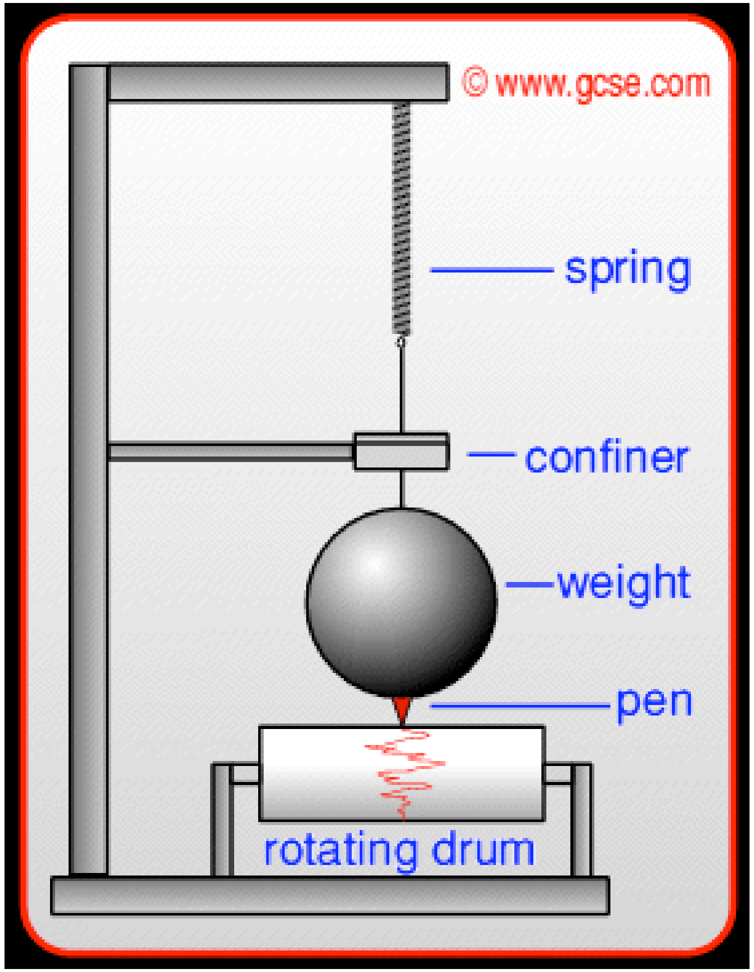
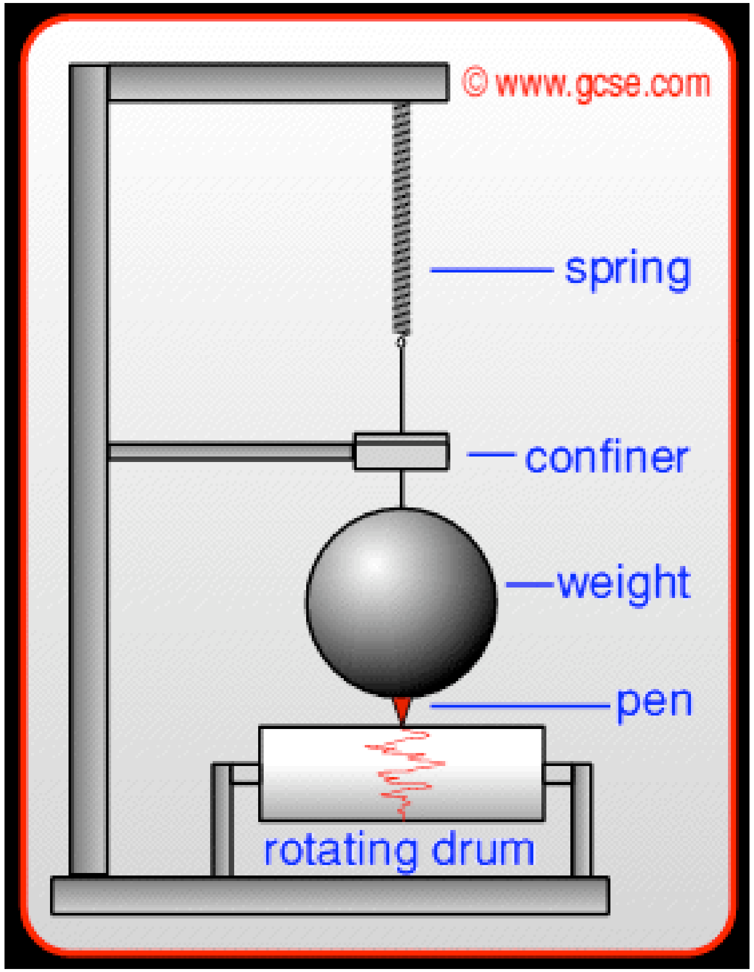
SEISMOMETERS, SEISMOGRAPHS, SEISMOGRAMS

1. What is a seismometer?
2. What is a seismograph?
3. What is a seismogram

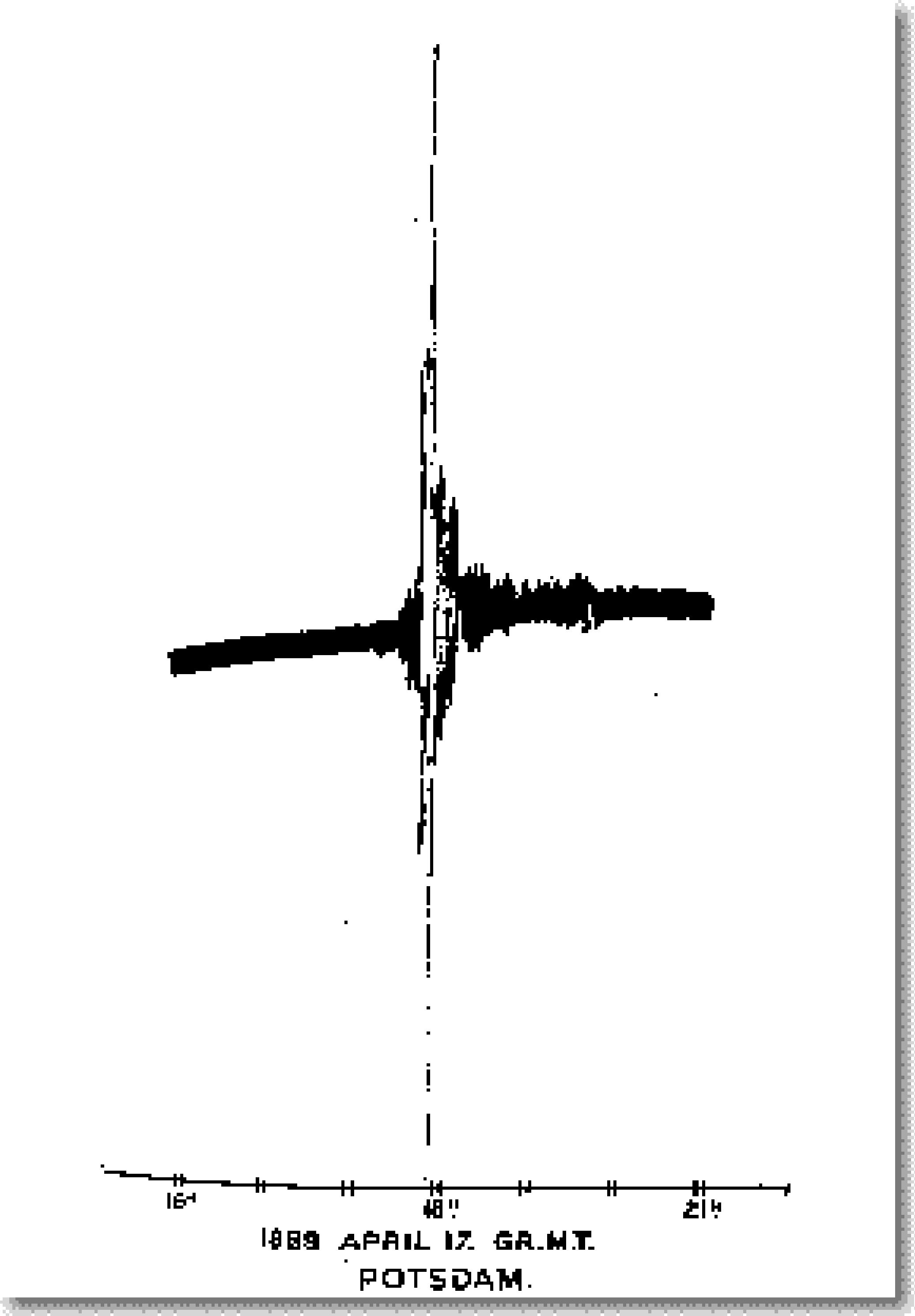
A **seismometer** is a mechanical device that measures and amplifies ground motion at a point on the Earth's surface or in a borehole



