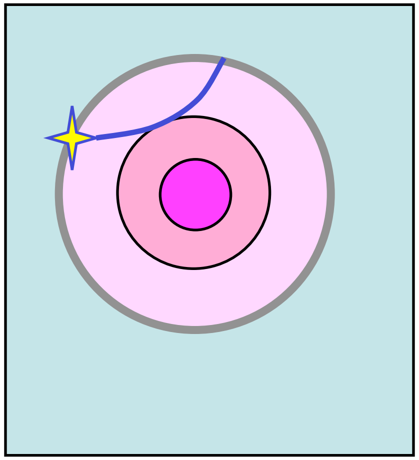
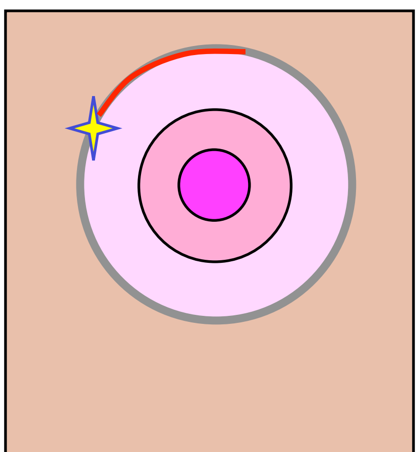
Two Kinds of Seismic Waves



body wave: travels through the inside the Earth



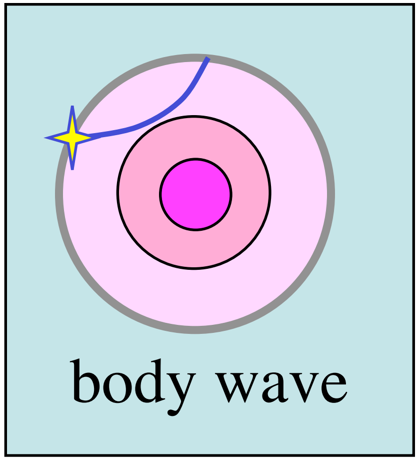
surface wave: travels along the surface of the Earth

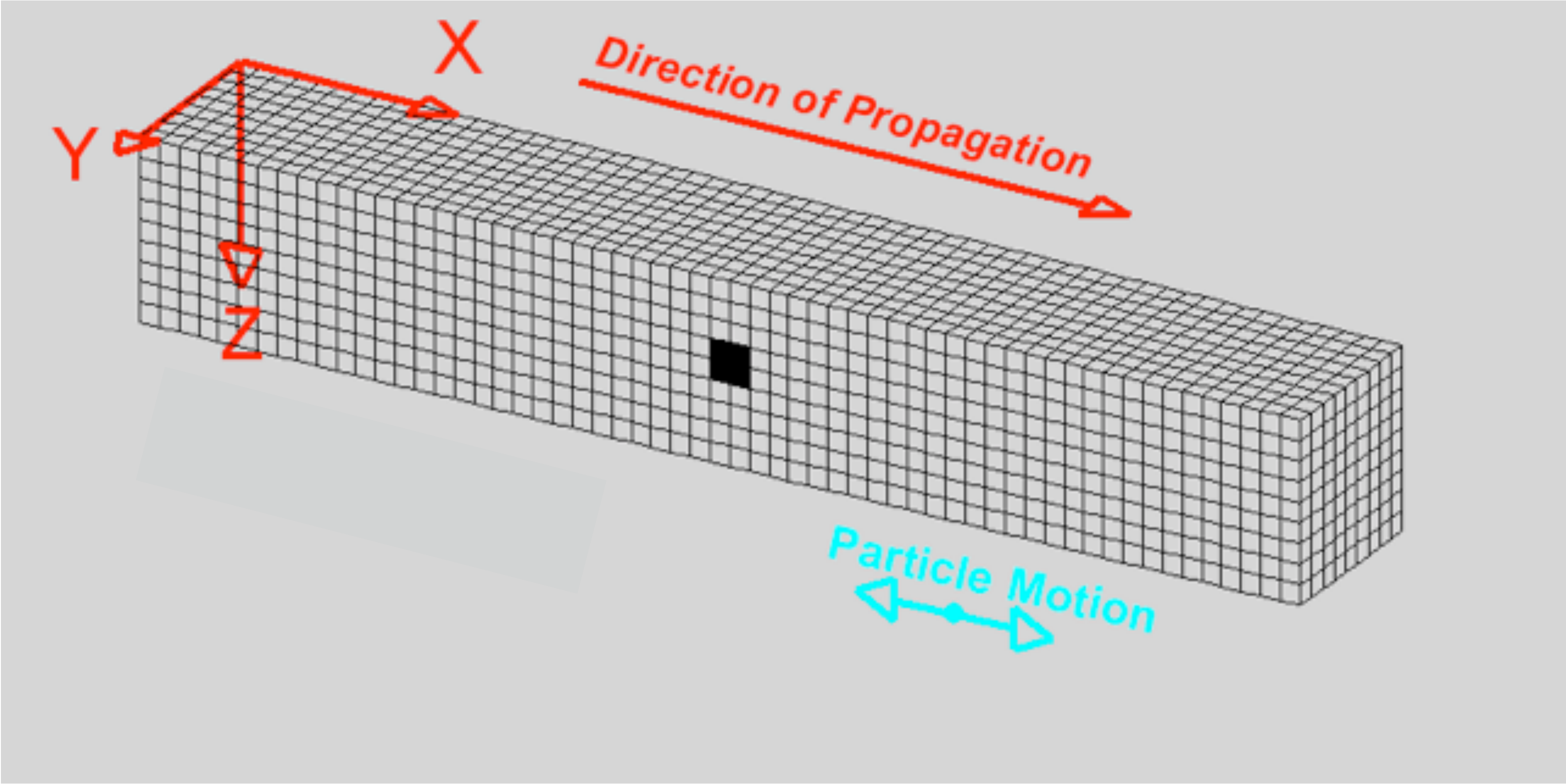
Seismic Body Waves

Wave Type (and names)	Particle Motion	Other Characteristics
P, **Compressional**, Primary, Longitudinal	Alternating compressions ("pushes") and dilations ("pulls") which are directed in the same direction as the wave is propagating (along the raypath)	P motion travels fastest in materials, so the P-wave is the first-arriving energy on a seismogram. Generally smaller and higher frequency than the S- and Surface waves. P waves in a liquid or gas are pressure waves, including sound waves.
S, **Shear**, Secondary, Transverse	Alternating transverse motions (perpendicular to the direction of propagation, and the raypath); commonly approximately polarized such that particle motion is in vertical or horizontal planes.	S-waves do not travel through fluids, so do not exist in Earth's outer core (inferred to be primarily liquid iron) or in air or water or molten rock (magma). S waves travel slower than P waves in a solid and, therefore, arrive after the P wave.

modified from http://web.ics.purdue.edu/~braile/edumod/waves/WaveDemo.htm

What type of a seismic body wave is this?





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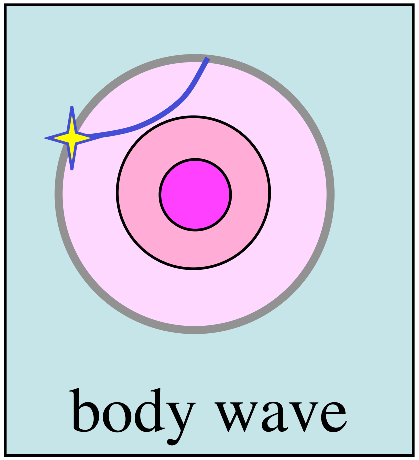

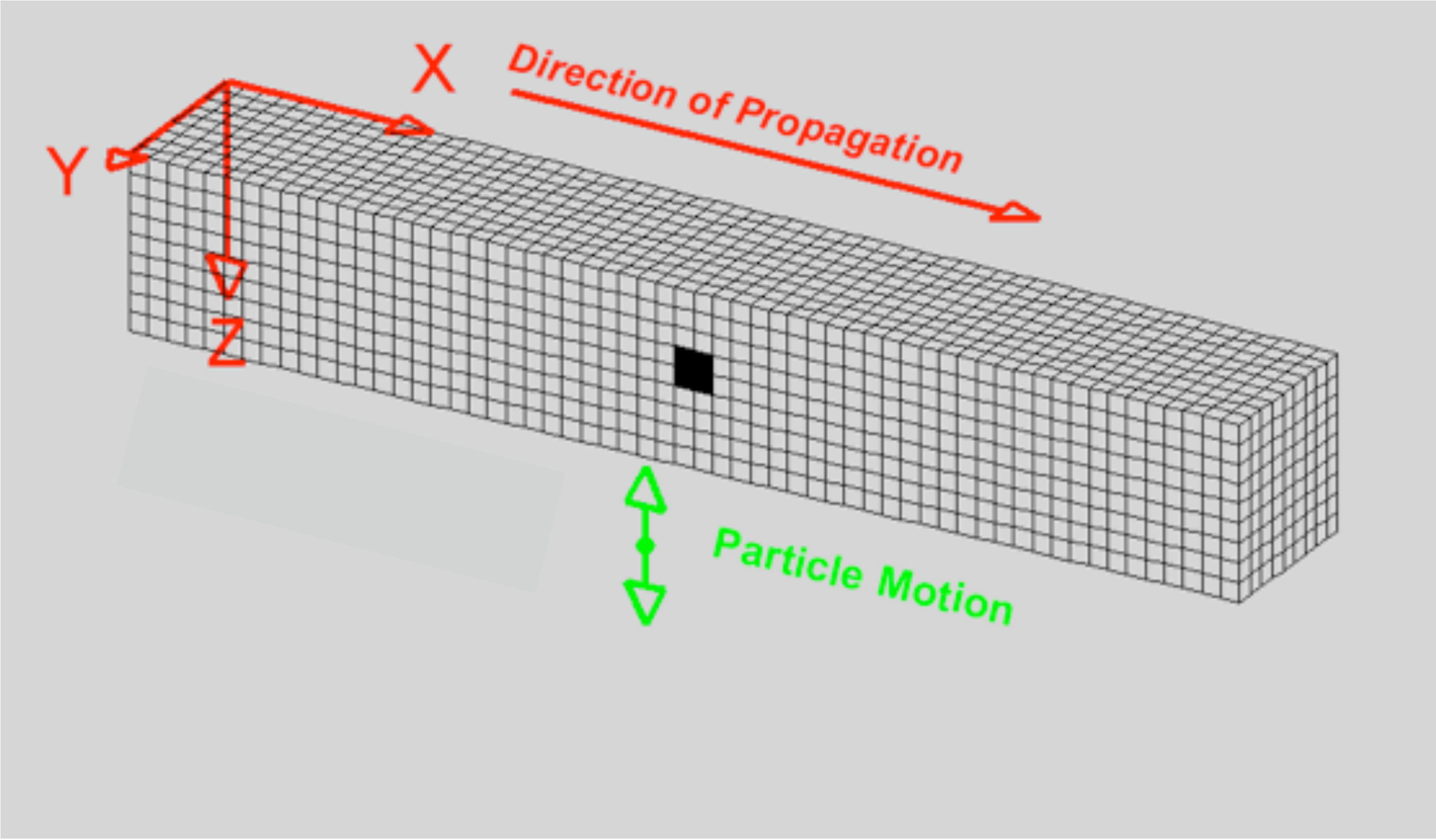

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Body Waves

- P Waves (Primary, or Compressional)
  - change in volume of the material
  - the wave spreads out in all directions from the earthquake in 3D (spherical spreading)
  - fastest seismic wave

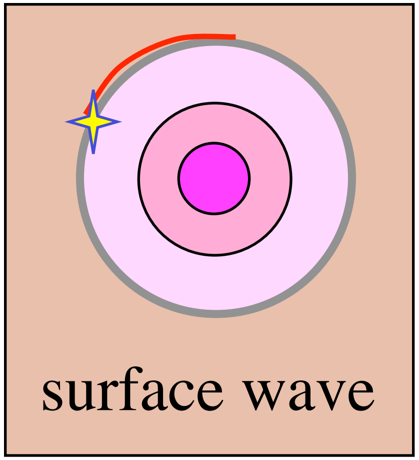
- S Waves (Shear, or Secondary)
  - change in shape of the material
  - spherical spreading
  - slower than P wave

