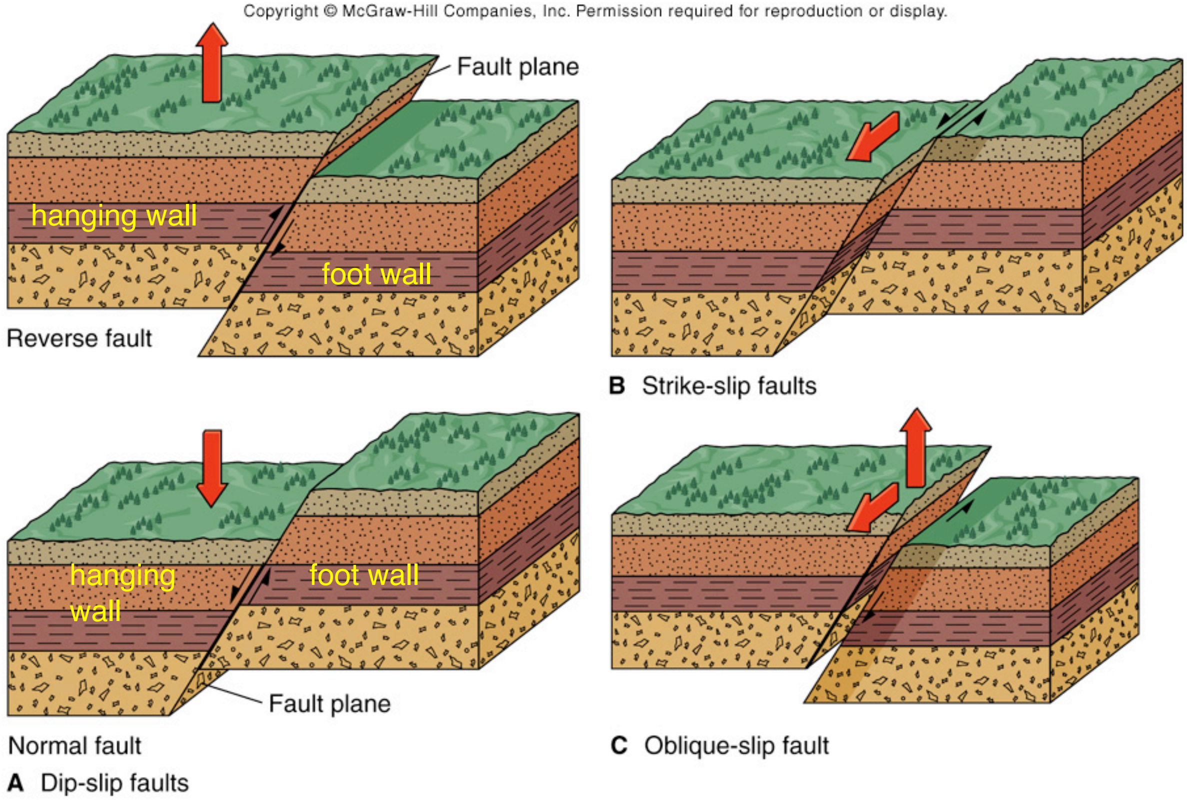
Magnitude



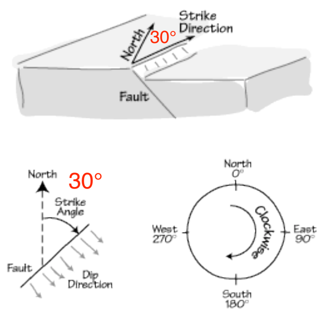
'reverse' or 'thrust' fault

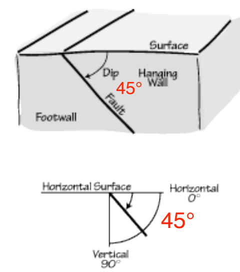
'normal' fault

'strike-slip' or 'transform' fault

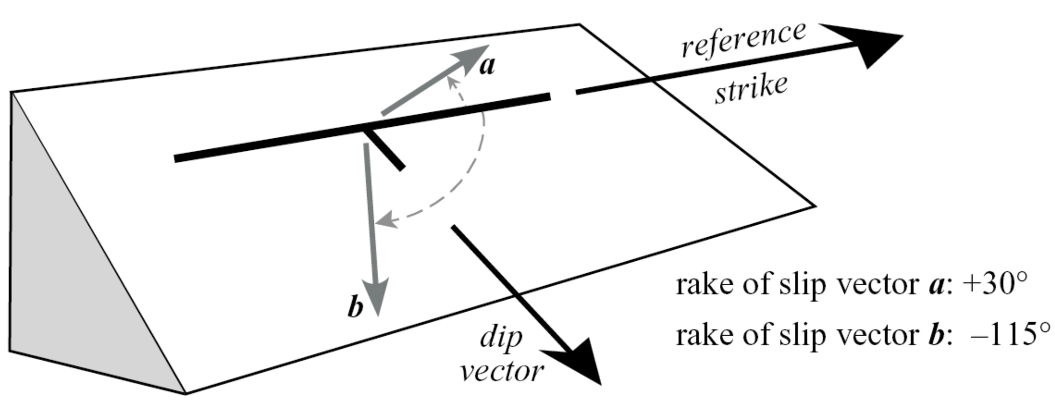


Fault surface orientation: strike and dip





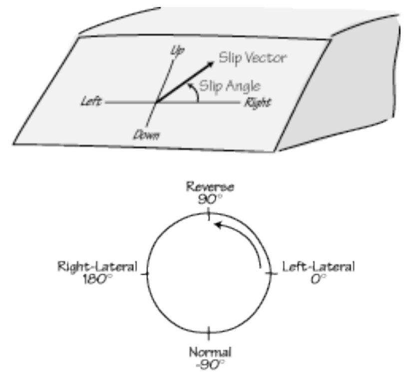
Indicating direction of slip quantitatively: the slip vector



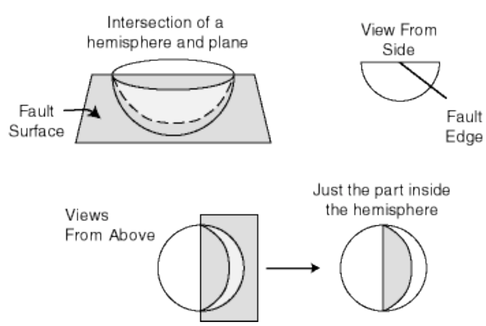
- let's define the slip direction (vector) in terms of the slip plane itself: "rake" of the slip vector, often just called "slip vector"