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

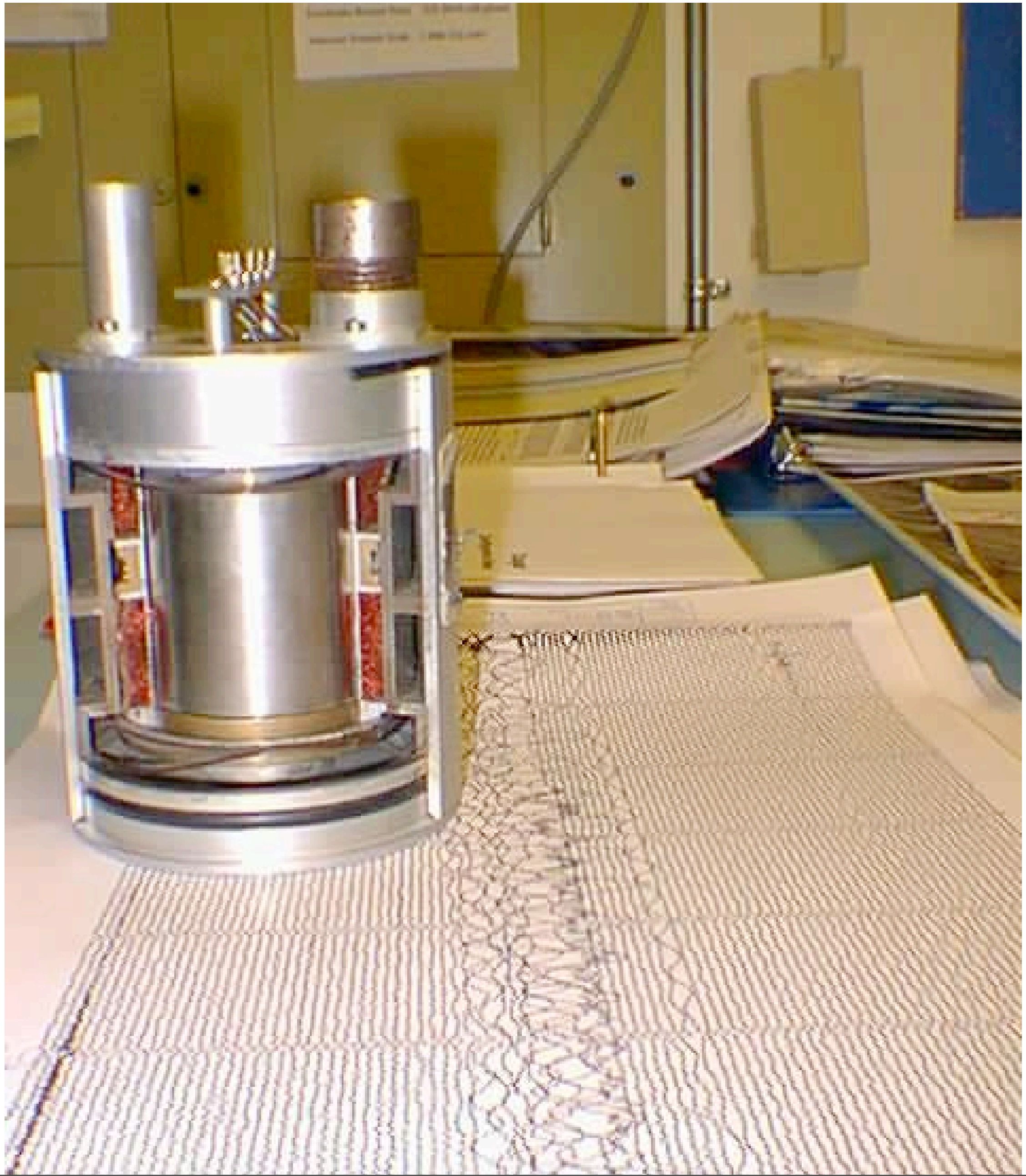
> work on damped pendulum theory

> resonant frequency at 1 Hz, 0.1 Hz

> mass incorporates solenoid which moves in a magnetic field

> Faraday's law states

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

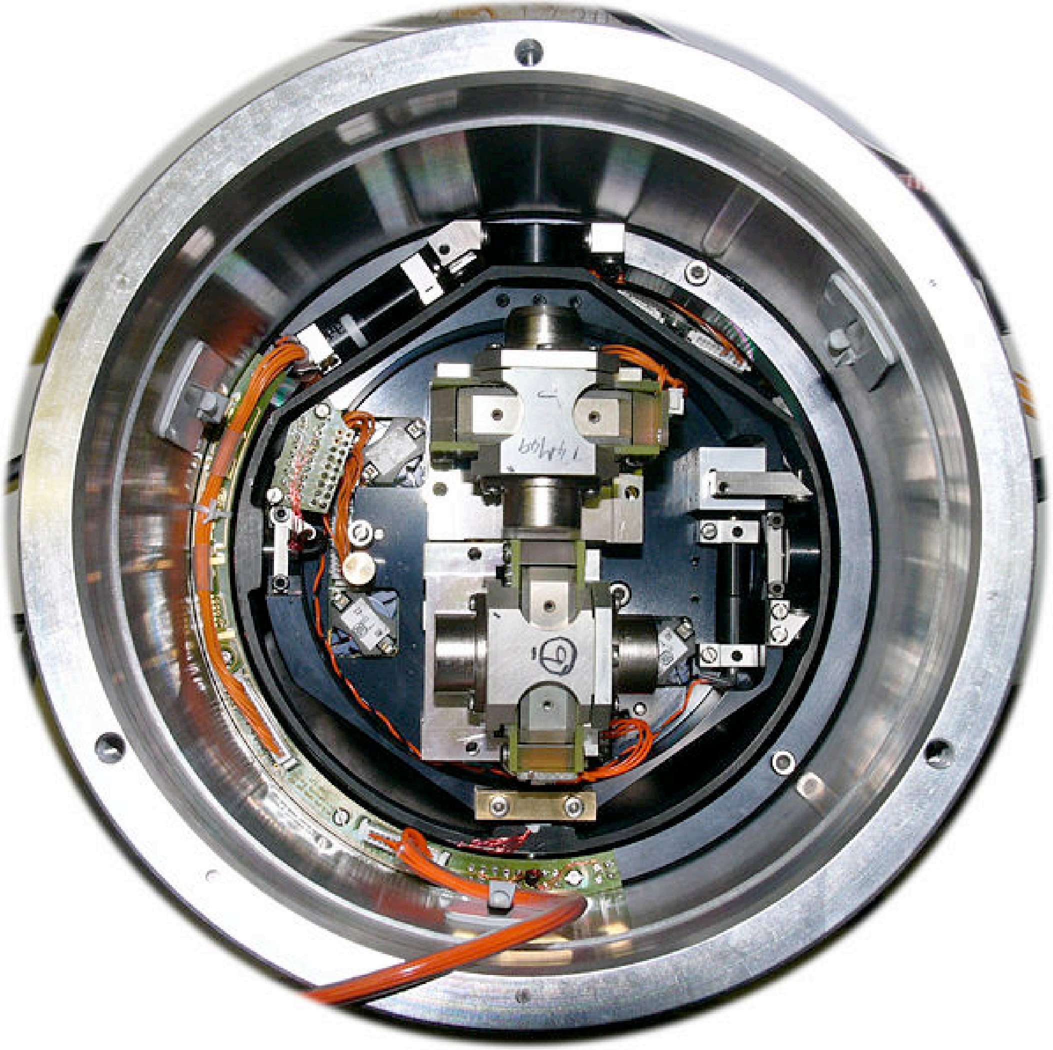


MODERN BROADBAND SEISMOMETERS

> 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

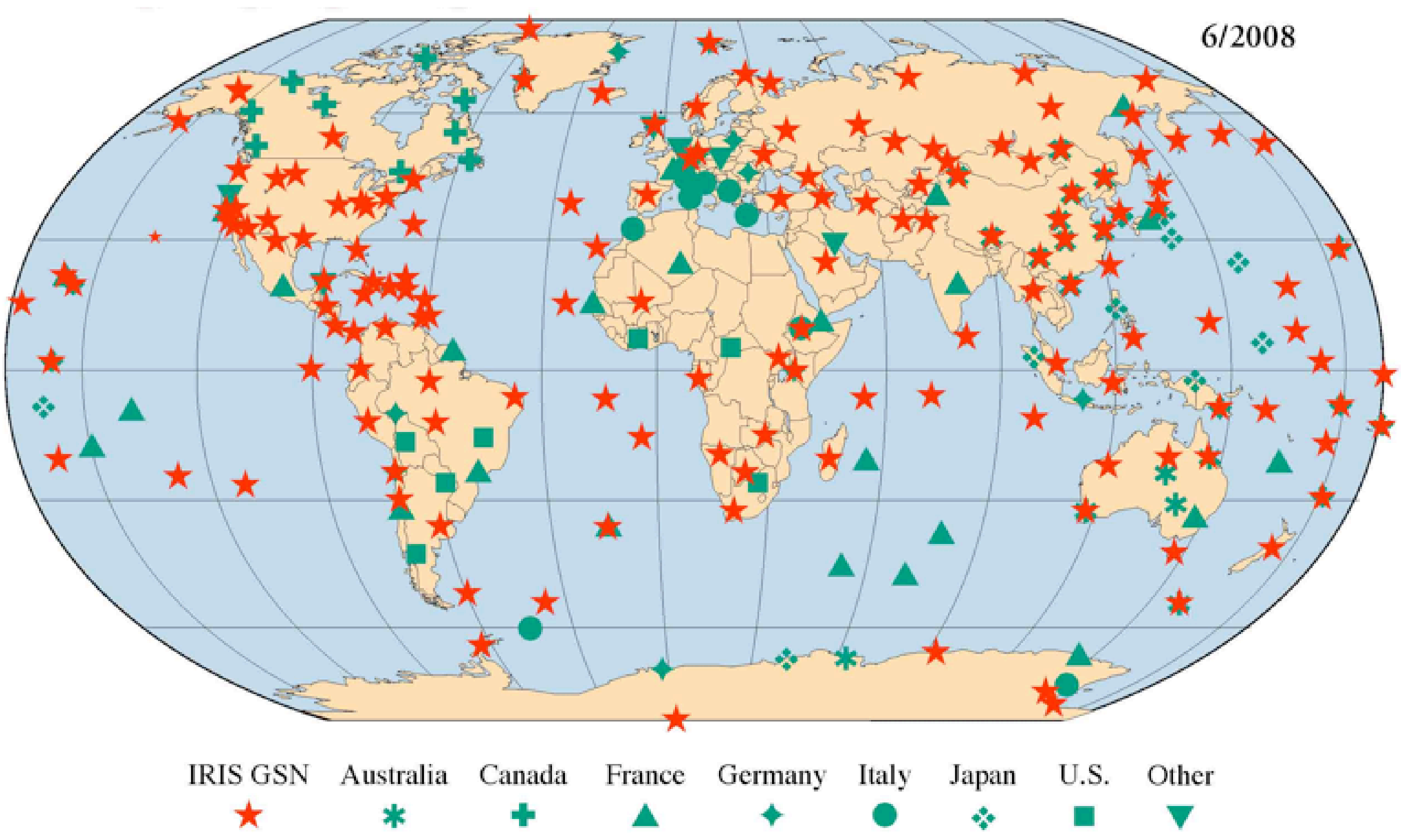
1. Global Seismic Network

2. Regional Networks