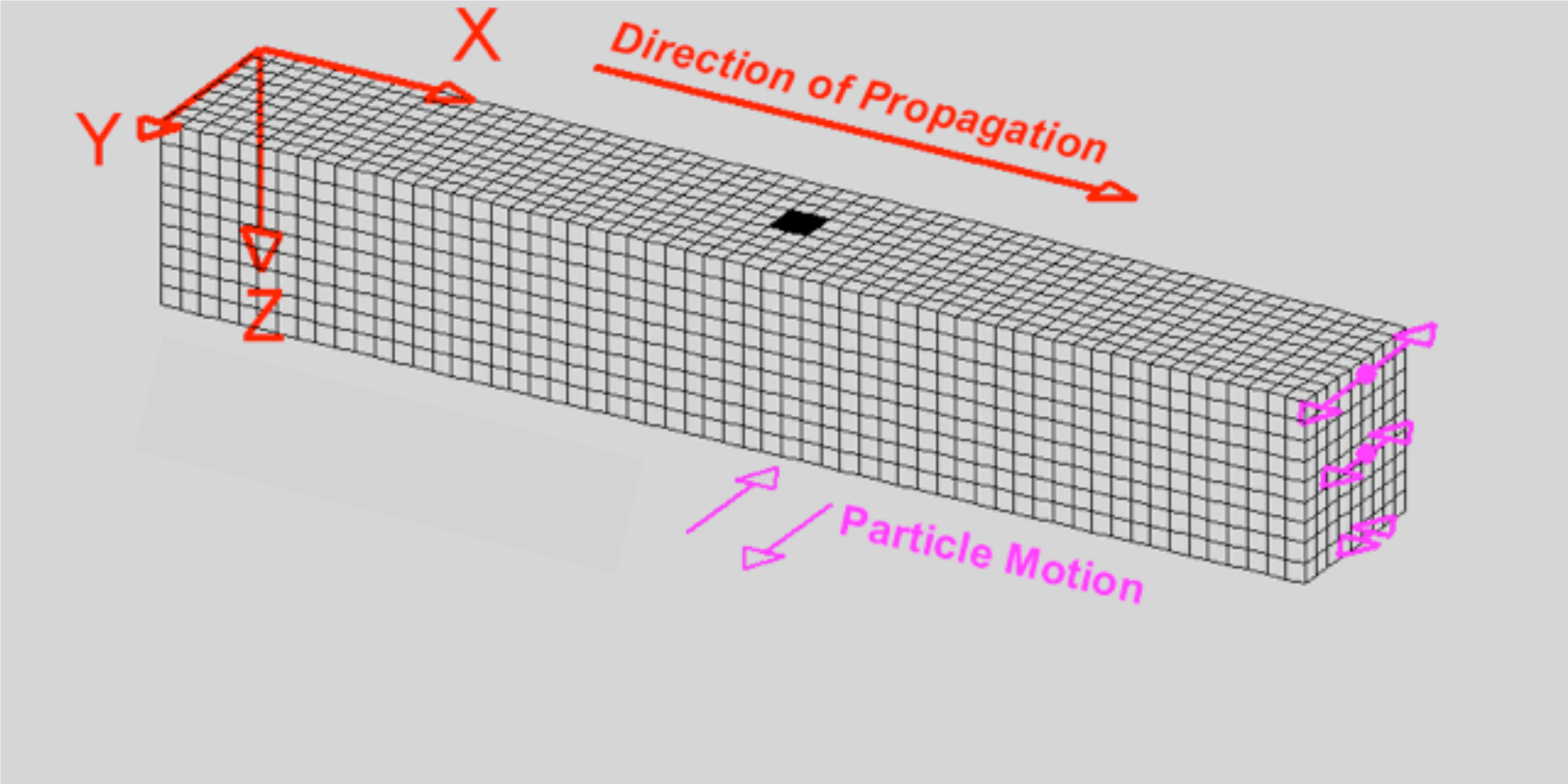
Seismic Surface Waves

L, Love waves	Transverse horizontal motion, perpendicular to the direction of propagation and generally parallel to the Earth's surface	V_L ~ 2.0 - 4.5 km/s in the Earth depending on frequency of the propagating wave	Love waves exist because of the Earth's surface. They are largest at the surface and decrease in amplitude with depth. Love waves are dispersive, that is, the wave velocity is dependent on frequency, with low frequencies normally propagating at higher velocity. Depth of penetration of the Love waves is also dependent on frequency, with lower frequencies penetrating to greater depth.
R, Rayleigh waves, "Ground roll"	Motion is both in the direction of propagation and perpendicular (in a vertical plane). Appearance and particle motion are similar to water waves.	V_R ~ 2.0 - 4.5 km/s in the Earth depending on frequency of the propagating wave	Rayleigh waves are also dispersive and the amplitudes generally decrease with depth in the Earth.

modified from http://web.ics.purdue.edu/~braile/edumod/waves/WaveDemo.htm

Particles move perpendicular to wave propagation direction, and horizontally. What kind of a surface wave is this?





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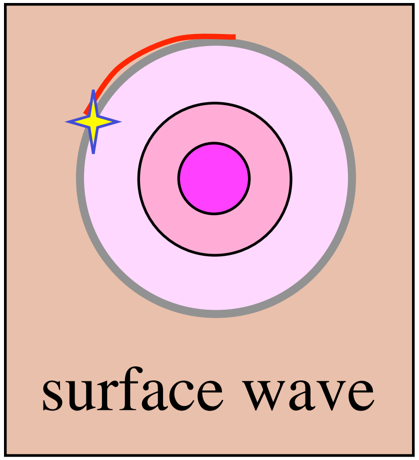
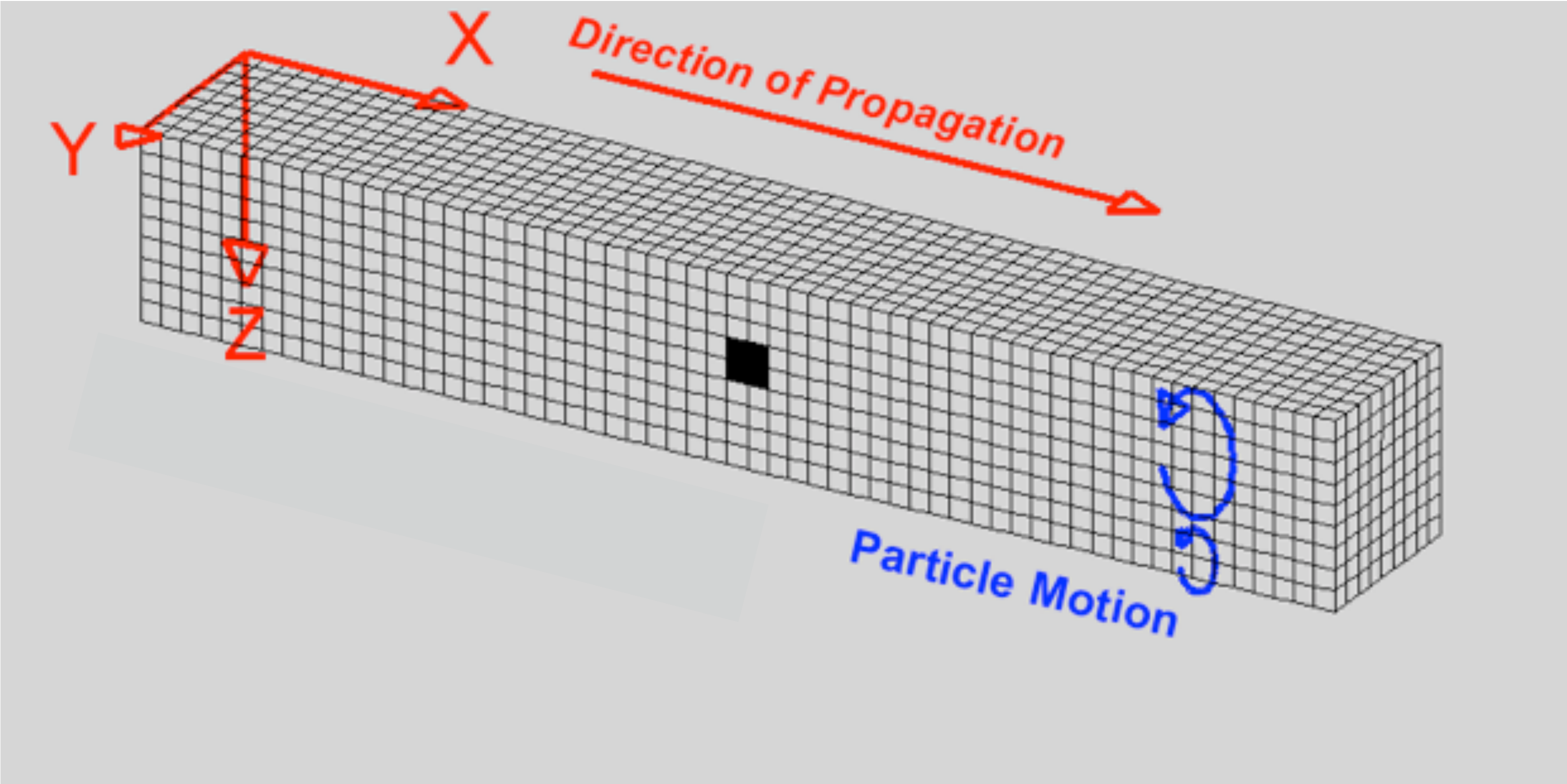
What kind of a surface wave is this?