- convention: slip vector shows displacement of the hanging wall relative to the footwall, and values are from -180° to 180°

Slip vector convention

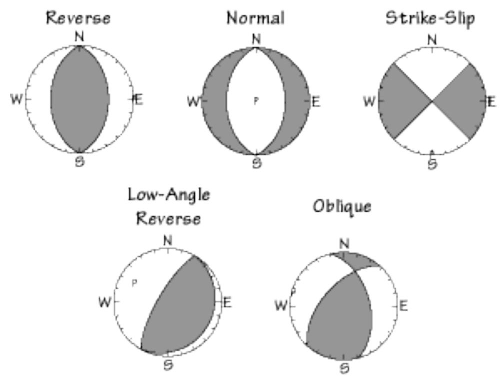


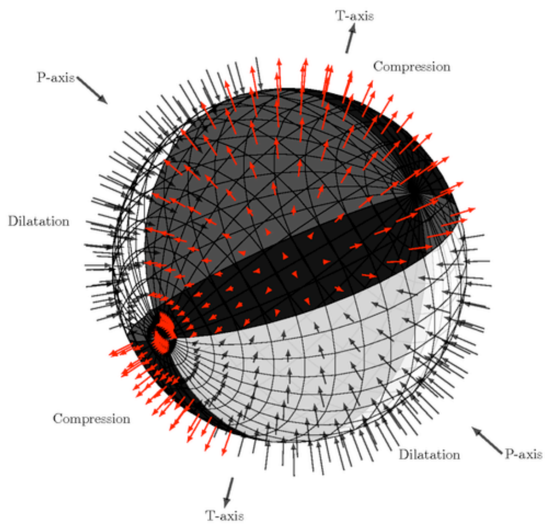
Fault plane may be shown in 2D by how it would intersect a bowl, as viewed from above



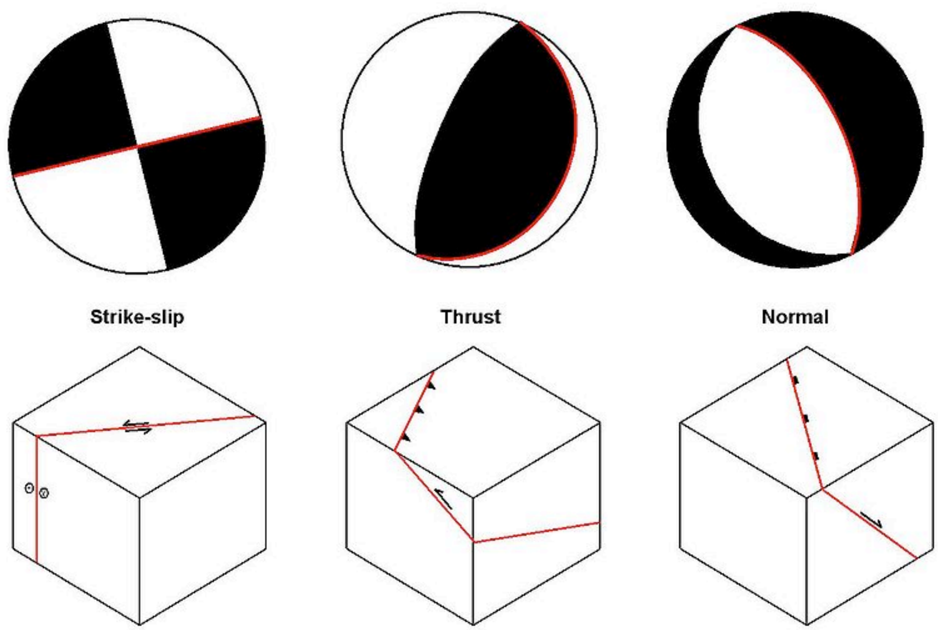
slip vector = intersection of this (slip) plane with another plane

"Beachball" symbol to express focal mechanism (fault plane orientation and slip vector)





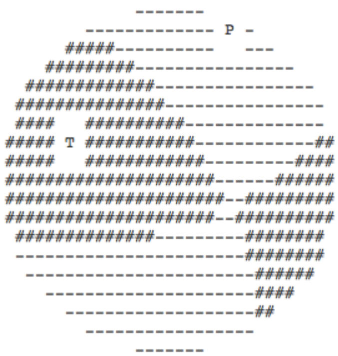
Seismic focal mechanism and Pression-Tension axis.



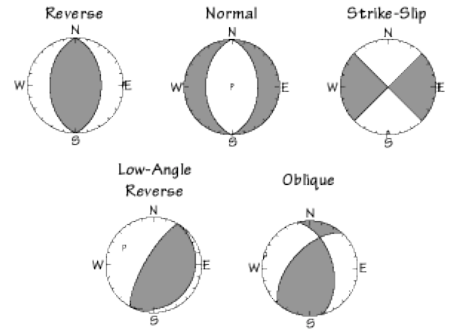
Types of 'beachball plot' associated with different fault end-members (nodal plane in red parallel to fault)

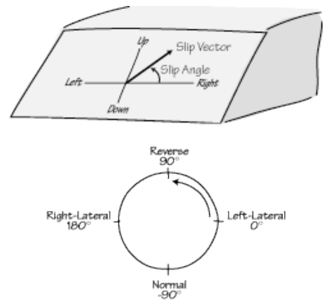
Haiti Earthquake focal mechanism

```
Best Double Couple:Mo=4.5*10**19
 NP1:Strike= 71 Dip=64 Slip=  25
 NP2:       330     68       151
```