3. Portable Arrays

4. EarthScope

GLOBAL SEISMIC NETWORKS



> 150+ stations globally distributed

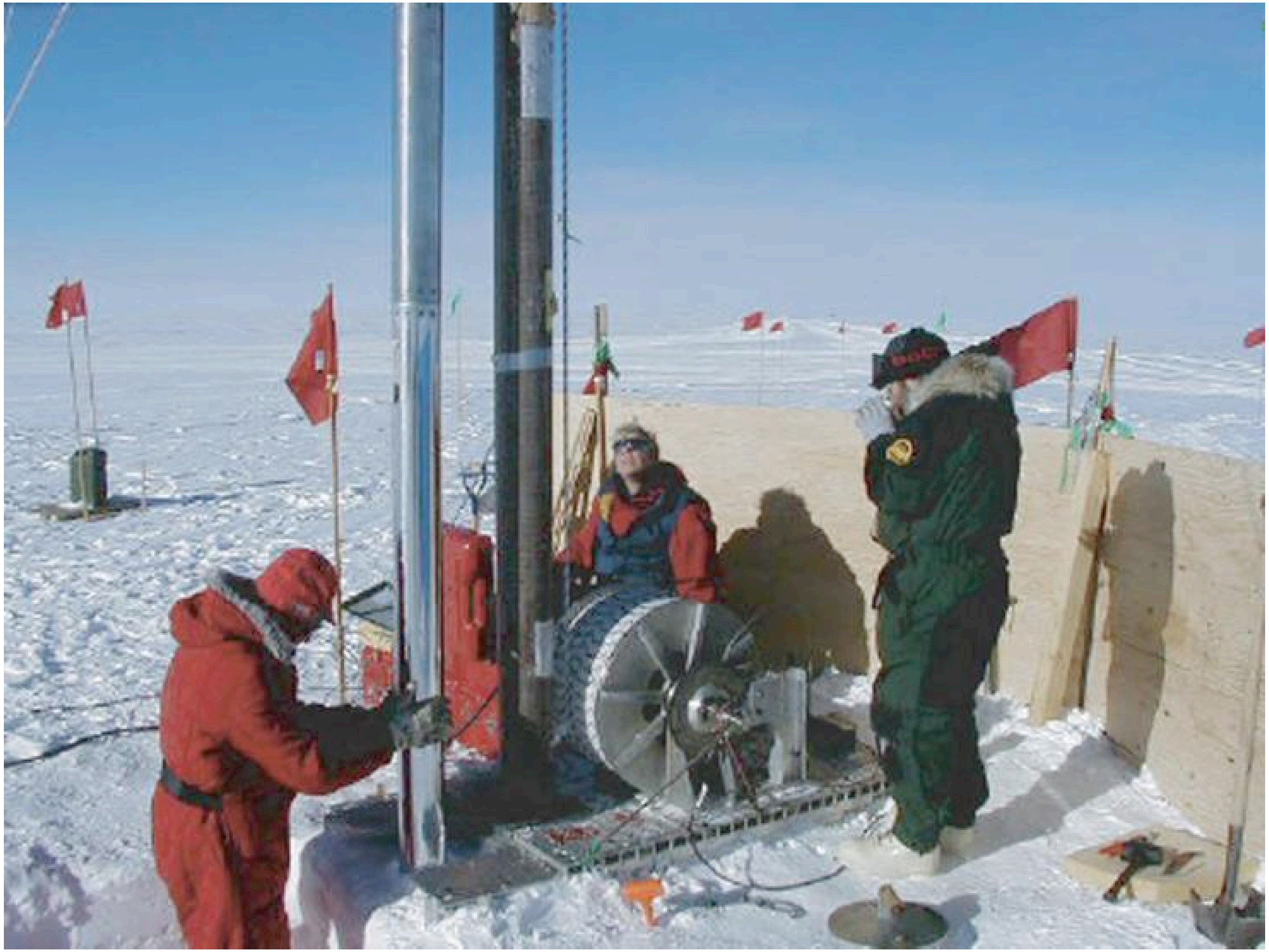
> high quality stations with detection limit ~M=4

> 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

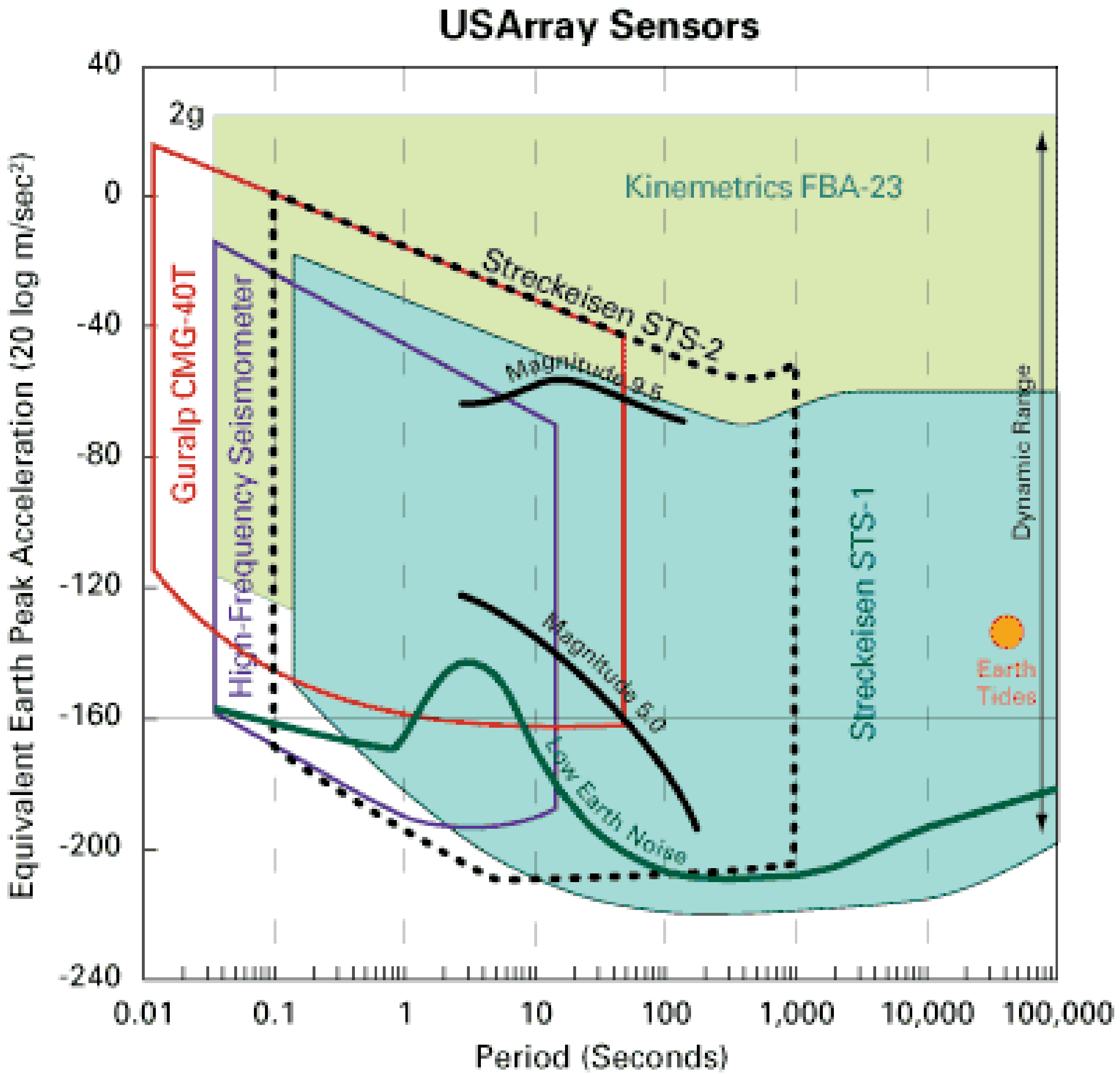


> some sites involve seismometers in boreholes to minimize noise

PITCAIRN ISLAND SITE

> most communications by satellite

HIGH PRECISION SEISMOMETERS



> highly sensitive : -200 is equivalent to what acceleration?