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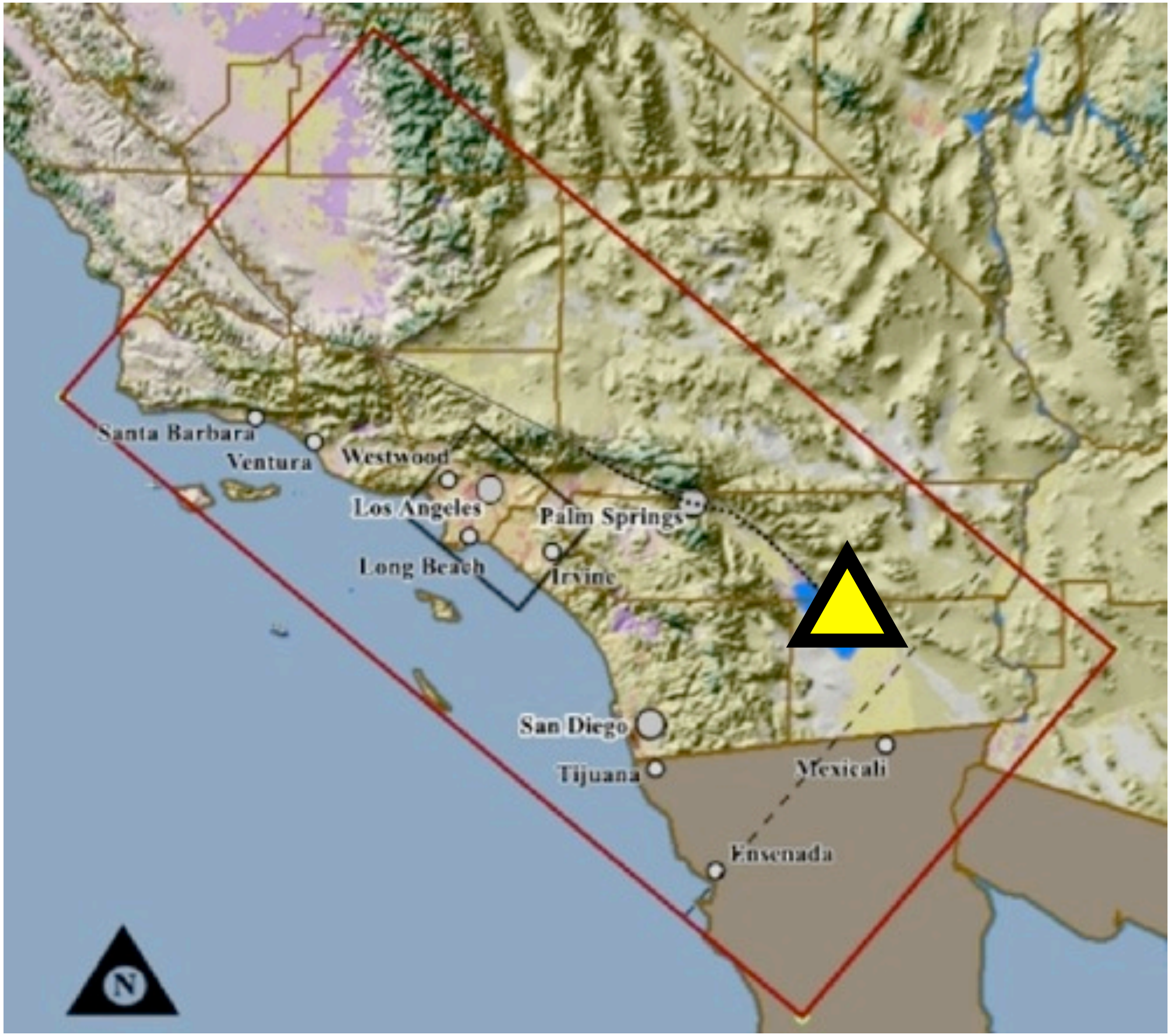
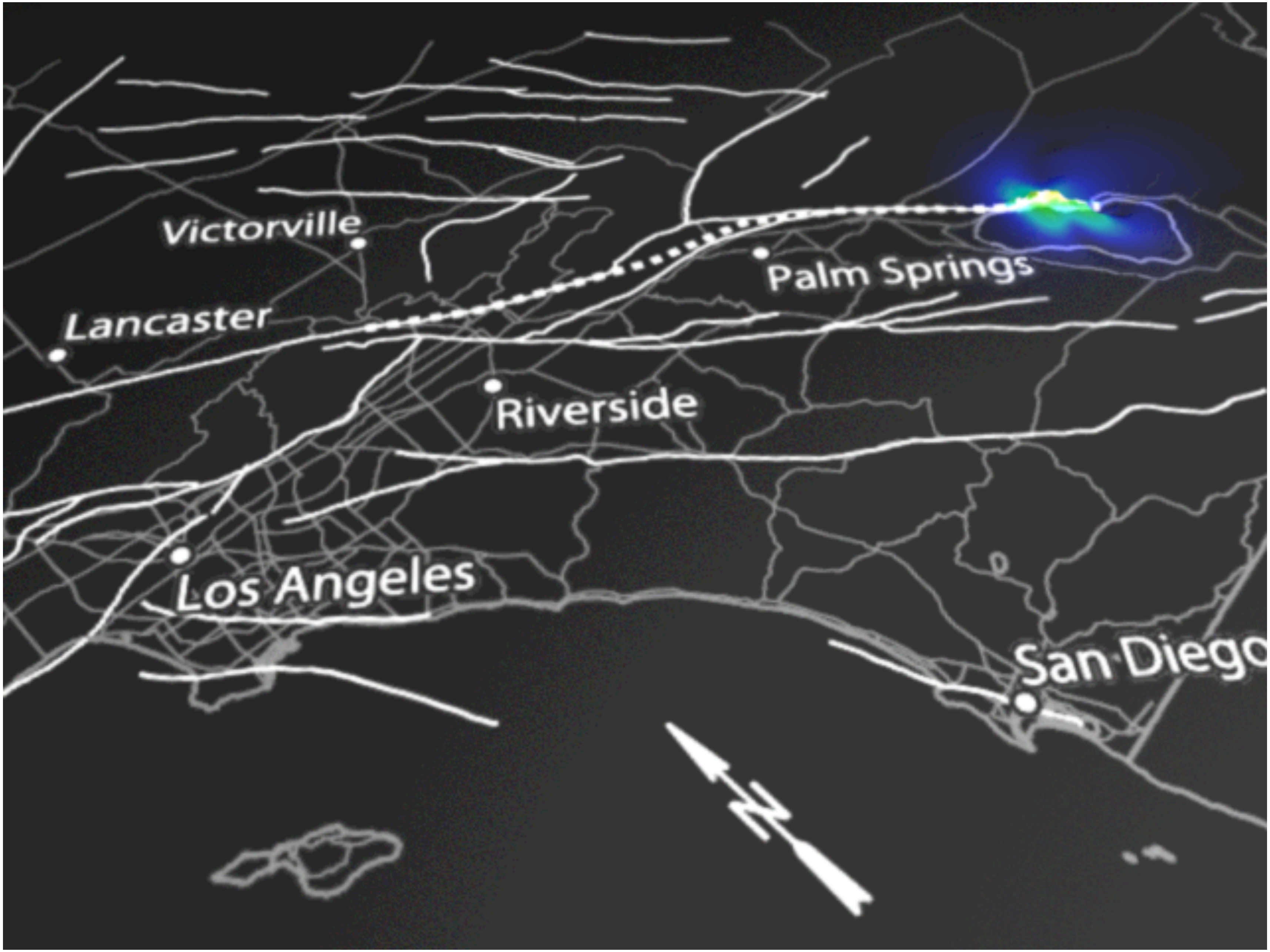
Surface waves vs. body waves

- Surface Waves
  - circular spreading from a point (2D), like ripples from a pebble thrown into a pond
  - amplitude decays as 1/(square root of distance)
- Body waves
  - circular spreading from a point (waves go out in 3D)
  - amplitude decays as 1/distance

Surface wave amplitudes decay less with distance traveled than body wave amplitudes do.

Animation of surface waves





Victorville
Lancaster
Palm Springs
Riverside
Los Angeles
San Diego
N

A seismogram

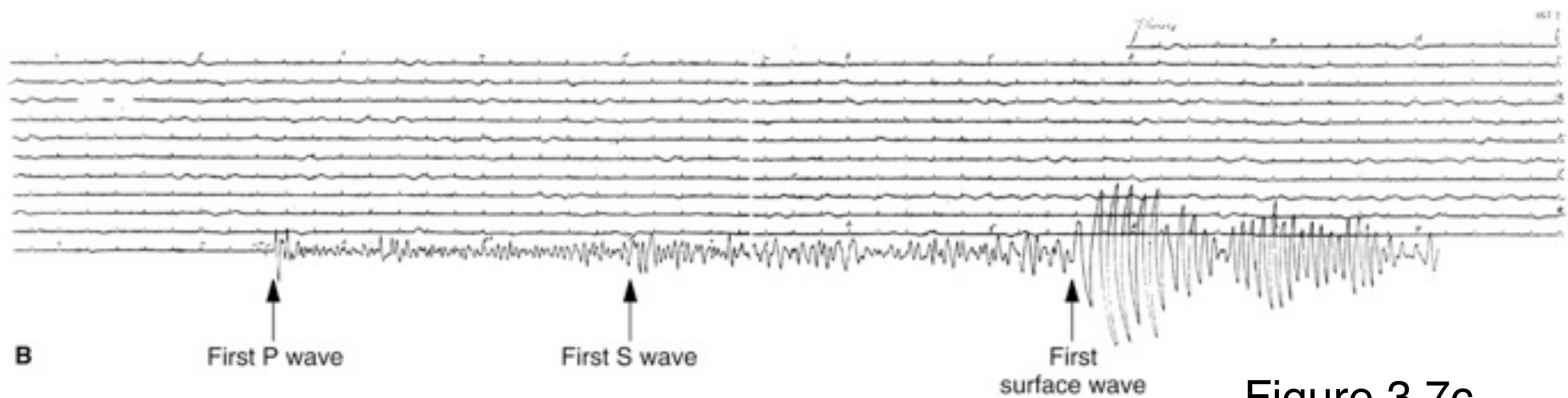
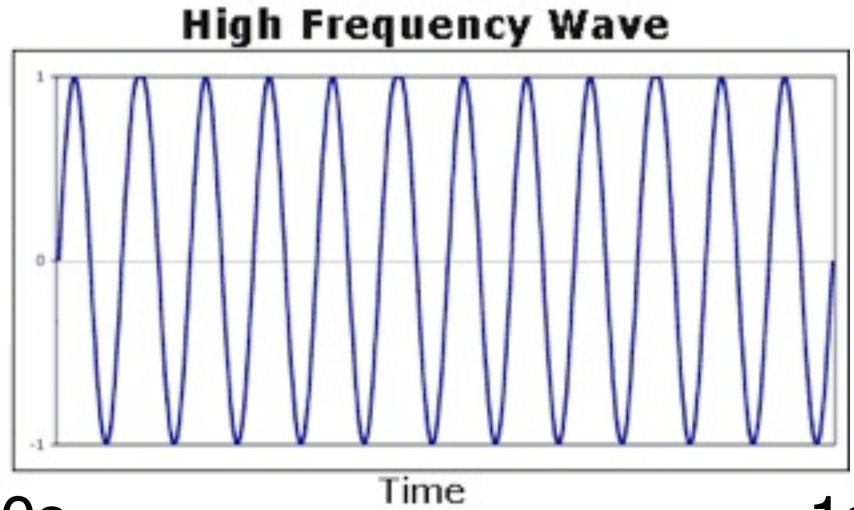


Figure 3.7c

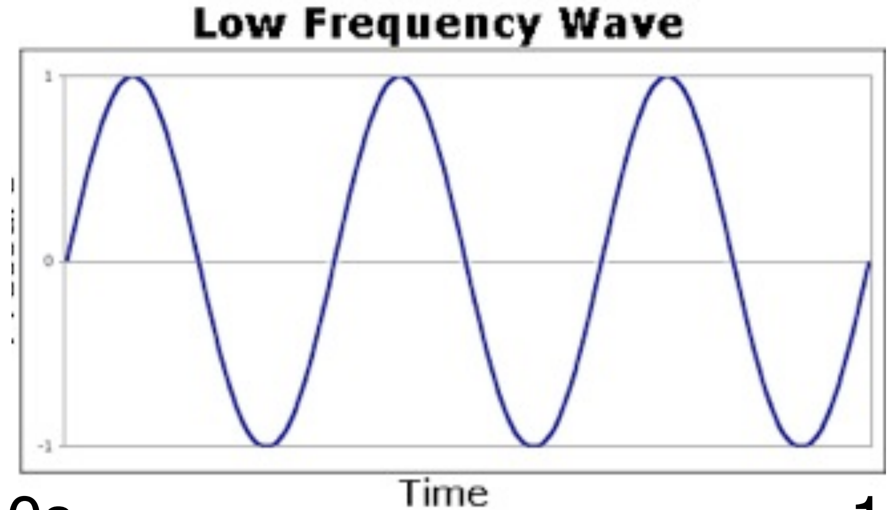
Usually shows ground displacement vs. time or ground velocity vs. time

(Some show acceleration vs. time)

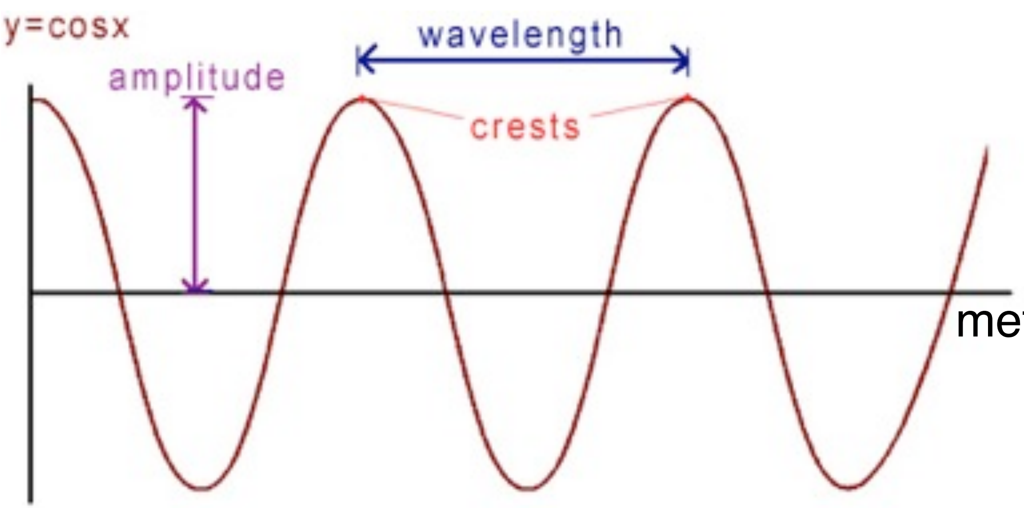
Frequency: number of waves that pass per second