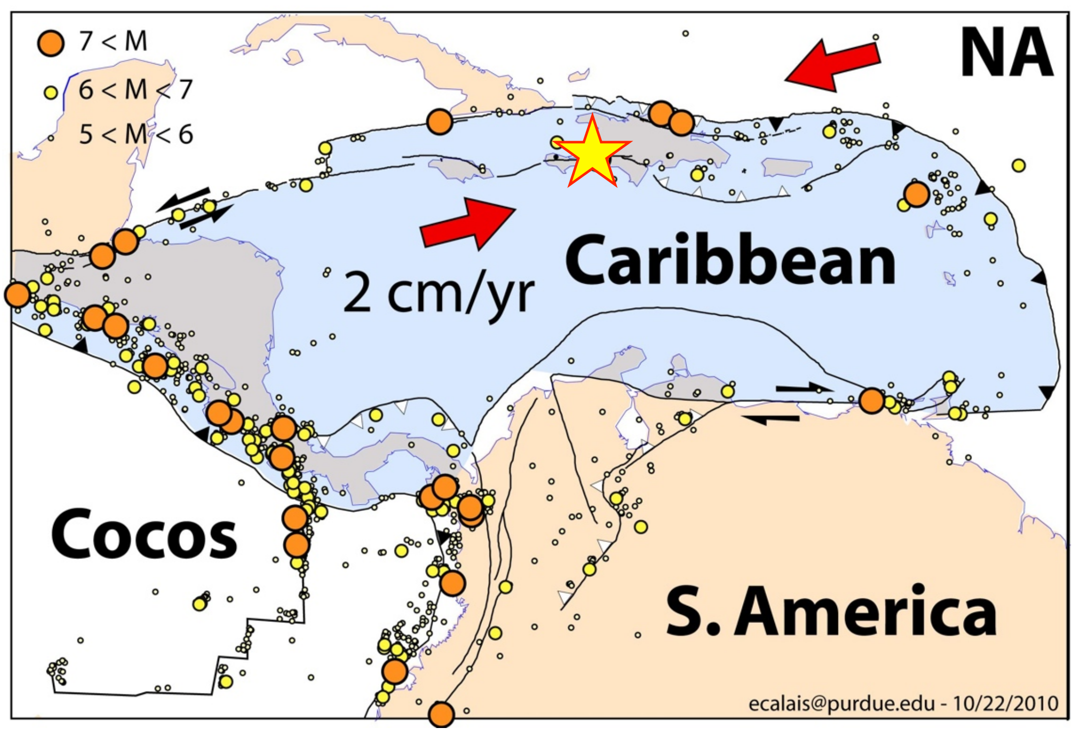


HAITI REGION
Mw 7.0
USGS Centroid Moment Tensor Solution





Left-lateral faulting earthquake makes sense... some oblique component, too.



Darfield Earthquake focal mechanism

```
PRINCIPAL AXES:
1.(T) VAL=  3.186;PLG= 8;AZM= 43
2.(N)       0.604;     81;    251
3.(P)      -3.790;      4;    134
BEST DBLE.COUPLE:M0= 3.49*10**26
NP1: STRIKE=179;DIP=82;SLIP=   3
NP2: STRIKE= 88;DIP=87;SLIP= 172

           -----######
       ---------##########
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       #########----------
           ######-----
```