$$x = 10^{-10}\,\mathrm{m\,s^{-2}}$$

REGIONAL SEISMOGRAPH NETWORKS

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

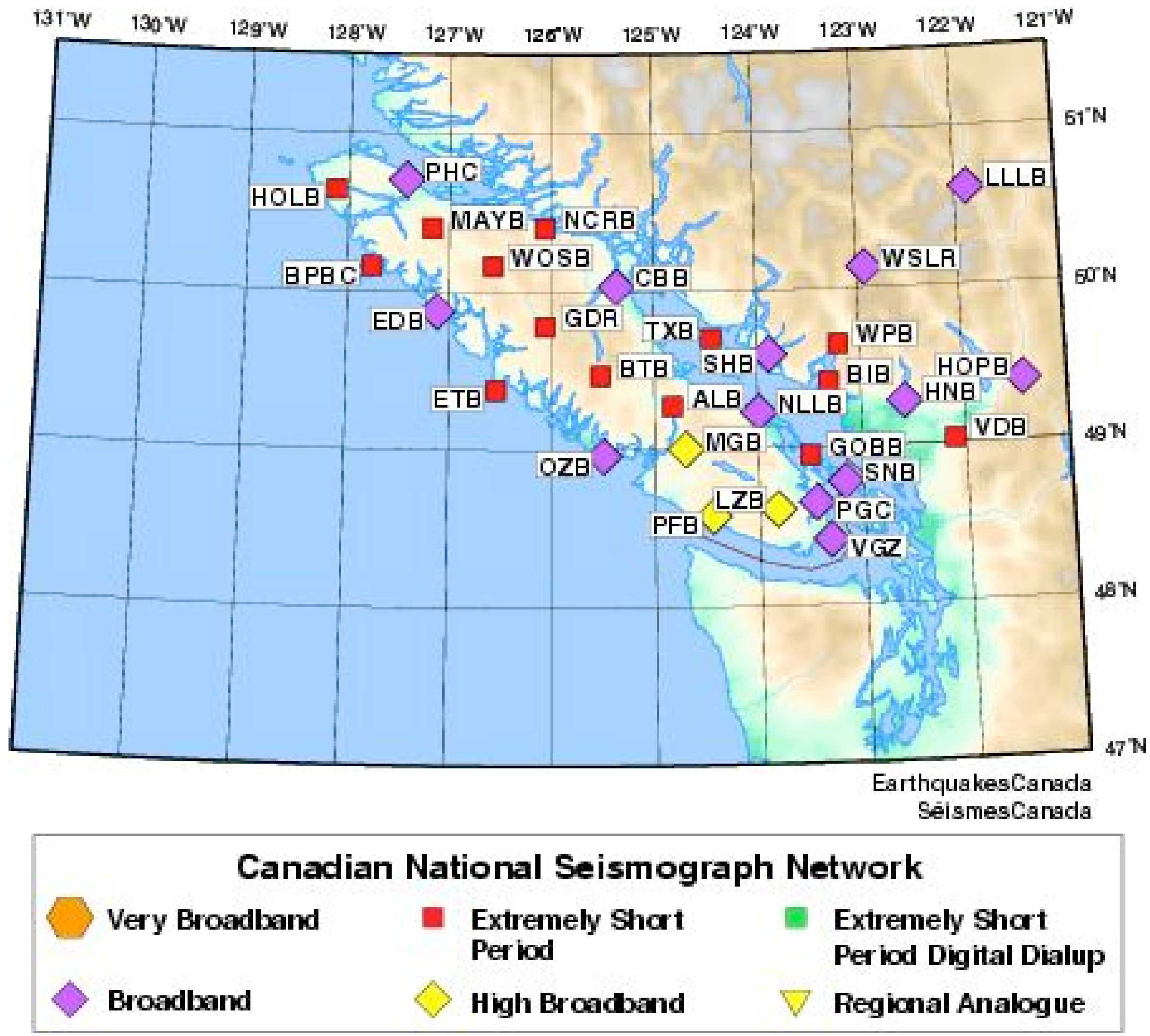
> since 2000, has led to many important discoveries

> 10-20 km spacing

CANADIAN NATIONAL SEISMOGRAPH NETWORK (B.C.)

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

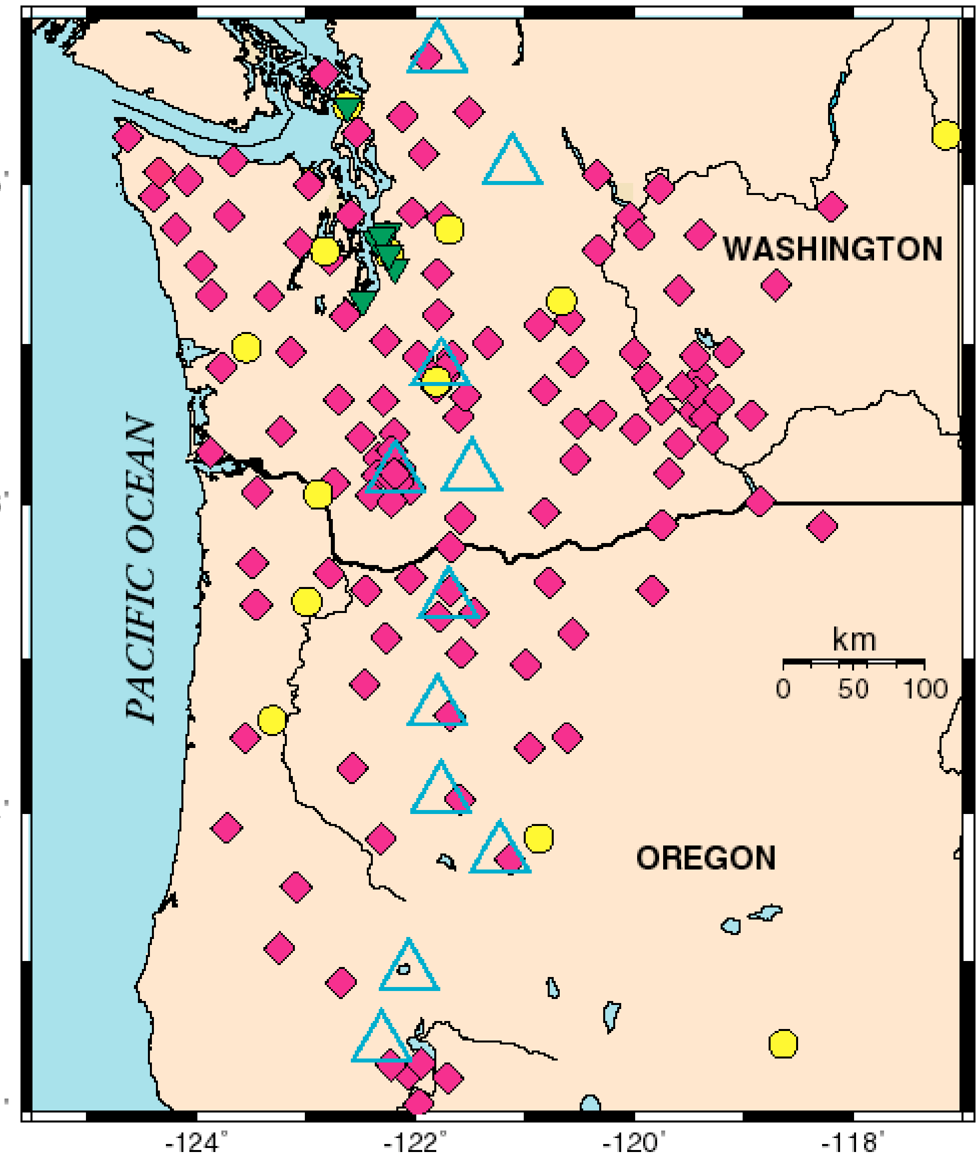
> note concentration on V.I. and lower mainland



PACIFIC NORTHWEST SEISMIC NETWORK

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

> significant data exchange between CNSN and PNSN



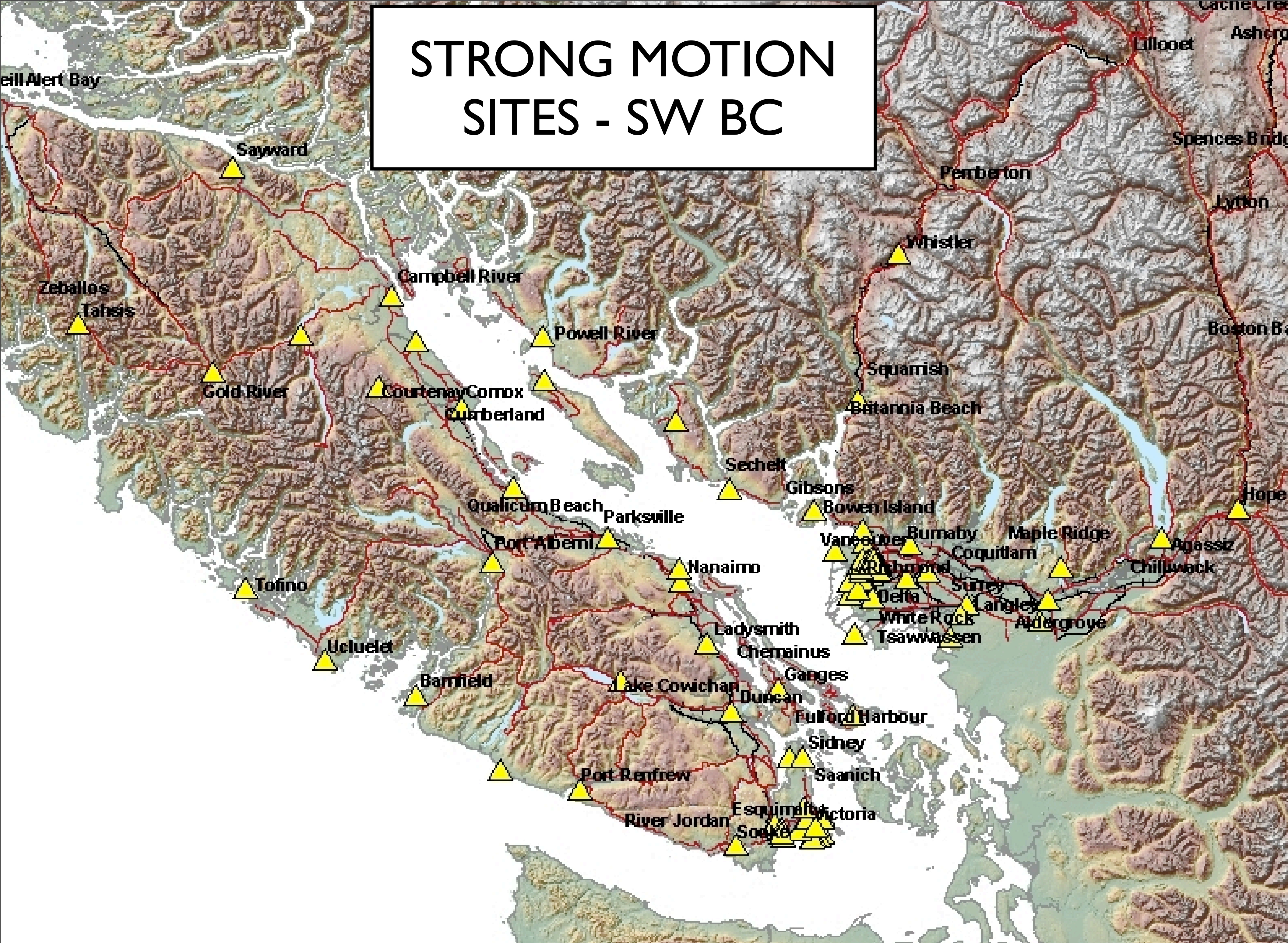
Accelerometer: Measures strong ground motion.