0s 12 per second = 12 Hertz 1s



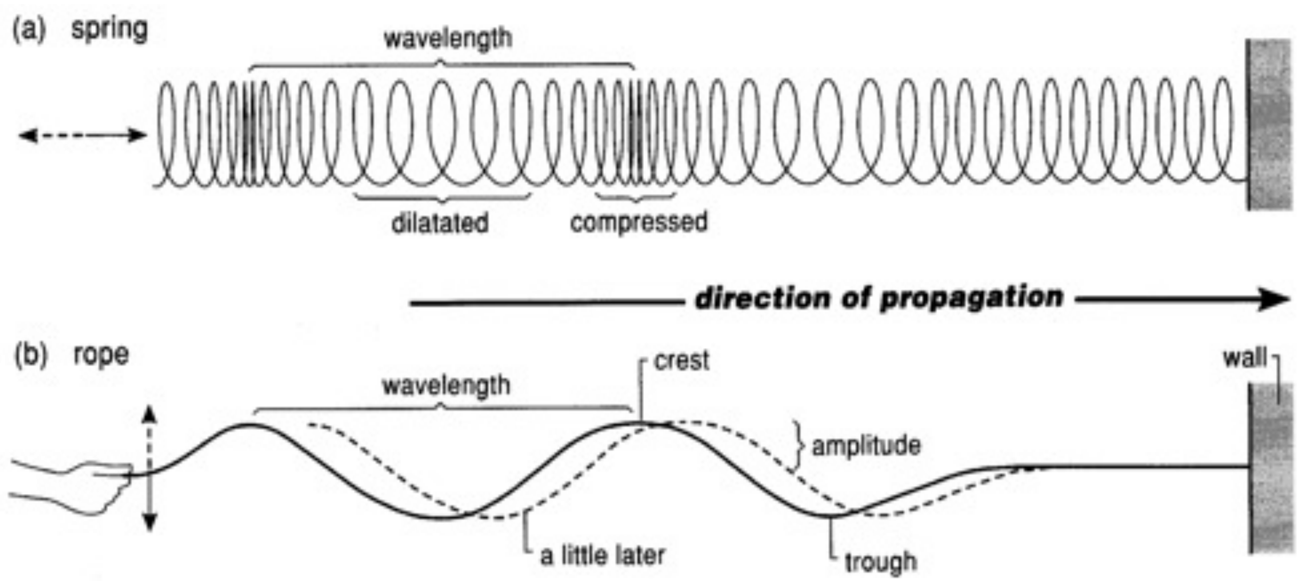
0s 3 per second = 3 Hertz 1s



meters

Wavelength: length of a wave in meters (trough to trough or peak to peak)

http://www.dosits.org/science/whatis/frequency.htm
and math 309 webpage



Frequency and wavelength are related to wave speed

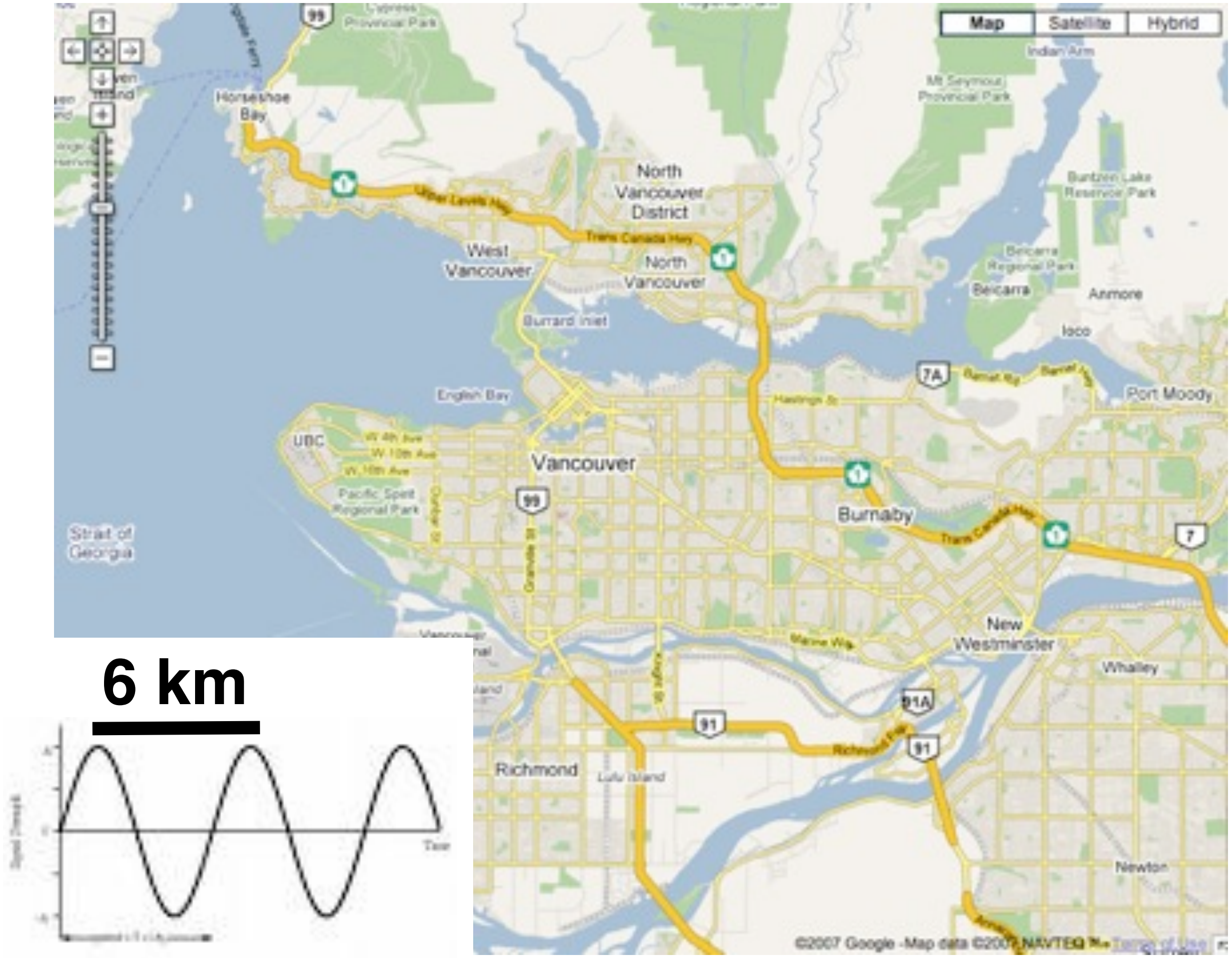
speed = frequency x wavelength

m/s *cycles/s* *m/cycle*

Music: Middle C (in air)

- frequency = 261.63 Hz
- wavelength = 1.32 m
- speed of sound in air = 345 m/s

How long are earthquake waves?



speed = frequency   x   wavelength

Average P-wave crustal velocity: ~6000 m/s or 6 km/s

Frequencies: very broad range

- for 10 Hz waves, wavelength = 600 m
- for 1 Hz waves, about 6 km

How long are earthquake waves?

speed = frequency   x   wavelength

Surface wave velocities: slower ~ 2 km/s

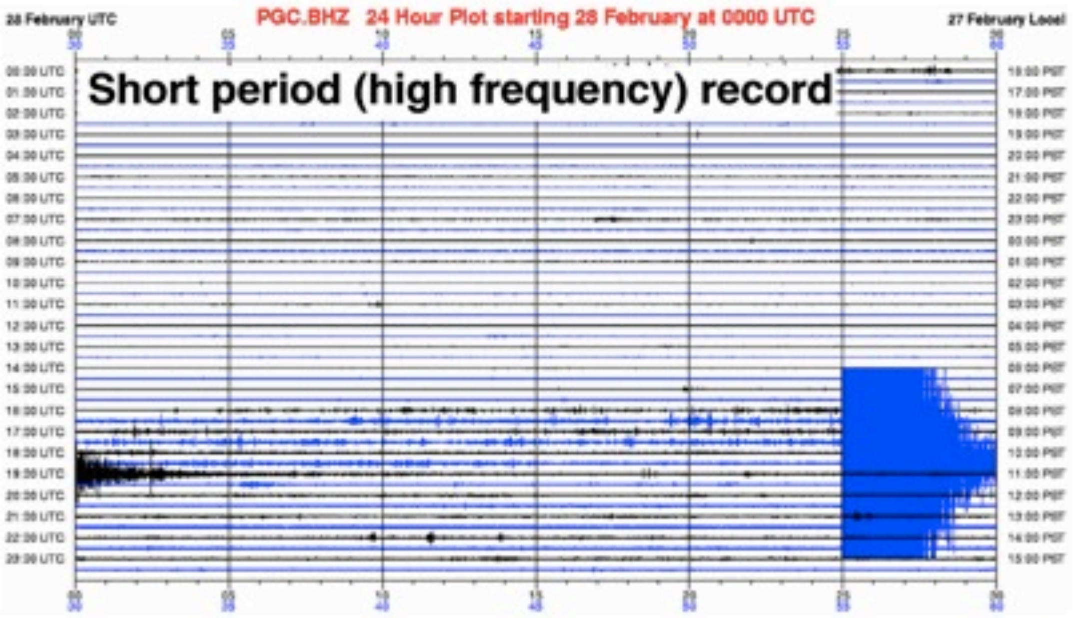
Frequencies: lower than body waves

- for 0.2 Hz waves, wavelength = 10 km

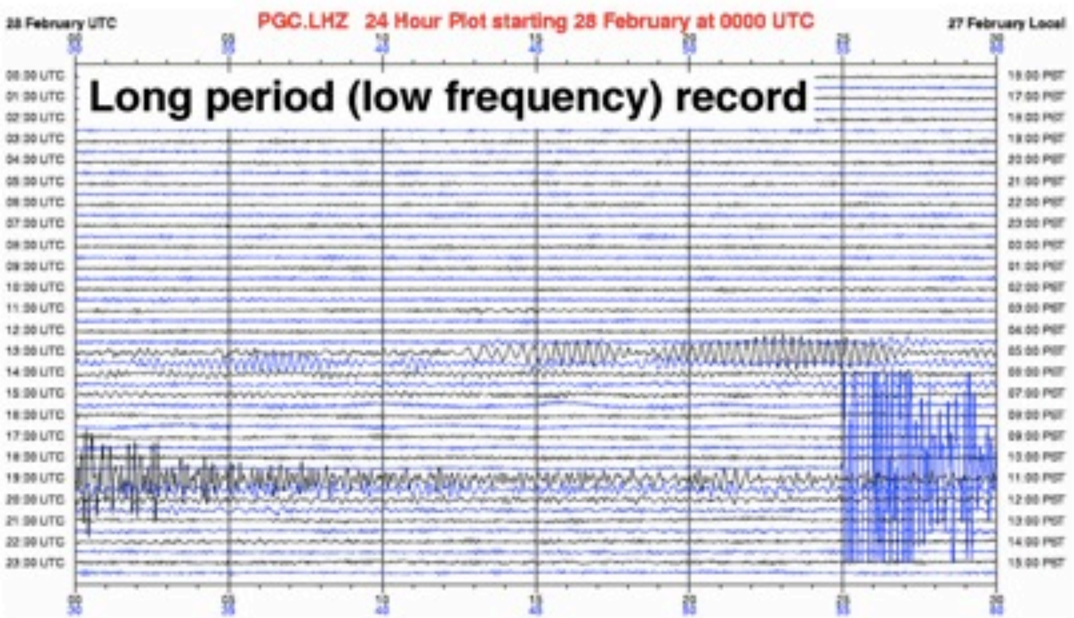
Amplitude? Up to **Meters** at the epicentre, smaller with distance

Feb. 28/2001 Olympia Earthquake: *PGC records*
6.8 Mw, 52 km depth

geophone:



"tweeter"



"woofer"