Global CMT Project Catalog Search

```
Best Double Couple:Mo=3.5*10**19
 NP1:Strike=268 Dip=87 Slip=-166
 NP2:        178     77        -3

             ---####
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```
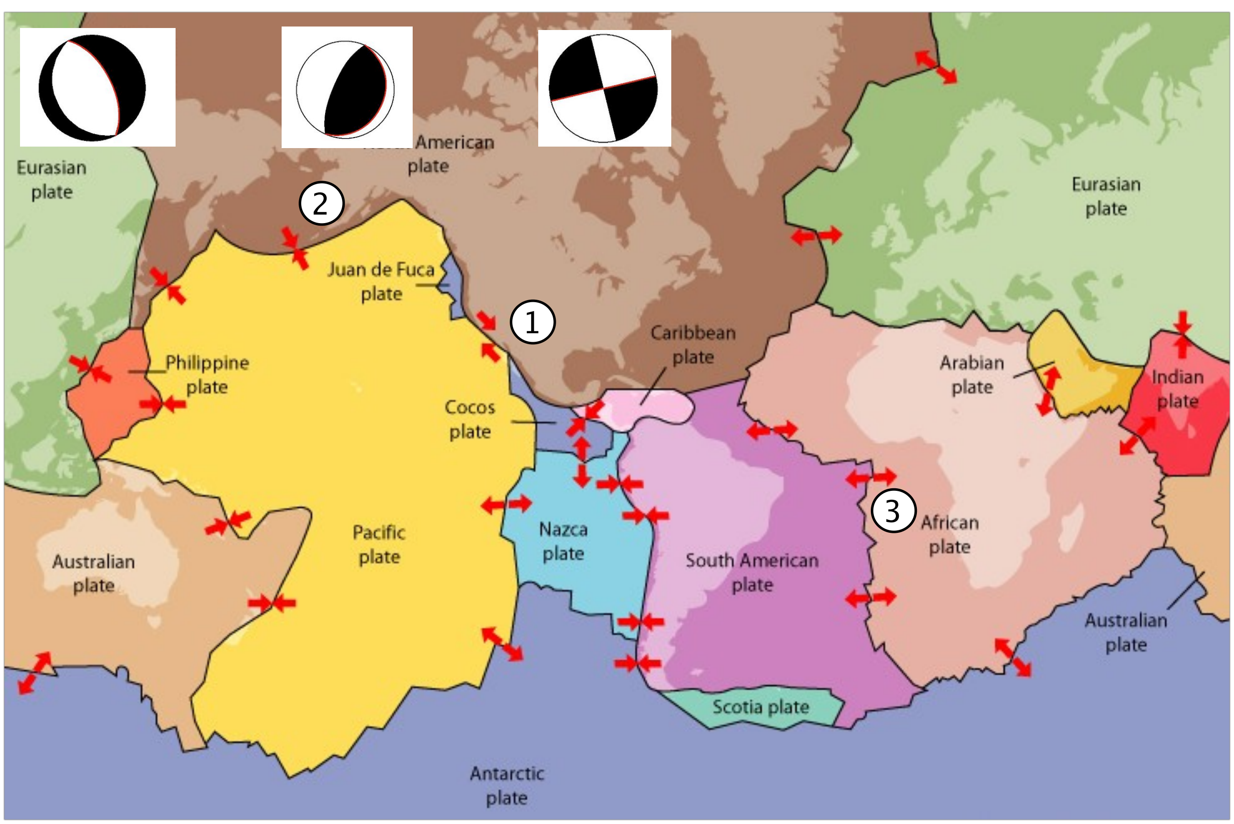

Faulting at plate boundaries



http://www.sciencelearn.org.nz/Contexts/Earthquakes/Sci-Media/Images/Tectonic-plate-boundaries

Strain

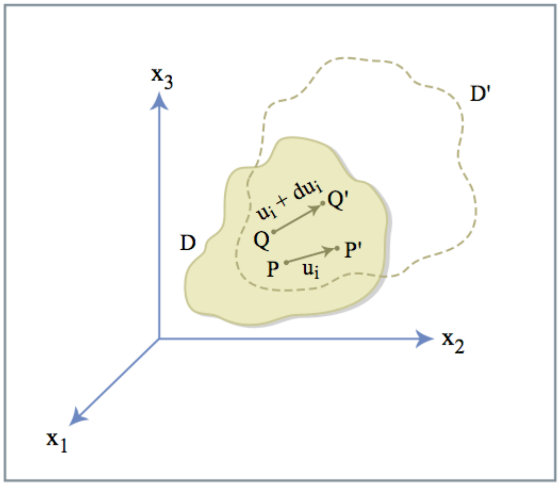


Figure 12.1
Figure by MIT OCW.

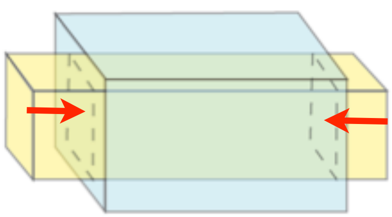
D and D' contain the same material but all points have moved.

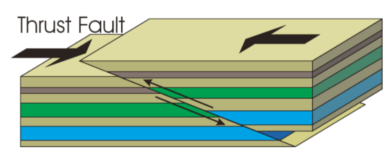
What are the possible ways to change the configuration of this stuff?

- translation
- rotation
- **strain** (distortion, i.e. change in shape and/or volume)

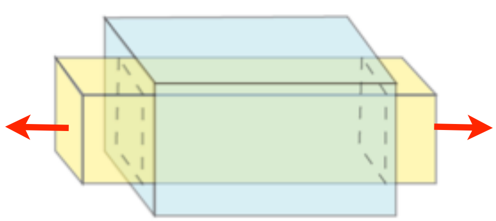
Types of stress (F/area) and resulting strain

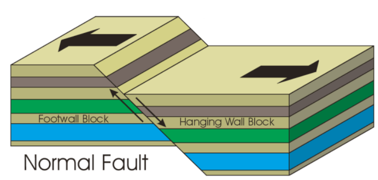
compression ("normal" stress and strain)



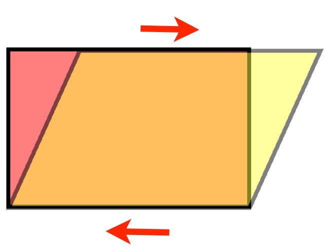


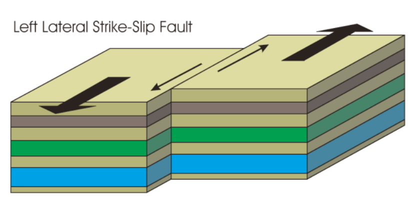
tension ("normal" stress and strain)





shear stress (and shear strain)





Stress and strain

- For ELASTIC materials, stress is proportional to strain (Hooke's law)
- Stress required to generate a certain amount of strain depends on Young's modulus E (infinite E means perfectly rigid)

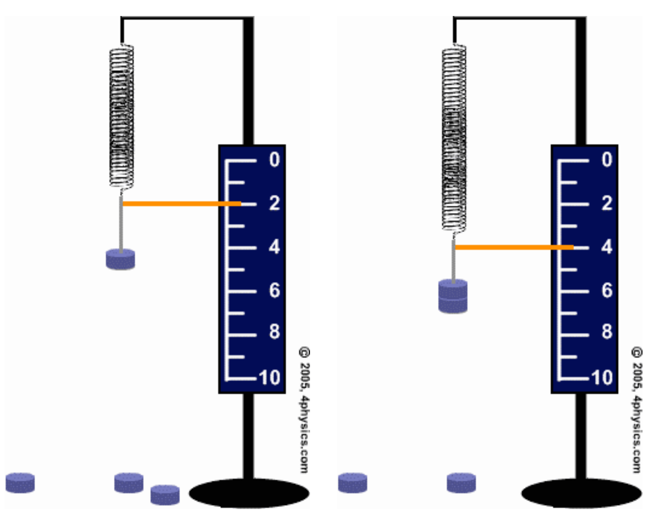
$$\sigma = E\epsilon$$

- Typical values of E for geological materials are 100 GPa (rocks) and 10 GPa (ice)

- For VISCOUS materials, stress is proportional to strain RATE
- Stress required to generate a certain strain RATE (i.e., flow) depends on viscosity η

$$\sigma = \eta\dot{\epsilon}$$

- Typical values of η for geological materials are 1e18-1e22 Pa s (upper mantle) 1e12-1e18 Pa s (ice)



Hooke's law in 1D: F = kx

Hooke's law in 3D:

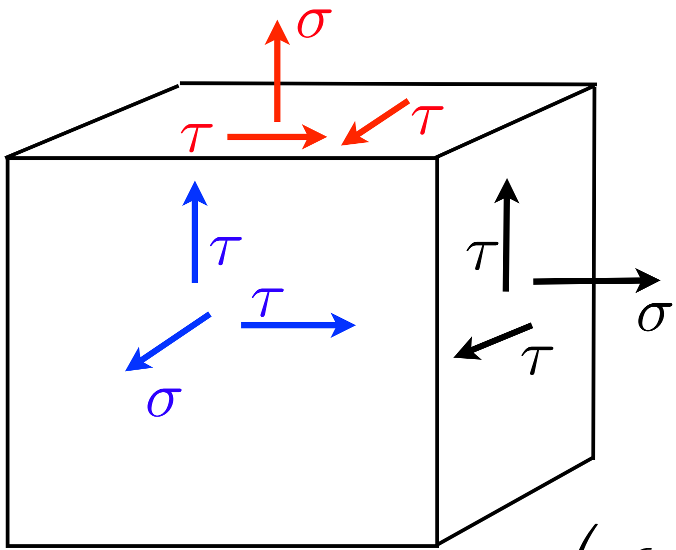
$$\sigma = E\varepsilon$$

Hooke's Law in 1D: all that matters is the lengthening of the spring.

In the Earth, stretching (or contraction) and distortion are three-dimensional.

This is strain, a second-order tensor.

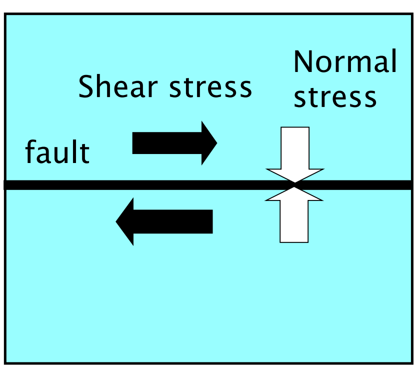
Stress is also a second-order tensor.



6 numbers are needed to describe stress (and strain) in 3D.

$$\begin{pmatrix} \epsilon_1 & \epsilon_6 & \epsilon_5 \\ \epsilon_6 & \epsilon_2 & \epsilon_4 \\ \epsilon_5 & \epsilon_4 & \epsilon_3 \end{pmatrix} = \epsilon$$

Faults & Byerlee's law



- Byerlee's law says that faults don't move unless the shear stress exceeds the normal stress times the static friction coefficient f $\tau = f\sigma_n$
- For almost all geological materials, f = 0.6-0.7