Seismometer (3 component): Measures vertical and N-S and E-W ground motions.

Seismometer (1 component): Measures only vertical ground motions.

Cascade volcanos

STRONG MOTION SITES - SW BC

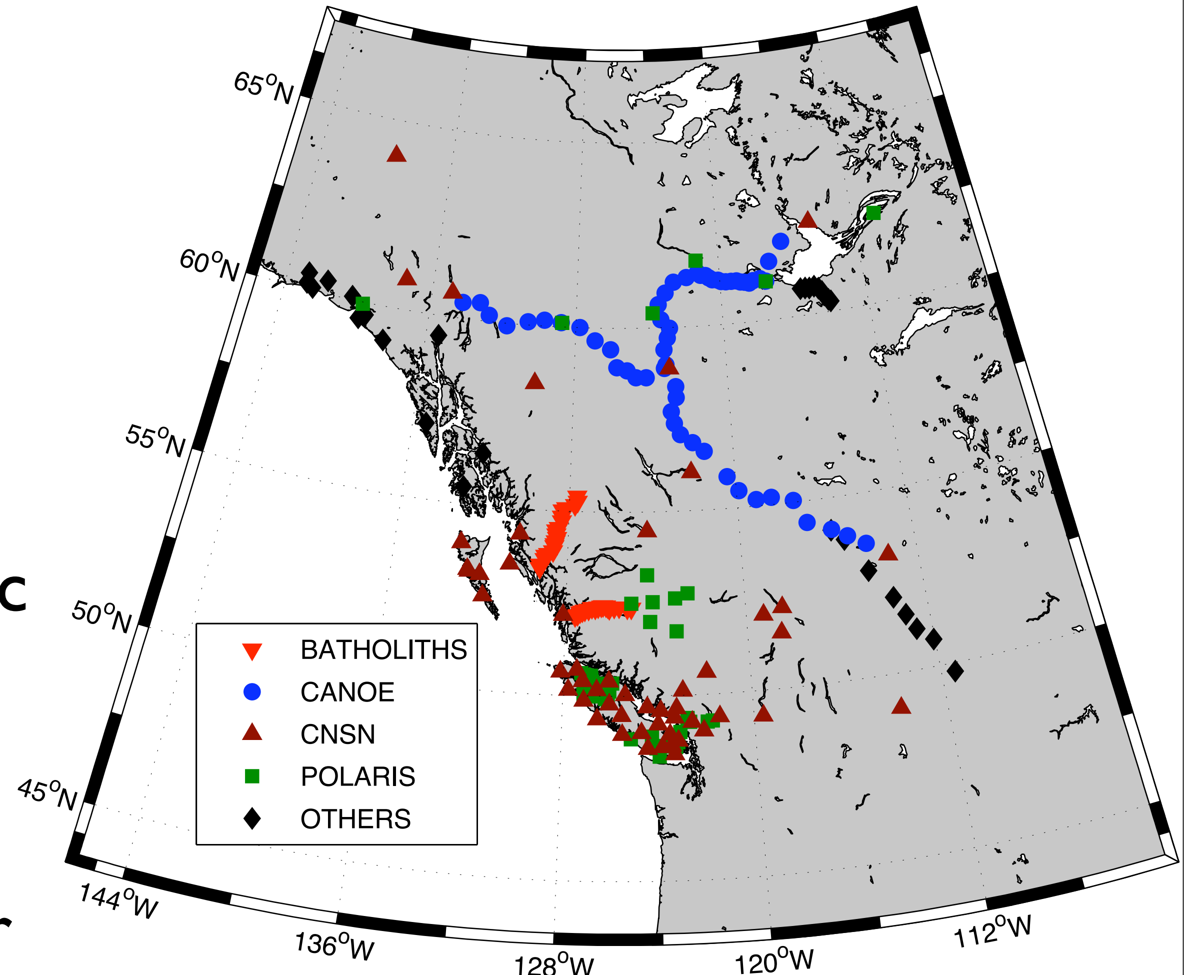


PORTABLE ARRAYS

> 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

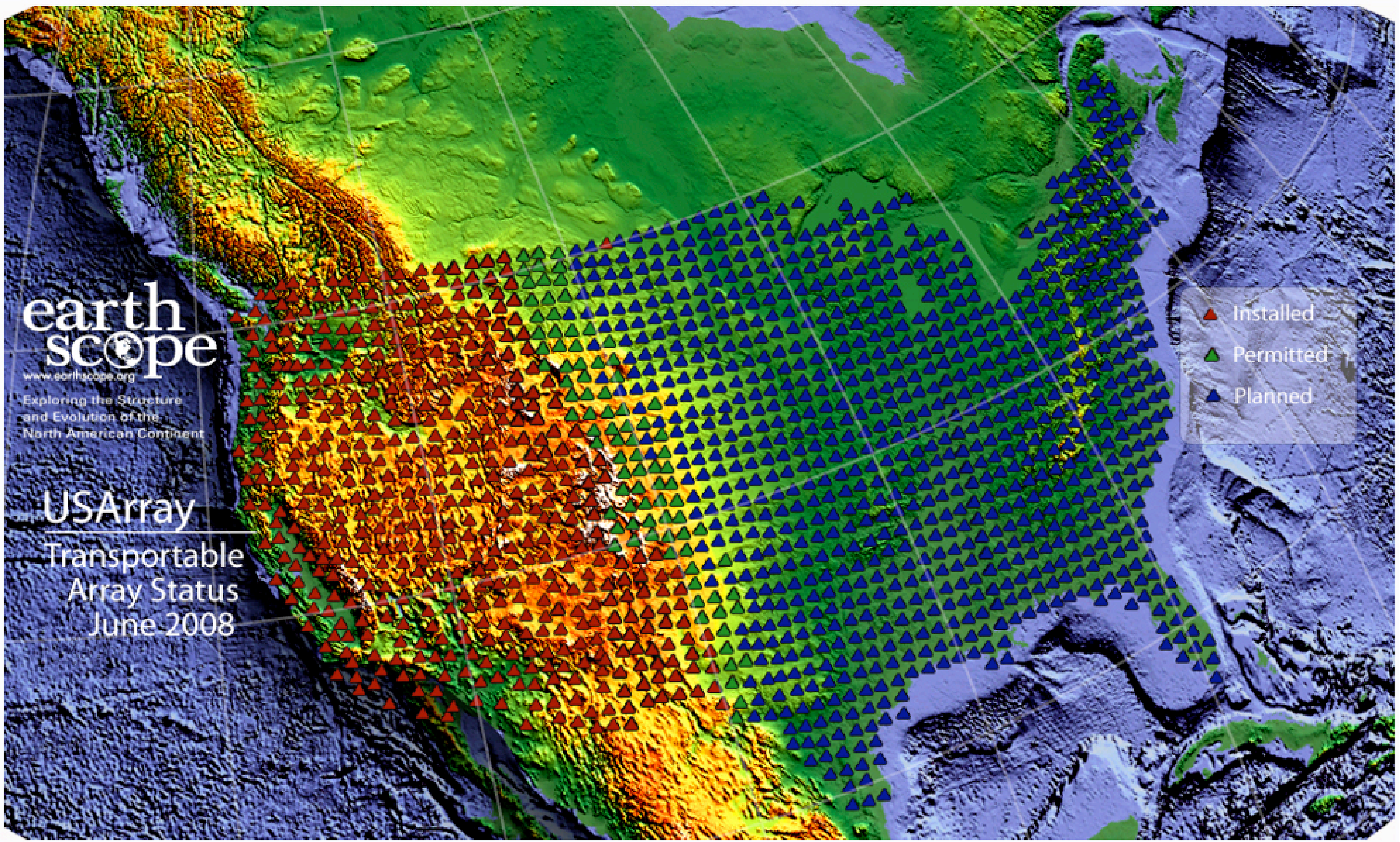


PORTABLE ARRAY VAULTS

> makeshift vaults with solar power