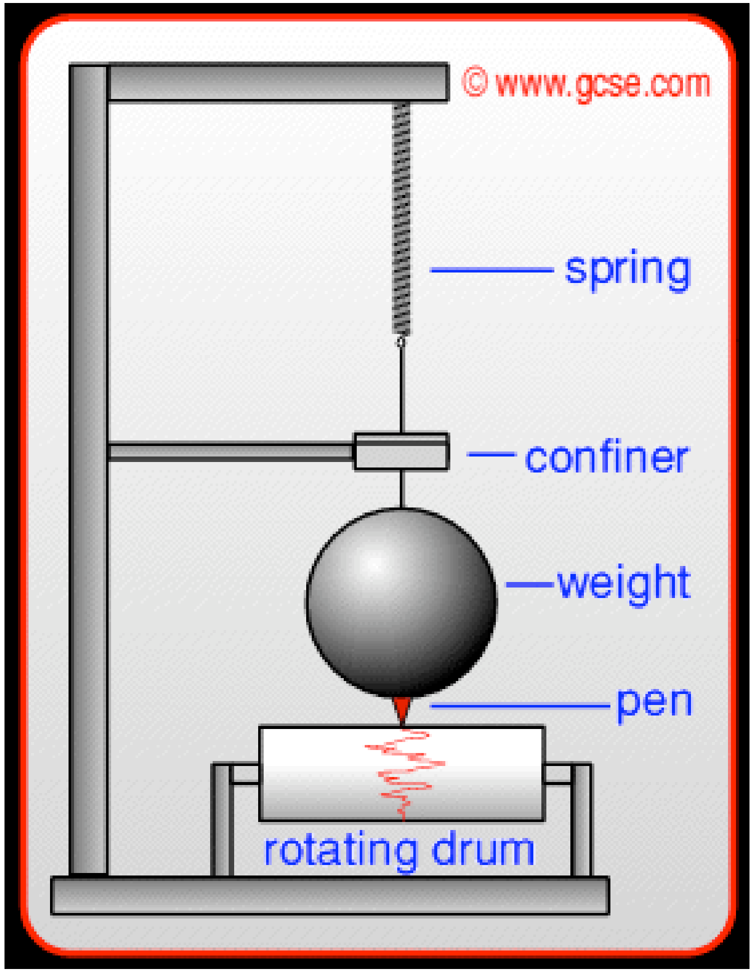
SEISMOMETERS, SEISMOGRAPHS, SEISMOGRAMS

1. What is a seismometer?

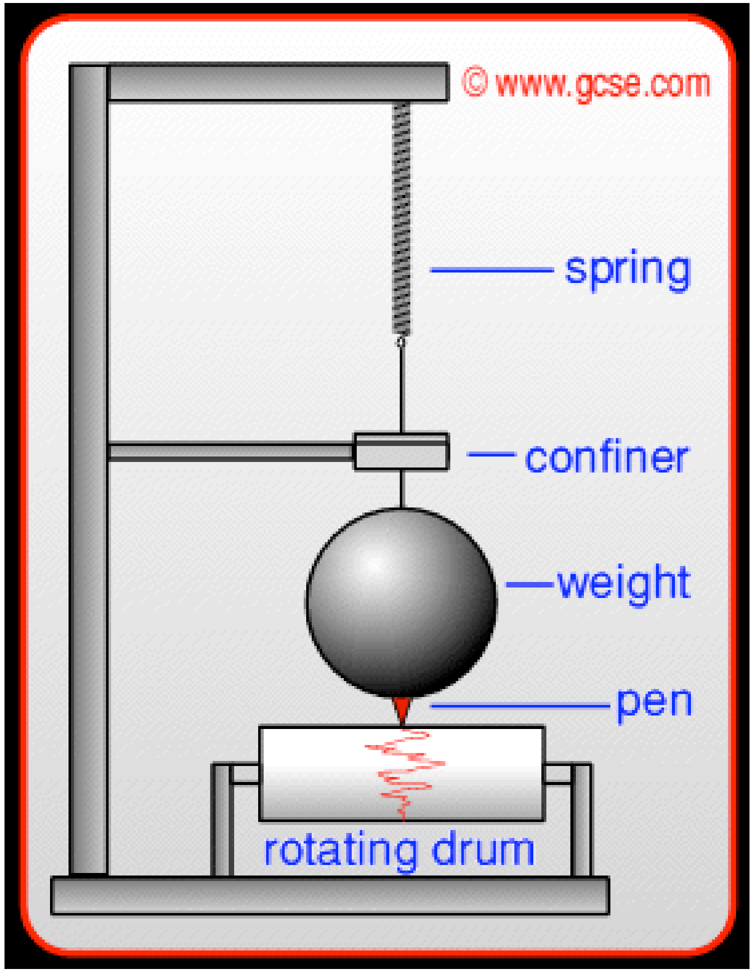
2. What is a seismograph?

3. What is a seismogram

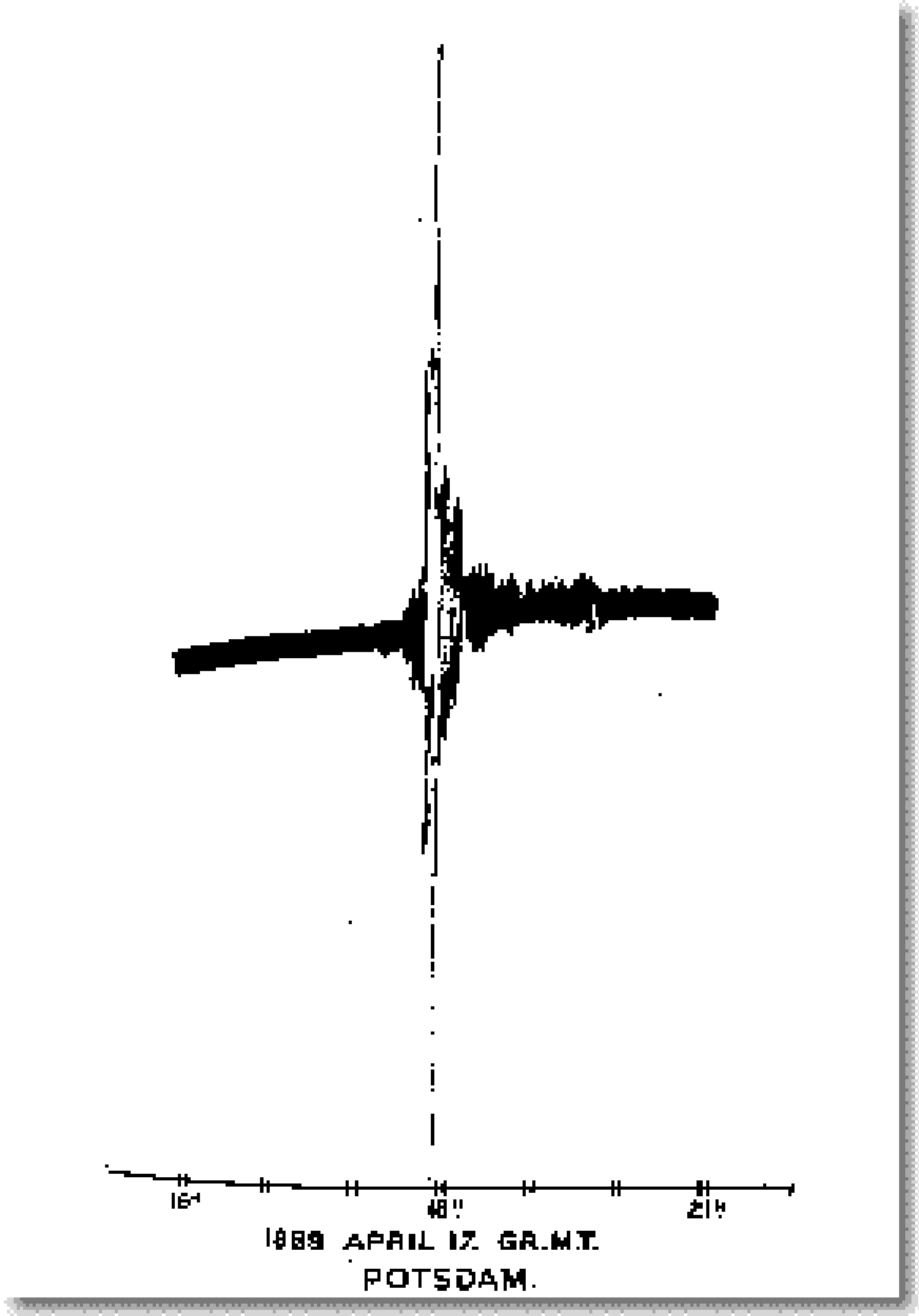
A **seismometer** is a mechanical device that measures and amplifies ground motion at a point on the Earth's surface or in a borehole



A modern **seismograph** records ground motion (from a seismometer) in digital format onto magnetic or optical disk



A **seismogram** is a visual representation of ground motion at a point in space as a function of time



SEISMOMETERS MEASURE GROUND MOTIONS

> ground motions can be described and measured in different ways:

1. ground displacement

2. ground velocity

3. ground acceleration

Q1. How are they related?

Q2. Which is most useful?

displacement $u(t)$

velocity $$\frac{du(t)}{dt}$$

acceleration $$\frac{d^2u(t)}{dt^2}$$

damage ~ force ~ acceleration

During large earthquakes, accelerations can approach or even exceed gravity

SEISMOMETRY EXERCISE

> ground motions provide much important information on both earthquakes and Earth structure

>NO seismometer provides a perfect representation of ground motion, each one has an (imperfect) ***response***

> we will derive response for a simple damped pendulum seismometer

> GROUP EXERCISE: I want you to analyse this response to see how true ground motions are modified by seismometer