- In general, the normal stress is the weight of the overburden:

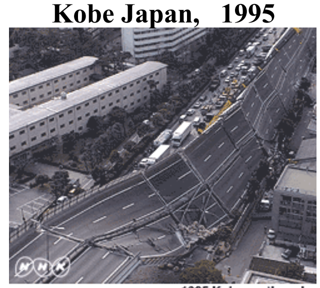
$$\sigma_n \approx \rho g h$$

- The shear stress τ is provided by tectonic forces

Earthquakes can be unusually devastating due to either
(1) high intensities in areas with high populations
or
(2) other events caused by the earthquake (landslides, fires, tsunamis, etc.) also poor construction.

Bam, IRAN 2003

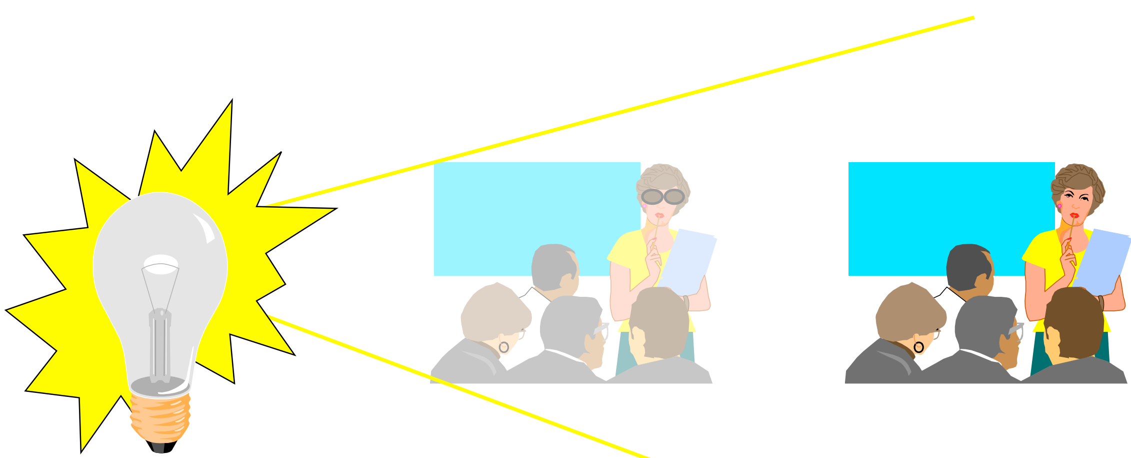
Kobe Japan, 1995



1995 Kobe earthquake

Both:
Magnitude only 6.7 to 6.9 but *intensity of 9 or more in* very populous areas
extreme damage and thousands of deaths

- We must distinguish between *magnitude* and *intensity*
  - magnitude indicates how much energy was released.
  - intensity is how strong the ground motion is at the felt location.
- Consider a light bulb …



Fixed *magnitude* **Local *intensity*** **Local *intensity***

Earthquake Intensity: factors that contribute

1. Earthquake magnitude
2. Distance from epicentre
3. Ground type
4. Duration

Subjective description of violence and duration of shaking, and damage. Not based on quantitative measures of ground displacement, velocity or acceleration.

The Mercalli Intensity Scale was devised before accurate seismometers were widespread.

Modified Mercalli Intensity Scale: I to XII

Example: VII "Strong"

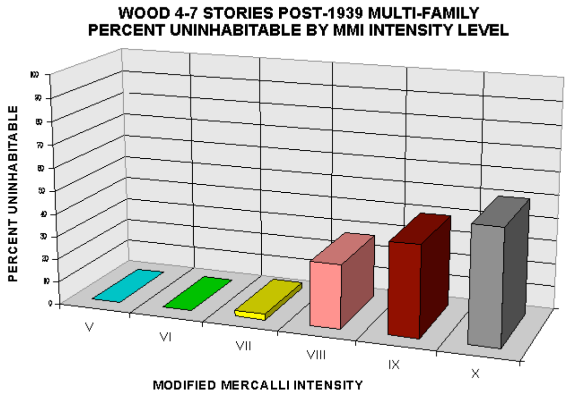
Difficult to stand. Noticed by drivers of motor cars. Hanging objects quiver. Furniture broken. Damage to masonry D, including cracks. Weak chimneys broken at roof line. Fall of plaster, loose bricks, stones, tiles, cornices (also unbraced parapets and architectural ornaments). Some cracks in masonry C. Waves on ponds; water turbid with mud. Small slides and caving in along sand or gravel banks. Large bells ring. Concrete irrigation ditches damaged.

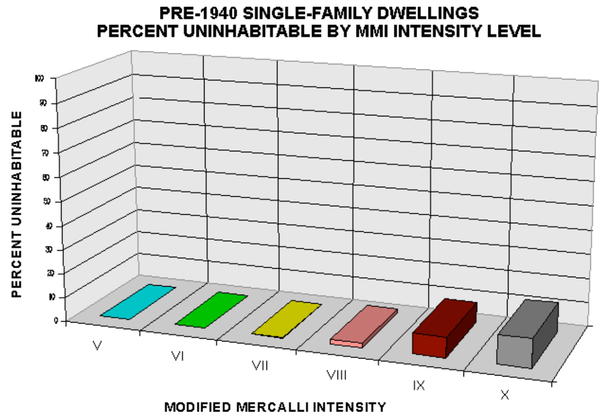
Masonry A: Good workmanship, mortar, and design; reinforced, especially laterally, and bound together by using steel, concrete, etc.; designed to resist lateral forces.
Masonry B: Good workmanship and mortar; reinforced, but not designed in detail to resist lateral forces.
Masonry C: Ordinary workmanship and mortar; no extreme weaknesses like failing to tie in at corners, but neither reinforced nor designed against horizontal forces.
Masonry D: Weak materials, such as adobe; poor mortar; low standards of workmanship; weak horizontally.

Mercalli scale was originally devised (and refined) 1883-1902, modified 1931 and 1958

Full descriptions is from: Richter, C.F., 1958. ***Elementary Seismology.*** W.H. Freeman and Company, San Francisco, pp. 135-149; 650-653.

Why bother with intensity?