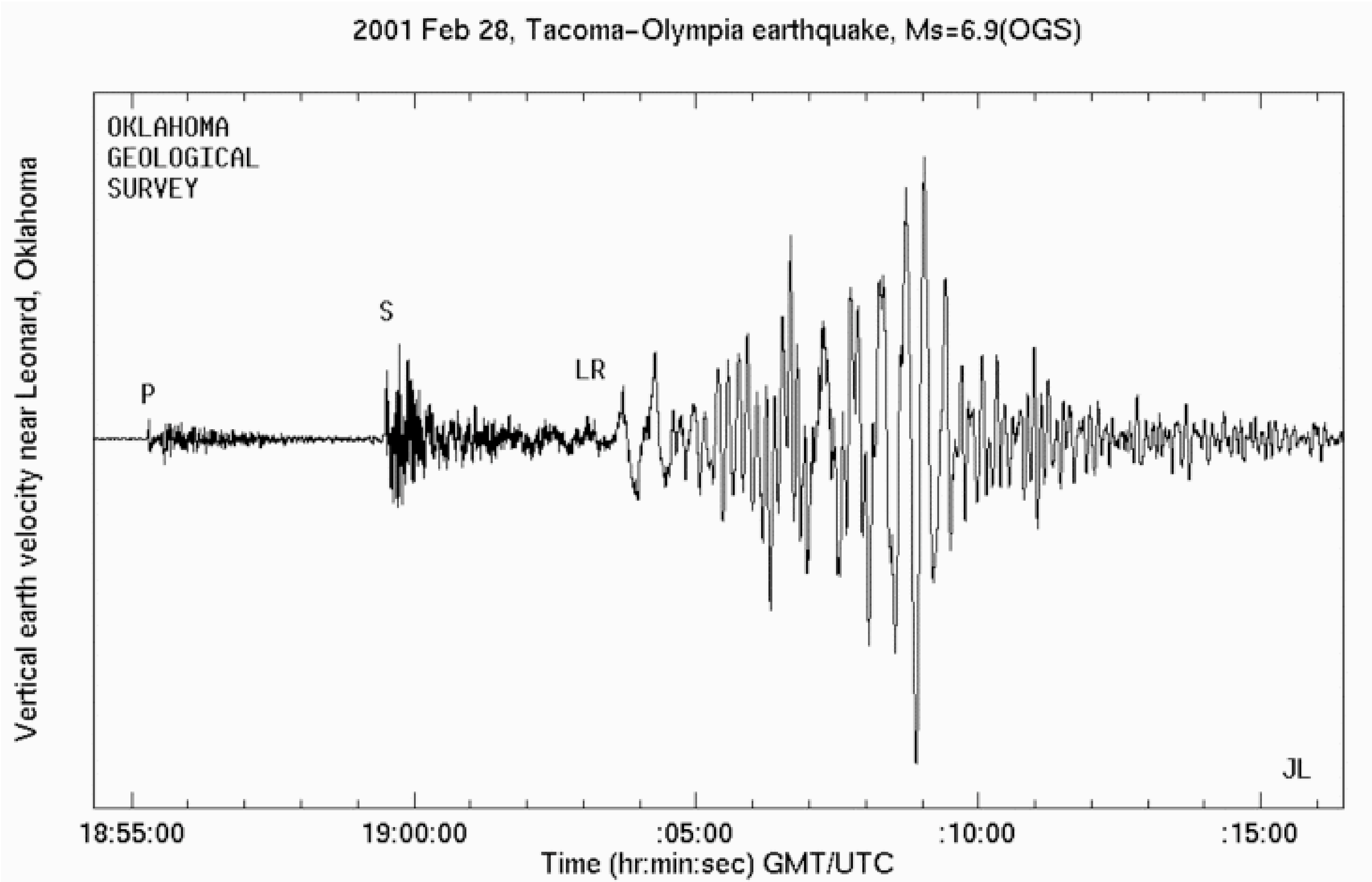
> data archived onto loggers that record continuously

> typical deployment 1-2 years

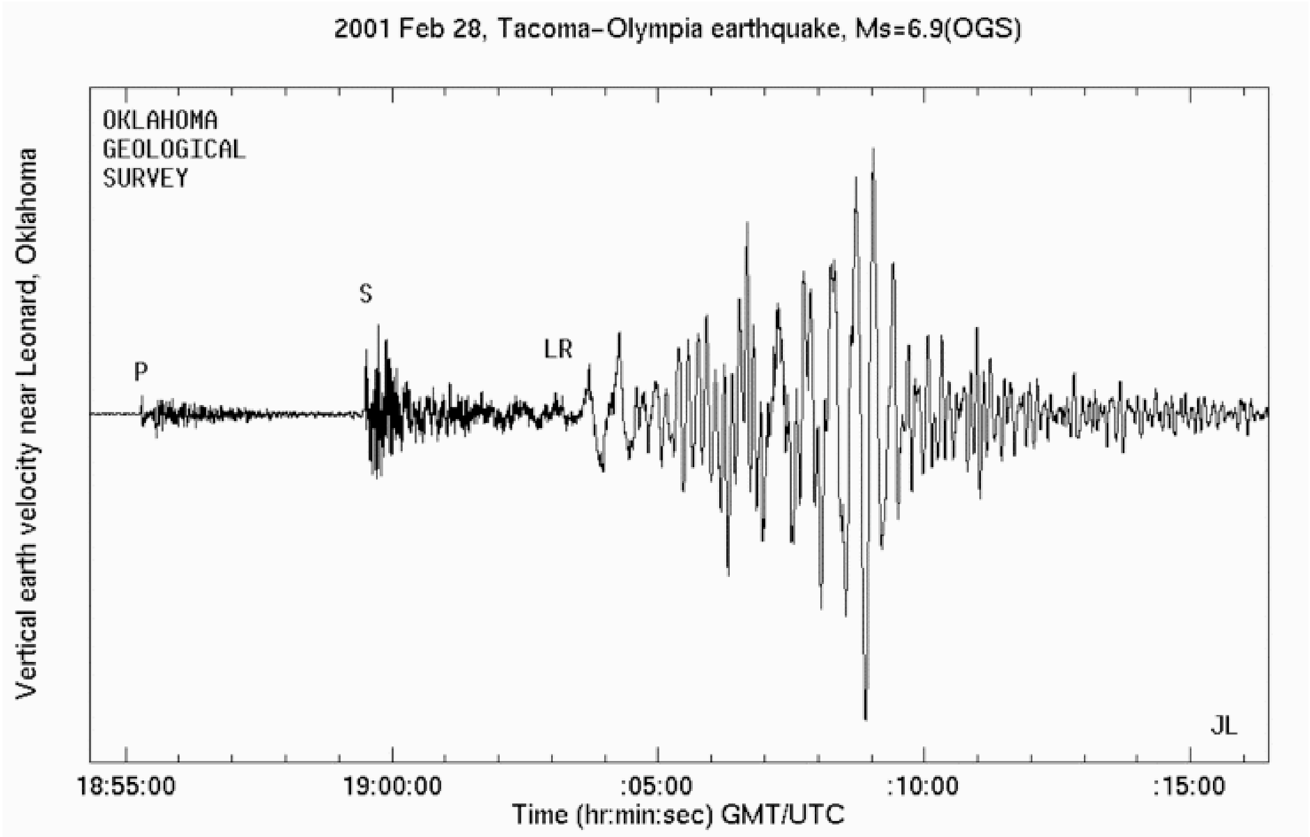


> new generation of portable experiment; cover whole USA at 70 km spacing
> each station active for 18 months, deployed roll-along array over 15 years

SEISMOGRAMS



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



Many ways to extract information from seismogram:

1. Identify main phases, extract time/amplitude
2. Identify scattered phases
3. Match whole seismogram

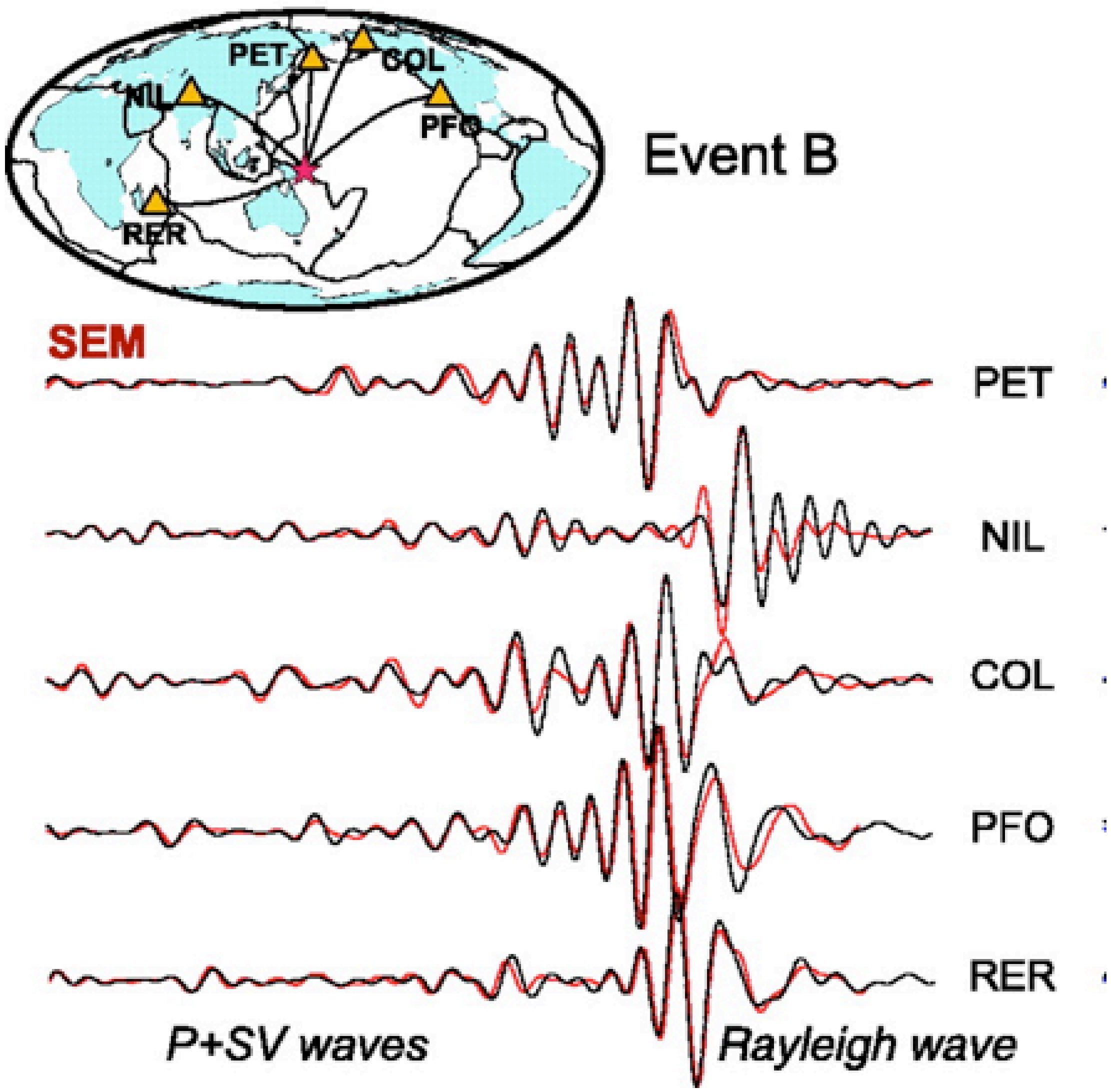
Use information to extract knowledge of ***earthquake*** and/or ***earth structure***

LONG PERIOD SEISMOGRAMS

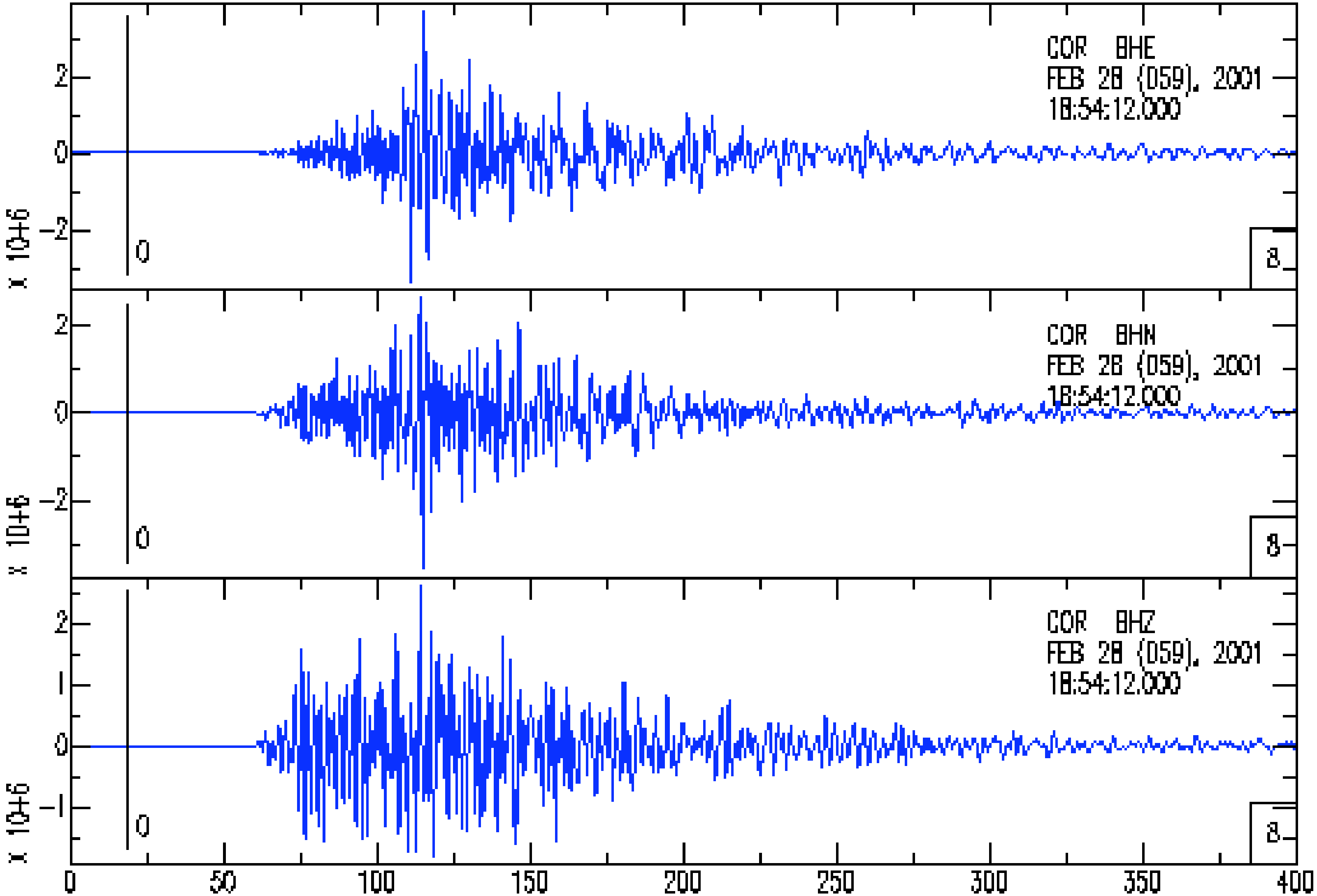
> T > 10 s

> dominated by S and surface waves

> simple to model

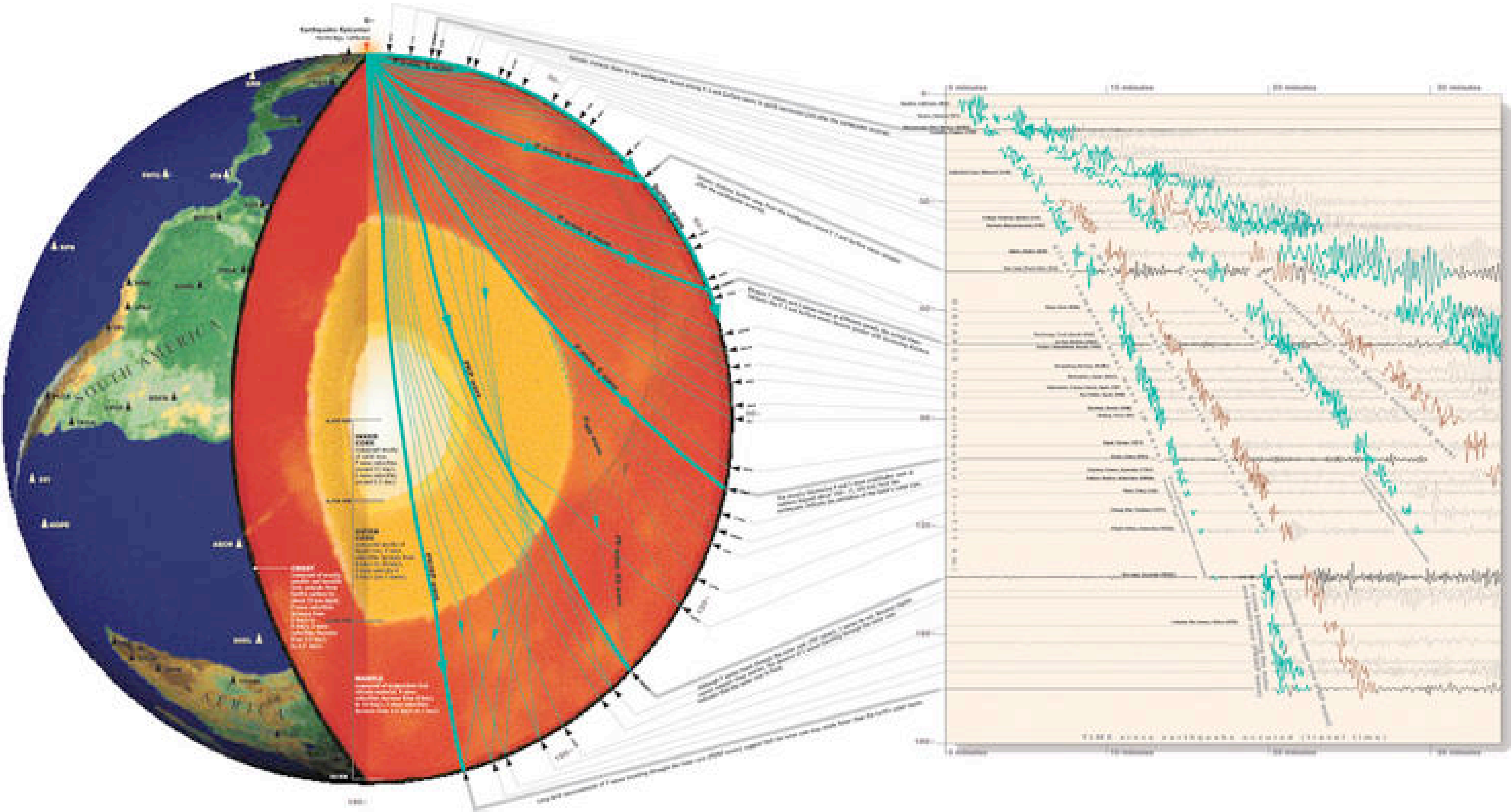


REGIONAL SEISMOGRAMS



> higher frequency (>1Hz), more complex, harder to identify individual P, S, surface waves