SHORT/LONG PERIOD SEISMOMETERS & GEOPHONES

> used prior to 1990's

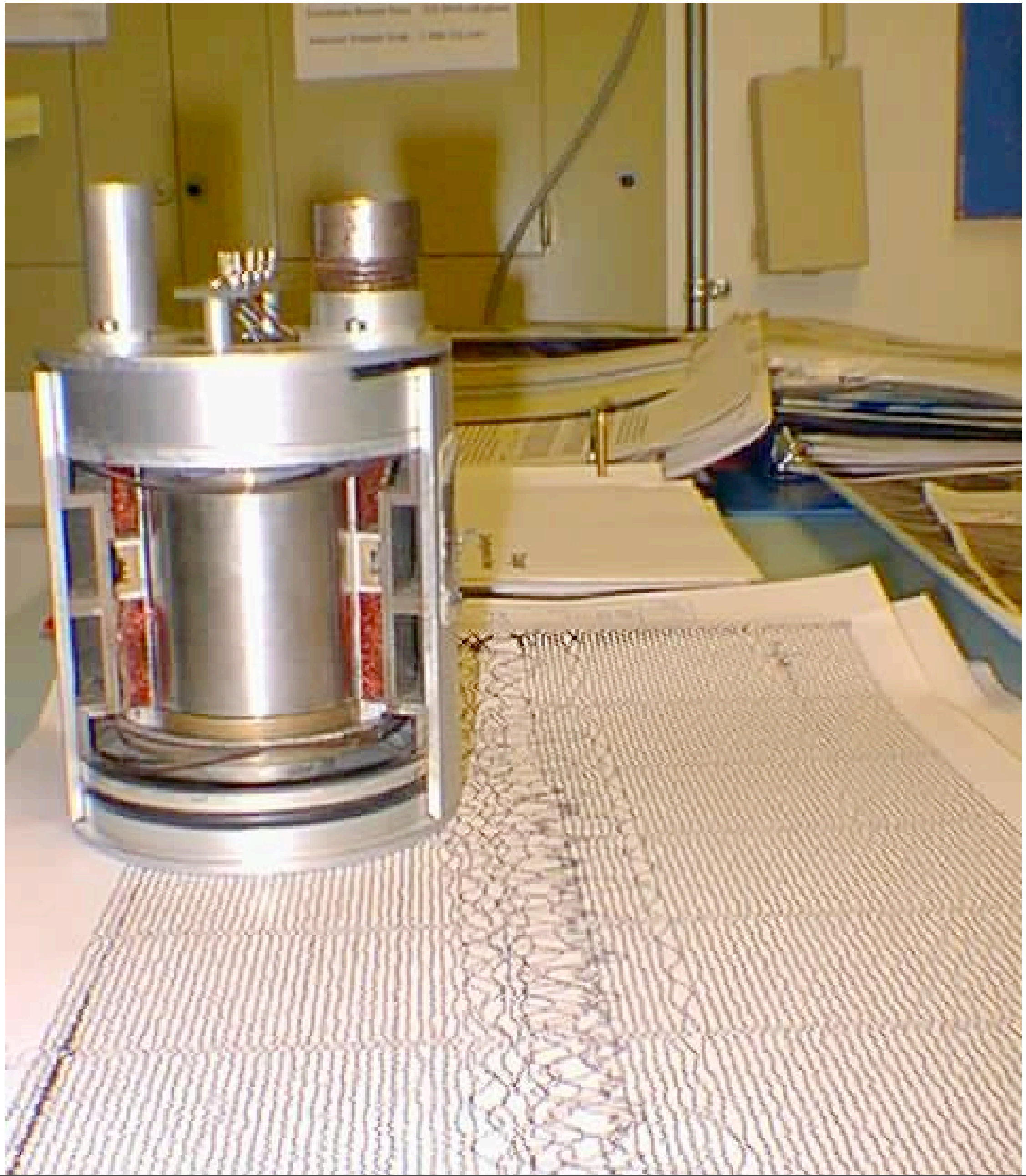
> work on damped pendulum theory

> resonant frequency at 1 Hz, 0.1 Hz

> mass incorporates solenoid which moves in a magnetic field

> Faraday's law states

$$\epsilon = -\frac{d\Phi}{dt} \sim \frac{dv}{dt}$$

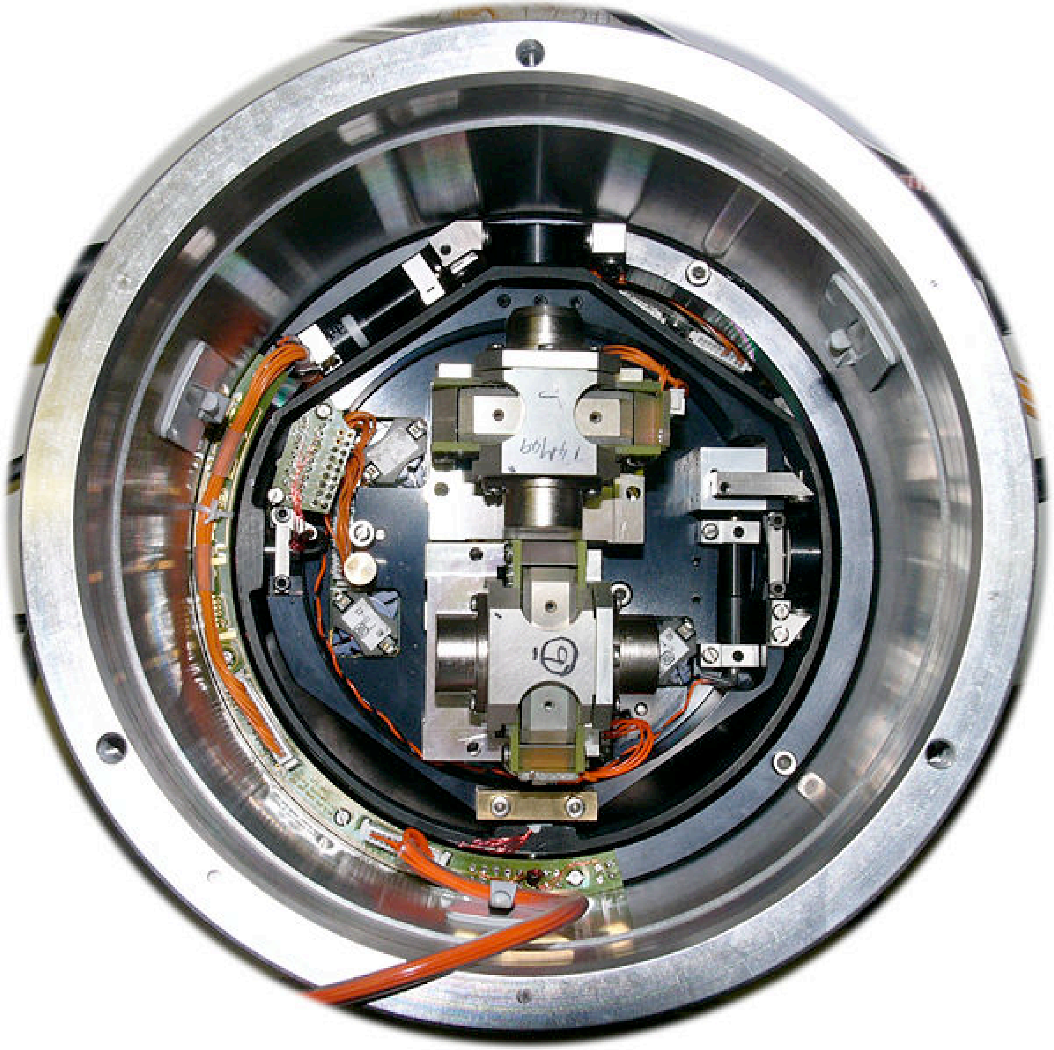


MODERN BROADBAND SEISMOMETERS

> record motions faithfully between 100 - 0.001 Hz

> driven by sophisticated feedback electronic circuits

> motion is measured through voltage required to keep masses stationary



STRONG MOTION SEISMOGRAPHS

> made from MEMS & sensitive to large accelerations

> regular seismometers go off scale

> used in triggered mode to study effects of large eq's

> employed by engineers to aid in design of earthquake resistant infrastructure

SEISMIC NETWORKS

> arrays of seismometers deployed for a common purpose

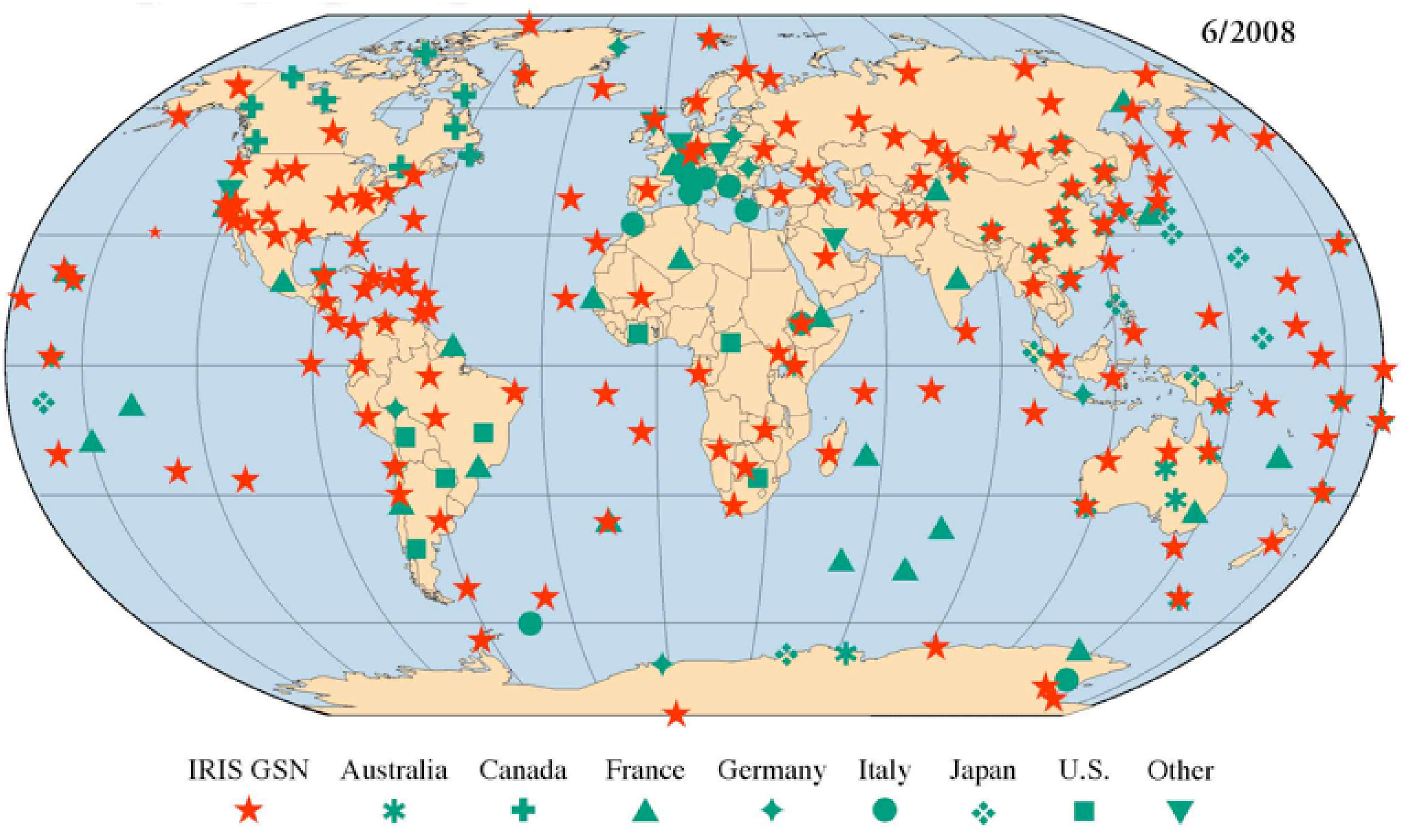
1. Global Seismic Network

2. Regional Networks

3. Portable Arrays

4. EarthScope

GLOBAL SEISMIC NETWORKS



> 150+ stations globally distributed

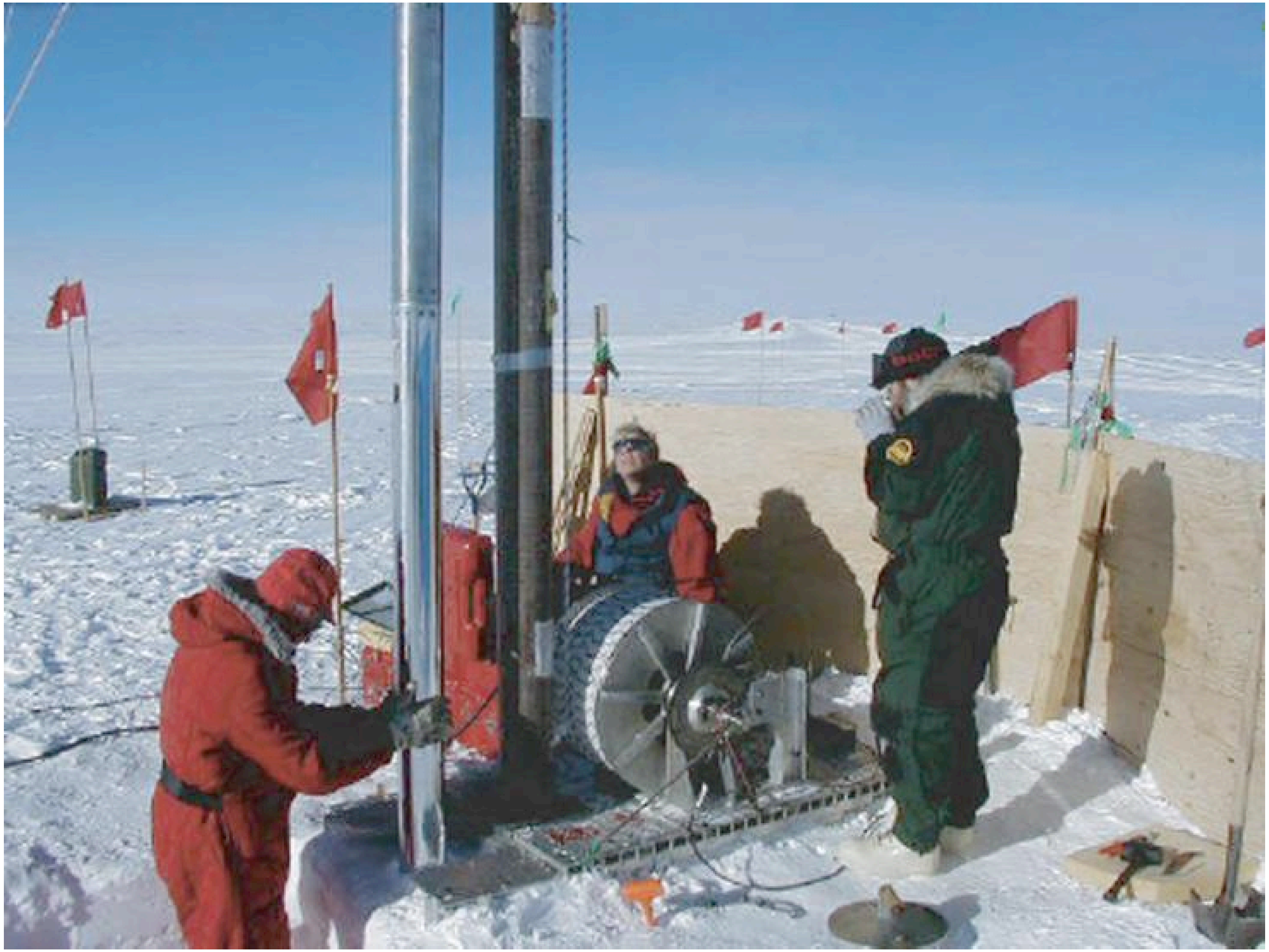
> high quality stations with detection limit ~M=4