- emergency response planning, insurance, loss estimating
- inferring magnitude from subjective historical accounts (such as the Lawson Report on the 1906 SF earthquake)

PAGER map for the Sichuan Earthquake

M 7.9 - EASTERN SICHUAN, CHINA

Monday, May 12, 2008 at 06:28:01 UTC
Location: 31.0°N 103.4°E Depth: 19km
Alert version 12

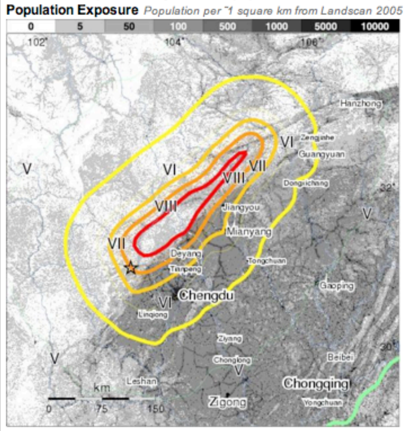
Summary | Maps | Exposure | Cities | Downloads | Details

Estimated Population Exposed to Earthquake Shaking

Est. Modified Mercalli Intensity	Est. Population Exposure (k = x1000)	Perceived Shaking	Potential Structure Damage: Resistant	Potential Structure Damage: Vulnerable
X	2k	Extreme	V. Heavy	V. Heavy
IX	530k	Violent	Heavy	V. Heavy
VIII	1,124k	Severe	Moderate/Heavy	Heavy
VII	3,815k	Very Strong	Moderate	Moderate/Heavy
VI	18,662k	Strong	Light	Moderate
V	63,137k*	Moderate	V. Light	Light
IV	1,563k*	Light	None	None
II-III	--*	Weak	None	None
I	--*	Not Felt	None	None

*Estimated exposure only includes population within the map area.

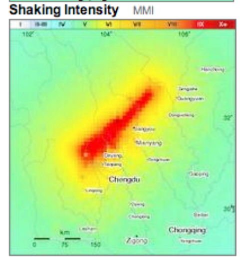
Population Exposure *Population per ~1 square km from Landscan 2005*



Selected City Exposure

MMI	City	Population
VII	Tianpeng	60k
VII	Jiangyou	127k
VII	Mianyang	264k
VI	Chengdu	3950k
VI	Guangyuan	213k
VI	Linqiong	55k
VI	Deyang	152k
V	Nanchong	7150k
V	Zigong	689k
V	Neijiang	546k
V	Chongqing	3967k

Shaking Intensity MMI



Generally, maximum intensity correlates with magnitude

Magnitude / Intensity Comparison

Magnitude	Typical Maximum Modified Mercalli Intensity
1.0 - 3.0	I
3.0 - 3.9	II - III
4.0 - 4.9	IV - V
5.0 - 5.9	VI - VII
6.0 - 6.9	VII - IX
7.0 and higher	VIII or higher

Table 3.6 Magnitude versus Length of Shaking

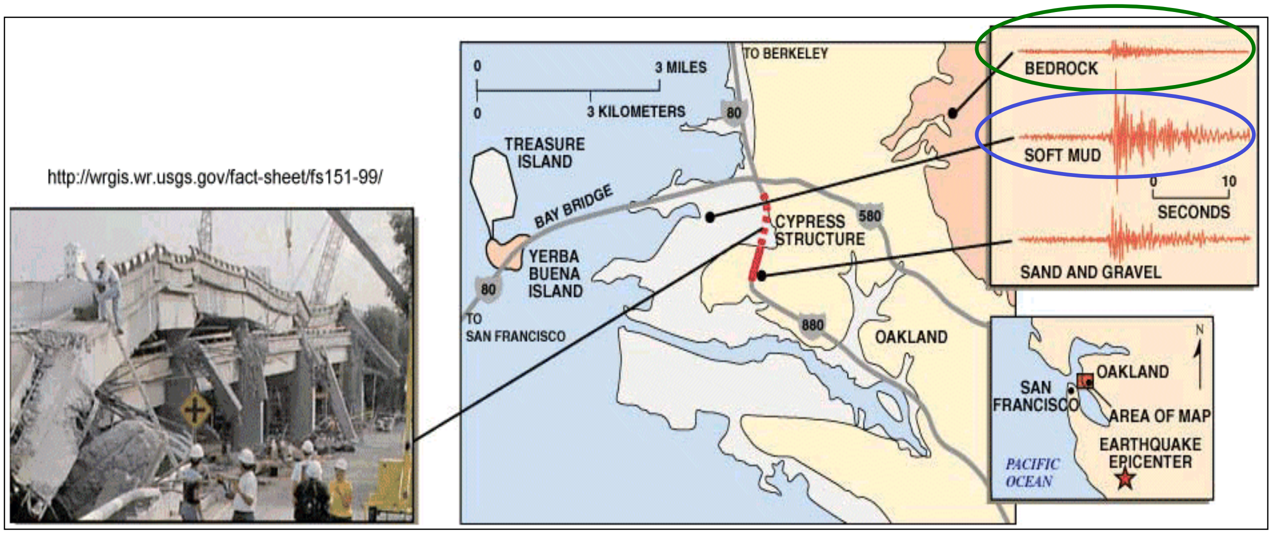
Magnitude	Duration of Strong Ground Shaking in Seconds
8–8.9	30 to 90
7–7.9	20 to 50
6–6.9	10 to 30
5–5.9	2 to 15
4–4.9	0 to 5

But proximity to the *epicenter*, local amplification of shaking, and other effects can make violence and duration of shaking worse than expected

Earthquake Intensity: Effect of ground type

- Harder rocks
  - no amplification
  - a mixture of frequencies

- Softer rocks
  - shaking is **amplified**
  - low-frequencies may reverberate in basins, plus soft rocks absorb high frequencies



Buildings in central Kobe, Japan.

Foreground: The complete collapse of a two- or three-story traditional Japanese wood-frame building with a heavy tile roof.

Background: A six- or seven-story office building of 1960s' or 1970s' vintage. This reinforced concrete building is a typical example of a mid-height story collapse.

Left: The high rise is post-1981 office building that has no apparent damage. Ground settlement in the vicinity of these buildings was between 30 and 60 centimeters.

The January 17, 1995 Kobe Earthquake. An EQE Summary Report, April 1995 at http://www.eqe.com/publications/kobe/building.htm

Intensity estimates come from

- felt reports from people (e.g., USGS "Did You Feel It" online questionnaires, generates "community internet intensity map")

- felt reports from seismometers (e.g., USGS ShakeMap, generates "rapid instrumental intensity map" from seismograms)

PAGER: population exposure to various intensities

Part of the USGS "Did You Feel It" questionnaire

While answering all these questions is optional, we encourage you to fill out as many as possible so we can provide a more accurate intensity estimate.

What was your situation during the earthquake? [No answer ▾]

If you were inside please select the type of building or structure:

[No building ▾]

If other, please describe: [ ]

Were you asleep during the earthquake?

[No ▾]

Did you feel the earthquake? (If you were asleep, did the earthquake wake you up?)

☐ No ☐ Yes

Did others nearby feel the earthquake?

[No answer/Don't know/Nobody else nearby ▾]

Your experience of the earthquake:

How would you best describe the ground shaking? [No description ▾]

About how many seconds did the shaking last? [ ]

How would you best describe your reaction? [No answer/Don't remember ▾]

How did you respond? (Select one.) [No answer/Don't remember ▾]

If other, please describe: [ ]

Was it difficult to stand or walk? [No answer/Did not try ▾]

Earthquake effects:

Did you notice the swinging/swaying of doors or hanging objects? [No answer/Did not look ▾]

Did you notice creaking or other noises? [No answer/Did not pay attention ▾]

Did objects rattle, topple over, or fall off shelves? [No answer/No shelves ▾]

Did pictures on walls move or get knocked askew? [No answer/No pictures ▾]

Did any furniture or appliances slide, tip over, or become displaced? [No answer/No furniture ▾]

Was a heavy appliance (refrigerator or range) affected? [No answer/No heavy appliance ▾]

Were free-standing walls or fences damaged? [No answer/No walls ▼]

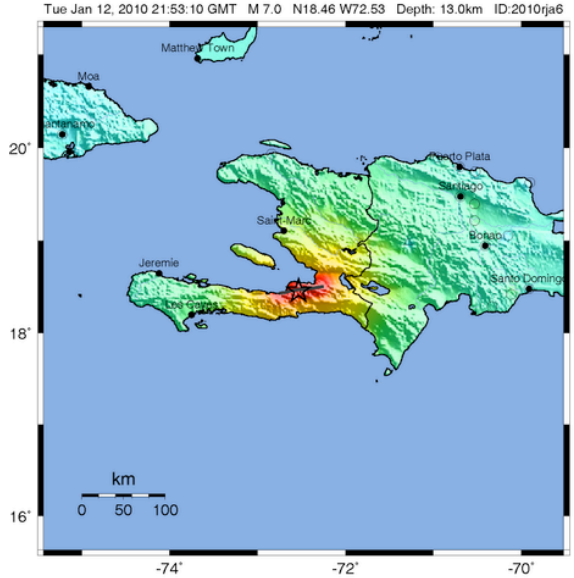
If you were inside, was there any damage to the building? Check all that apply.

- ☐ No damage
- ☐ Hairline cracks in walls
- ☐ A few large cracks in walls
- ☐ Many large cracks in walls
- ☐ Ceiling tiles or lighting fixtures fell
- ☐ Cracks in chimney
- ☐ One or several cracked windows
- ☐ Many windows cracked or some broken out
- ☐ Masonry fell from block or brick wall(s)
- ☐ Old chimney, major damage or fell down