> partly underwritten by military agencies to aid in nuclear test ban verification treaties

UNDER GROUND VAULT - KYRGYZSTAN

> note thermal insulation, concrete bunker

SOUTH POLE SITE



> some sites involve seismometers in boreholes to minimize noise

REGIONAL SEISMOGRAPH NETWORKS

> Japanese Hi-Net has over 600 short-period, borehole stations

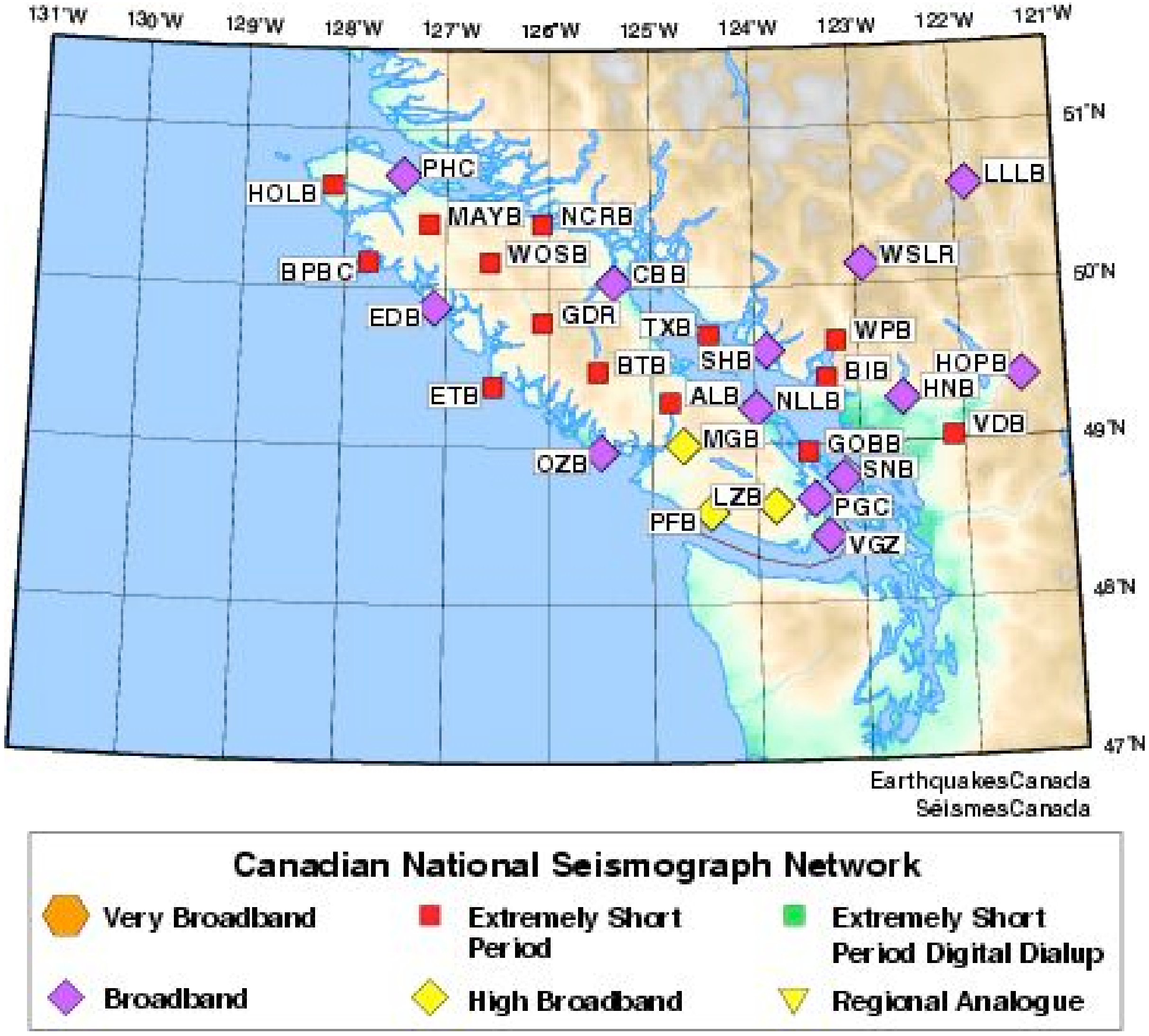
> since 2000, has led to many important discoveries

> 10-20 km spacing

CANADIAN NATIONAL SEISMOGRAPH NETWORK (B.C.)

> G.S.C. operates ~30 seismographs in SW B.C.

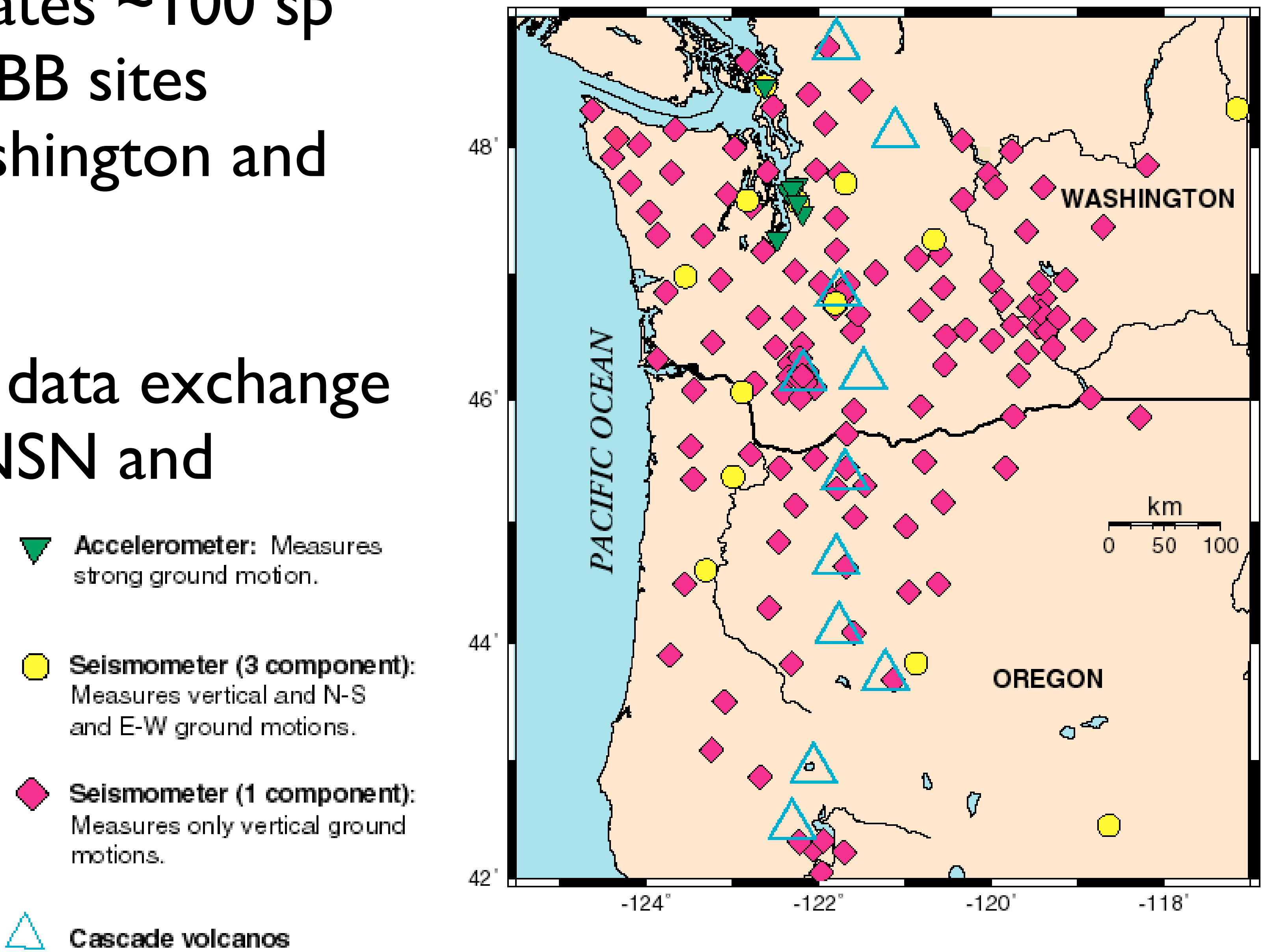
> note concentration on V.I. and lower mainland