- ☐ Modern chimney, major damage or fell down
- ☐ Outside wall(s) tilted over or collapsed completely

2010 Haiti Earthquake Intensity

USGS ShakeMap : HAITI REGION

Tue Jan 12, 2010 21:53:10 GMT M 7.0 N18.46 W72.53 Depth: 13.0km ID:2010rja6



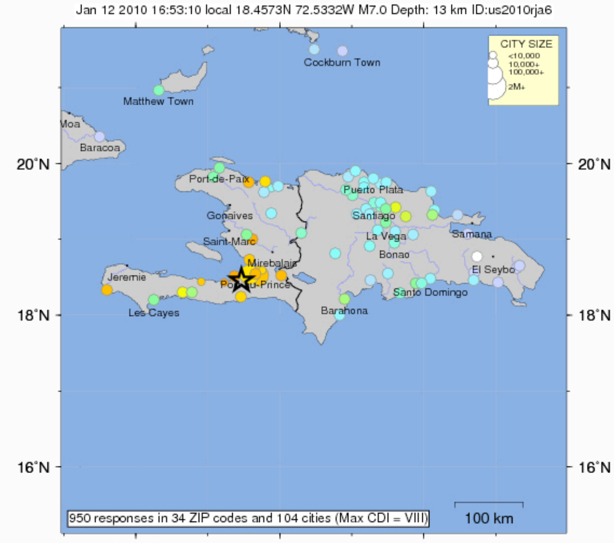
Map Version 7 Processed Wed Jan 13, 2010 06:53:11 PM MST -- NOT REVIEWED BY HUMAN

PERCEIVED SHAKING	Not felt	Weak	Light	Moderate	Strong	Very strong	Severe	Violent	Extreme
POTENTIAL DAMAGE	none	none	none	Very light	Light	Moderate	Moderate/Heavy	Heavy	Very Heavy
PEAK ACC.(%g)	<.17	.17-1.4	1.4-3.9	3.9-9.2	9.2-18	18-34	34-65	65-124	>124
PEAK VEL.(cm/s)	<0.1	0.1-1.1	1.1-3.4	3.4-8.1	8.1-16	16-31	31-60	60-116	>116
INSTRUMENTAL INTENSITY	I	II-III	IV	V	VI	VII	VIII	IX	X+

USGS Community Internet Intensity Map

HAITI REGION

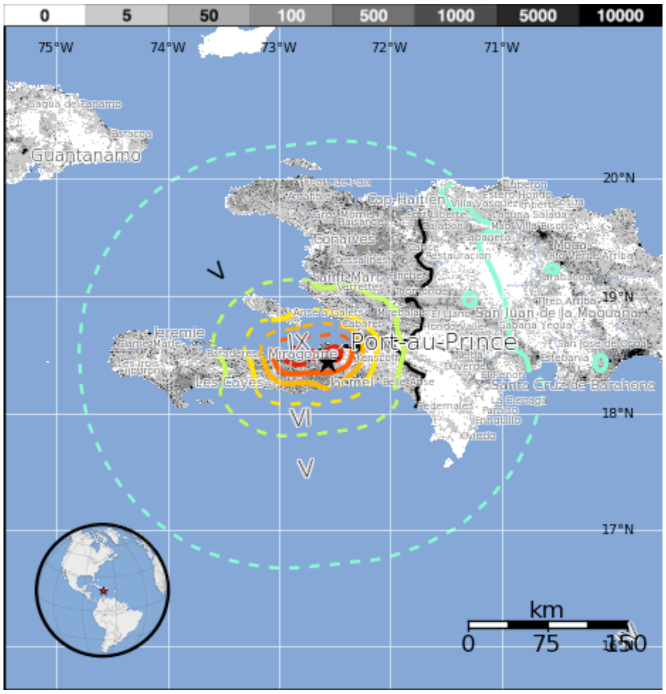
Jan 12 2010 16:53:10 local 18.4573N 72.5332W M7.0 Depth: 13 km ID:us2010rja6



INTENSITY	I	II-III	IV	V	VI	VII	VIII	IX	X+
SHAKING	Not felt	Weak	Light	Moderate	Strong	Very strong	Severe	Violent	Extreme
DAMAGE	none	none	none	Very light	Light	Moderate	Moderate/Heavy	Heavy	V. Heavy

Processed: Thu Oct 21 00:33:46 2010

USGS PAGER maps show number of people exposed to different Mercalli intensities, and estimate (based on local construction) casualties and financial losses



Selected Cities Exposed

from GeoNames Database of Cities with 1,000 or more residents.

MMI	City	Population
X	Petit Goave	118k
X	Grand Goave	49k
X	Gressier	26k
IX	Leogane	134k
VIII	Port-au-Prince	1,235k
VIII	Carrefour	442k
VIII	Delmas 73	383k
VIII	Miragoane	89k
V	Verrettes	49k
IV	Santo Domingo	2,202k
IV	Santiago de los Caballeros	556k

(k = x1,000)

Probability of shaking at different Mercalli intensities, in the next 100 years

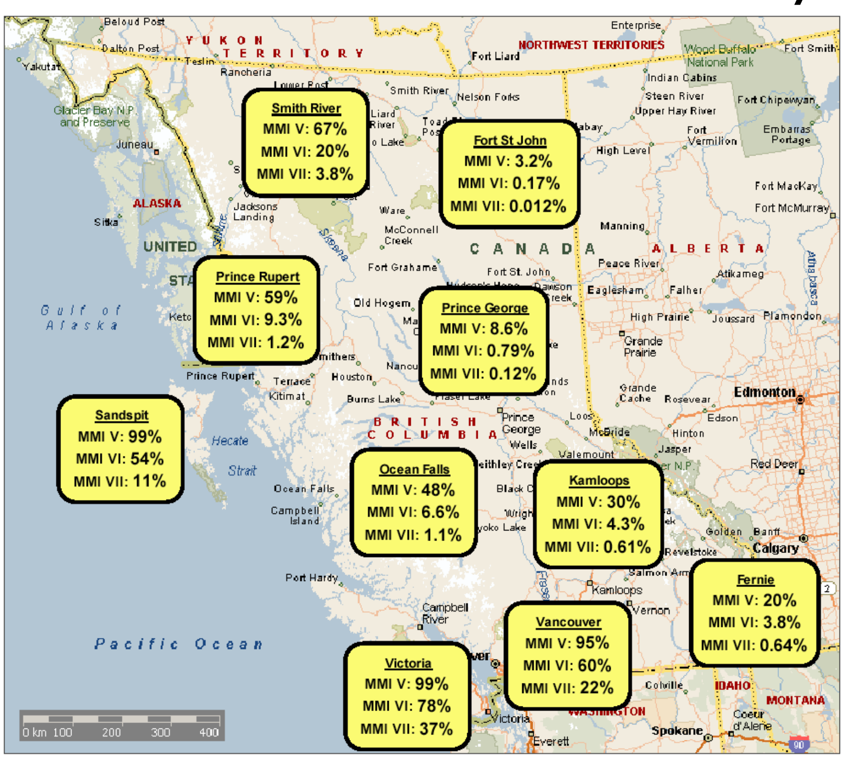


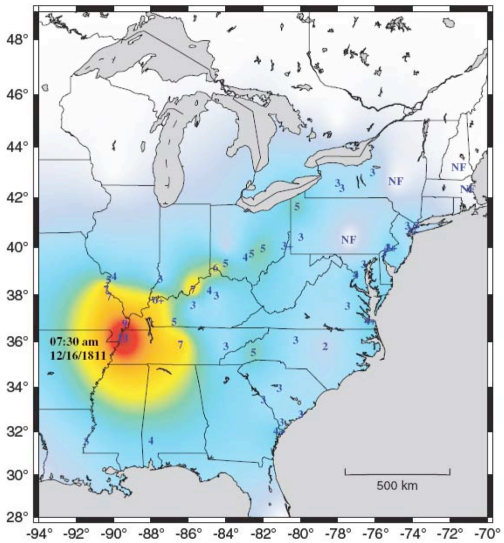
Figure 5. Distribution of earthquake shaking probabilities in BC within a 100-year period (for firm ground)

Onur and Seeman, 2004

http://www.pgc.nrcan.gc.ca/seismo/person/people/pubs/13WCEE1065.pdf

These are minimum values: numbers will be higher on softer ground

Earthquake intensity for 1811-1812 New Madrid earthquakes, based on historical accounts



PERCEIVED SHAKING	Not felt	Weak	Light	Moderate	Strong	Very strong	Severe	Violent	Extreme
POTENTIAL DAMAGE	none	none	none	Very light	Light	Moderate	Moderate/Heavy	Heavy	Very Heavy
PEAK ACC.(%g)	<.17	.17-1.4	1.4-3.9	3.9-9.2	9.2-18	18-34	34-65	65-124	>124
PEAK VEL.(cm/s)	<0.1	0.1-1.1	1.1-3.4	3.4-8.1	8.1-16	16-31	31-60	60-116	>116
INSTRUMENTAL INTENSITY	I	II-III	IV	V	VI	VII	VIII	IX	X+

▲ **Figure 3.** Shaking intensity map for event NM1-A.