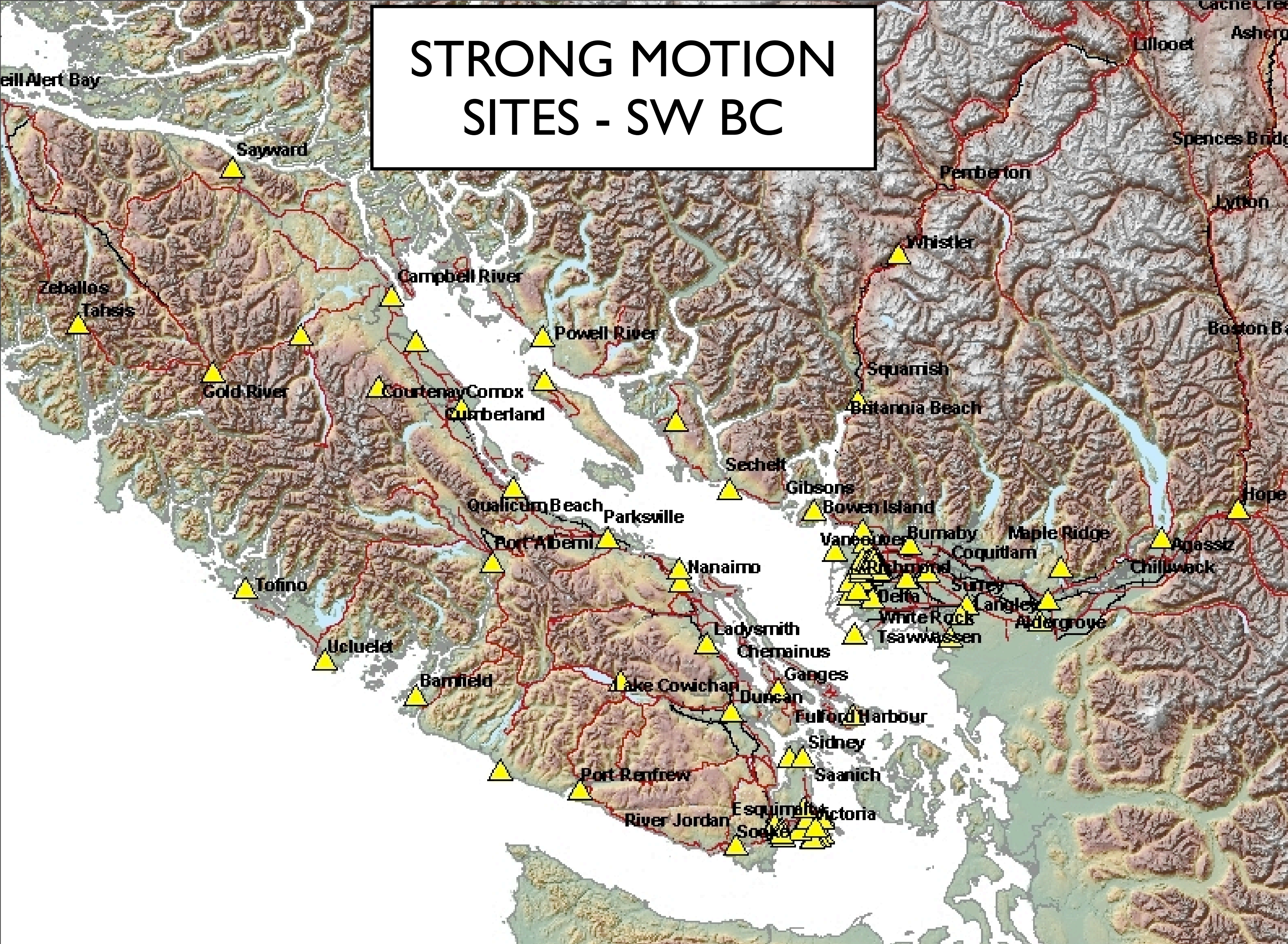
PACIFIC NORTHWEST SEISMIC NETWORK

> UW operates ~100 sp and ~10-20 BB sites through Washington and Oregon

> significant data exchange between CNSN and PNSN



STRONG MOTION SITES - SW BC

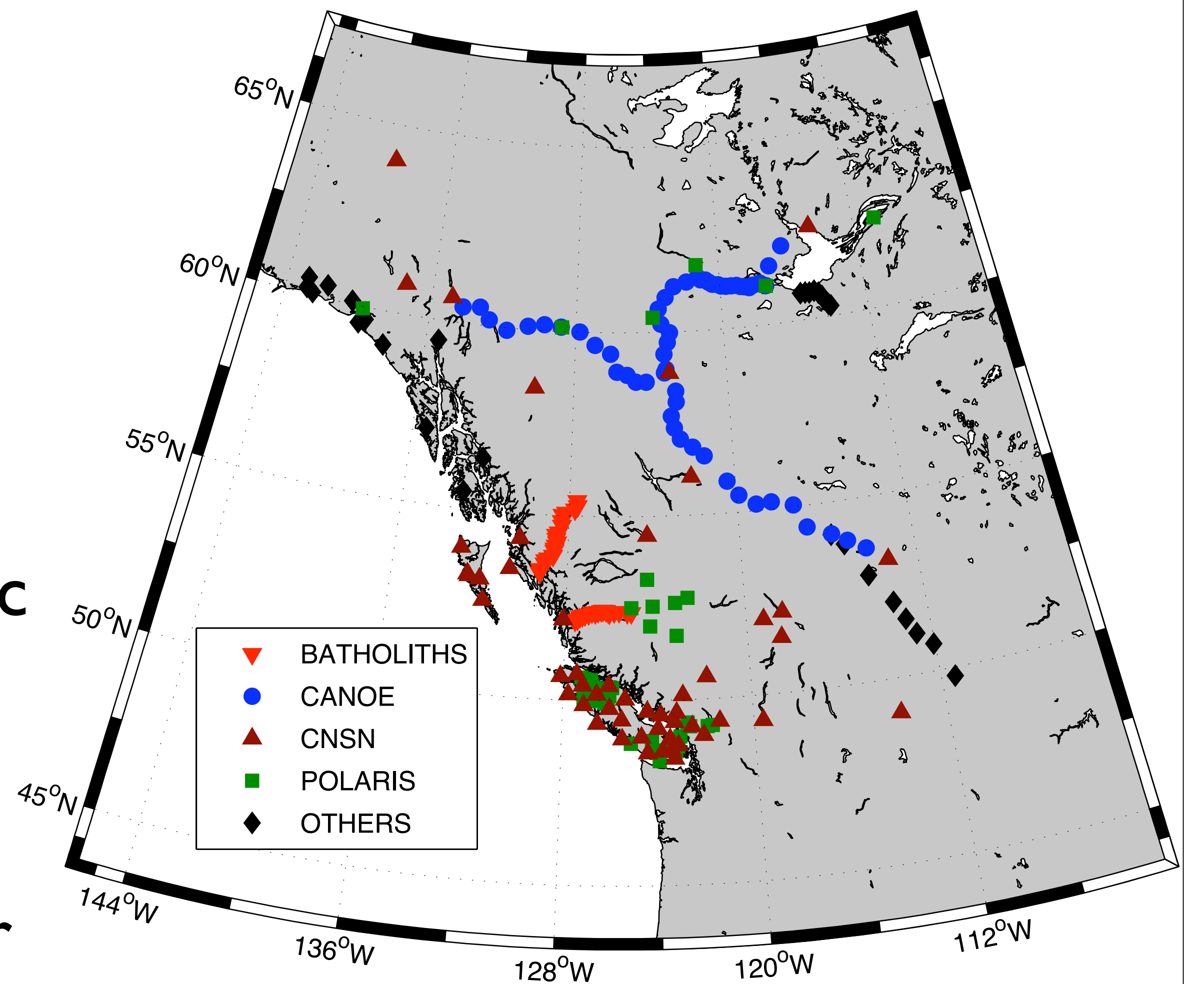


PORTABLE ARRAYS

> many countries possess portable instruments used for temporary field campaigns

> Canada: POLARIS (Portable Observatories for Lithospheric Analysis and Research Investigating Seismicity

> can be used in aftershock or structural studies

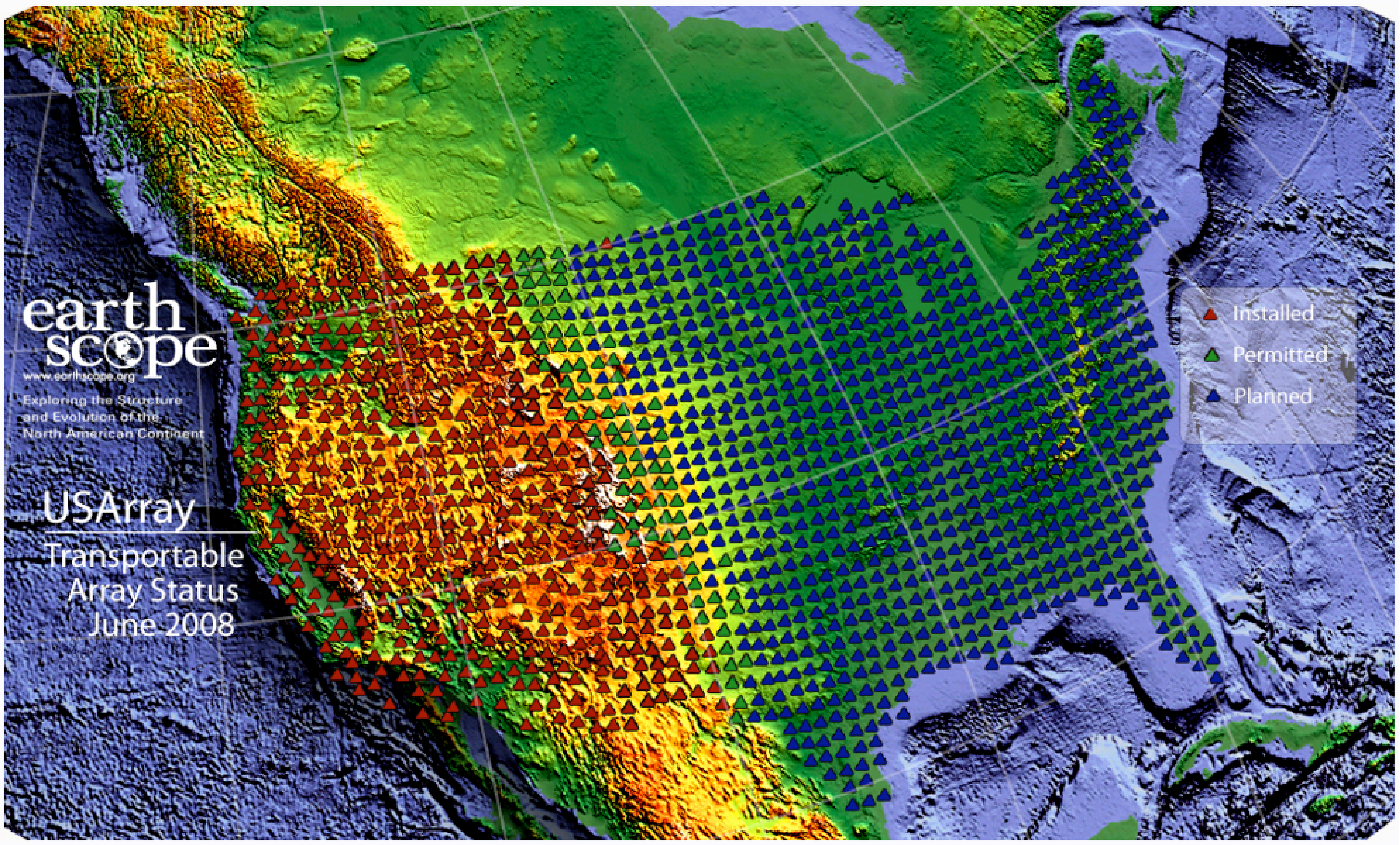


PORTABLE ARRAY VAULTS

> makeshift vaults with solar power

> data archived onto loggers that record continuously

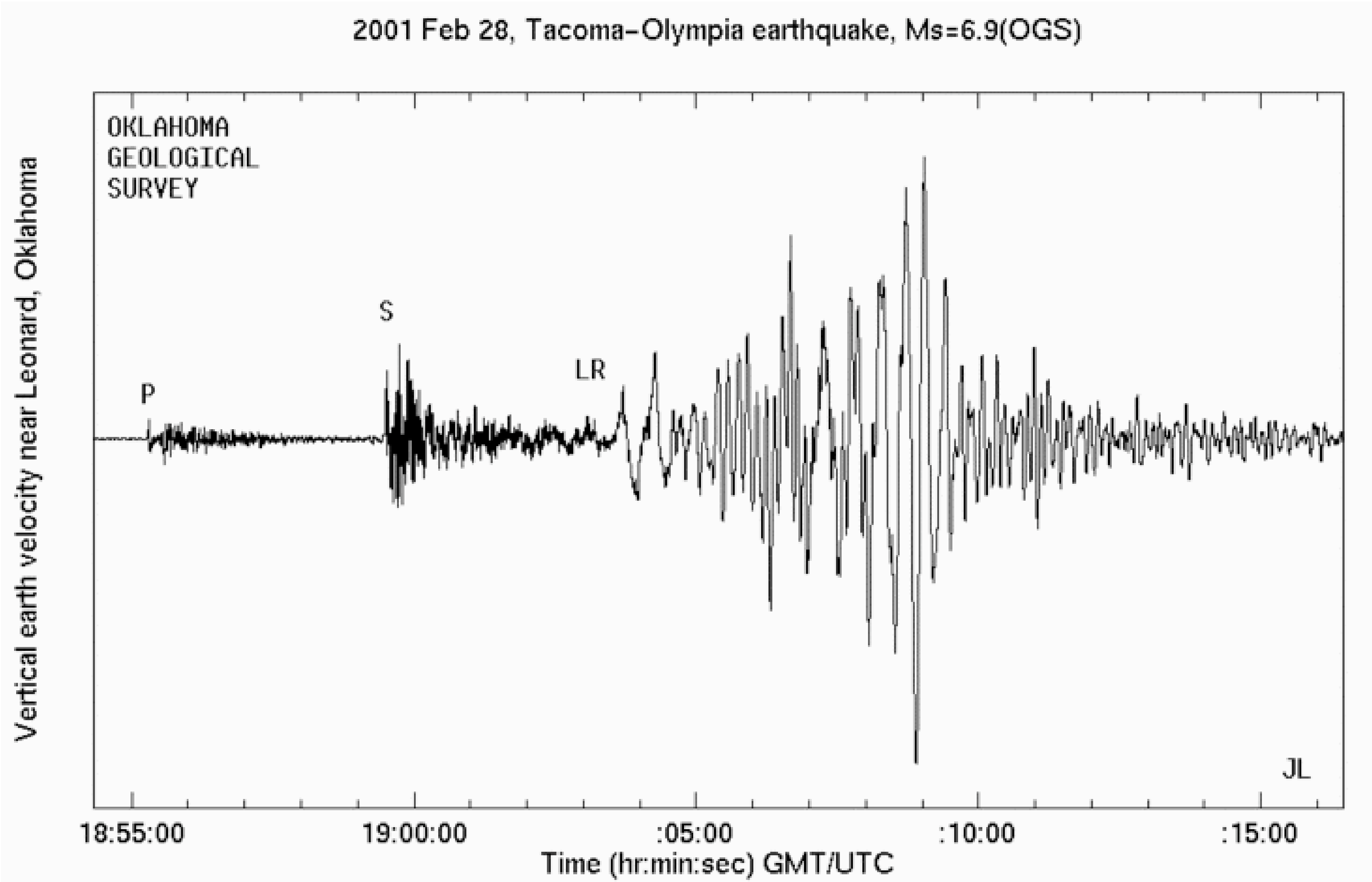
> typical deployment 1-2 years



> new generation of portable experiment; cover whole USA at 70 km spacing

> each station active for 18 months, deployed roll-along array over 15 years

SEISMOGRAMS



> incredibly rich and varied in appearance depending on source, frequency content, distance etc.