PRIMARY PHASES



> at global scale Earth looks like layered sphere

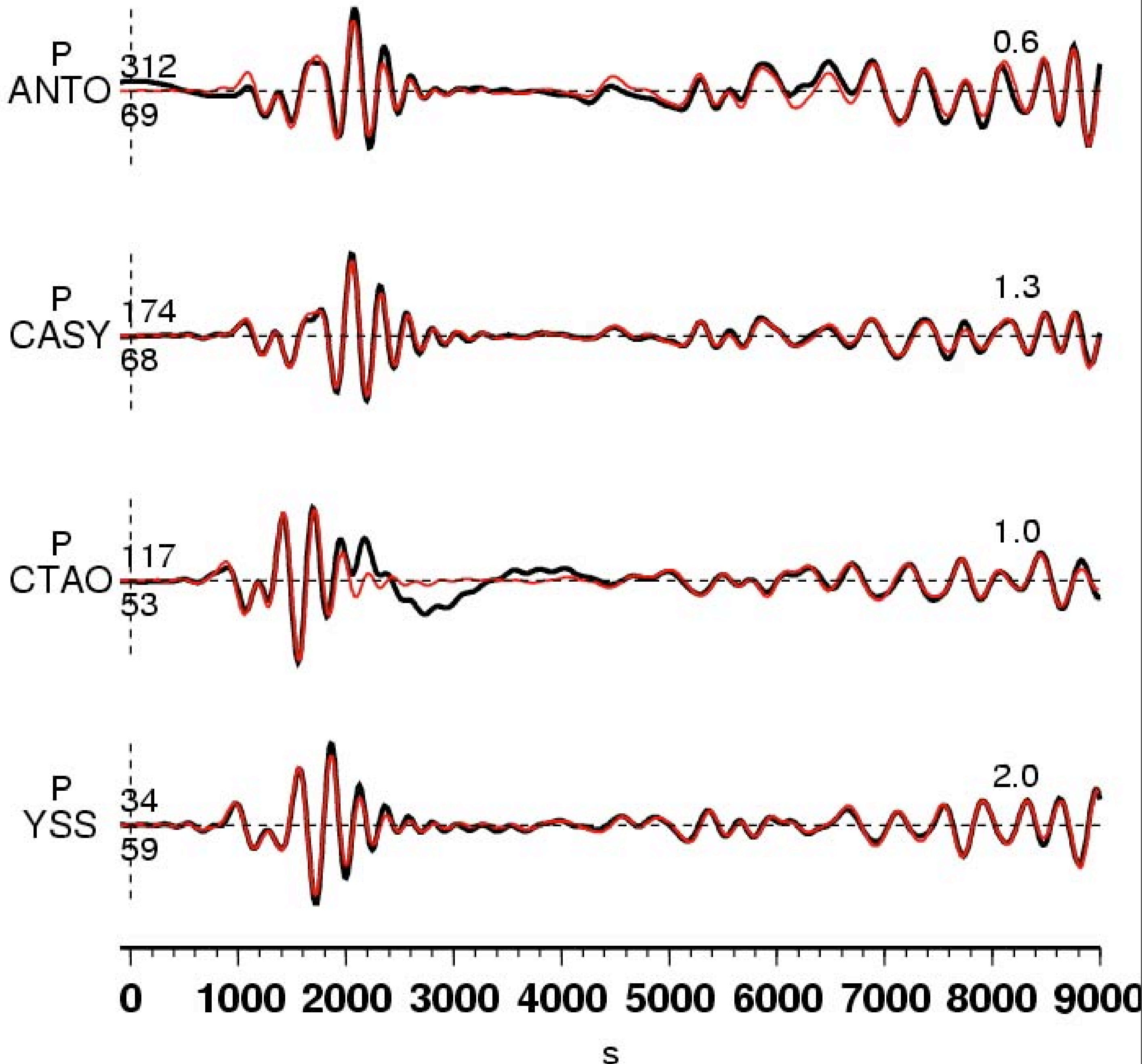
> readily predictable seismic phases propagating through crust, mantle, outer core, inner core

WAVEFORM MATCHING

> requires knowledge knowledge of model for both source and struture

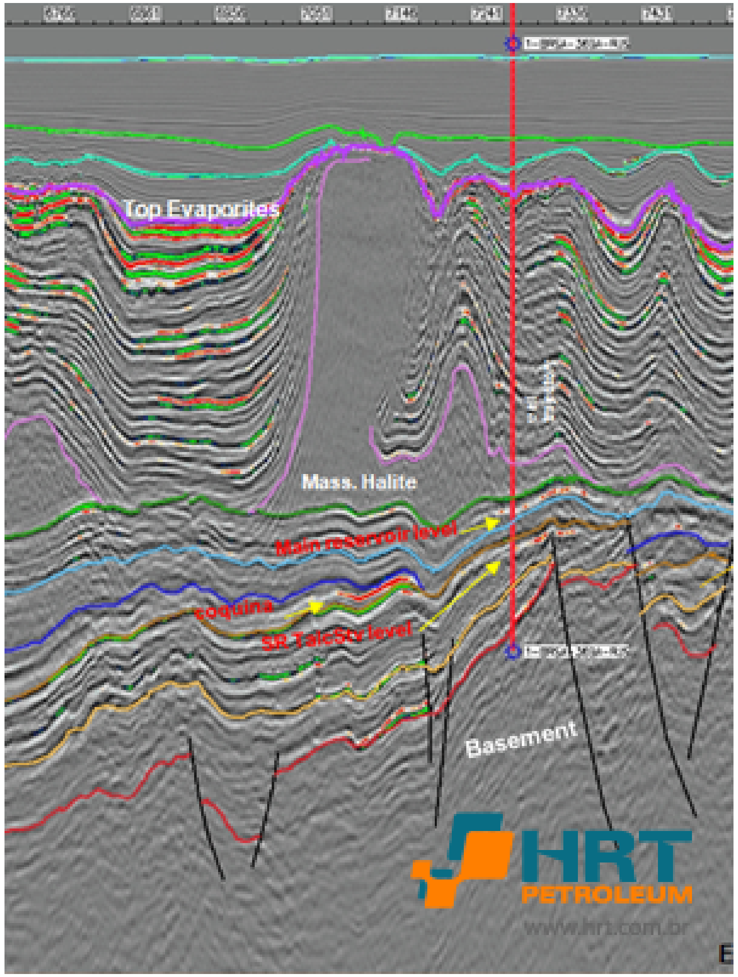
> data: black, model red

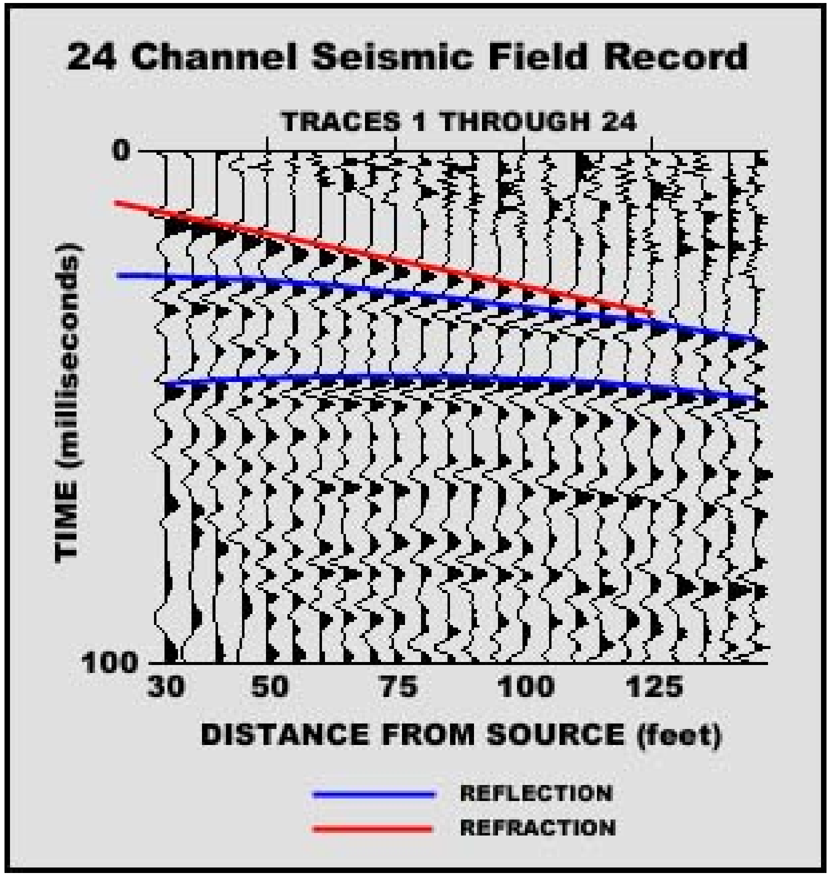
> at long periods (gt 10 s) we can model seismograms well, not so at short periods (lt 1s)



05/03/28 (Mw 8.5) , Sumatra Earthquake

SEISMIC REFLECTION IMAGING

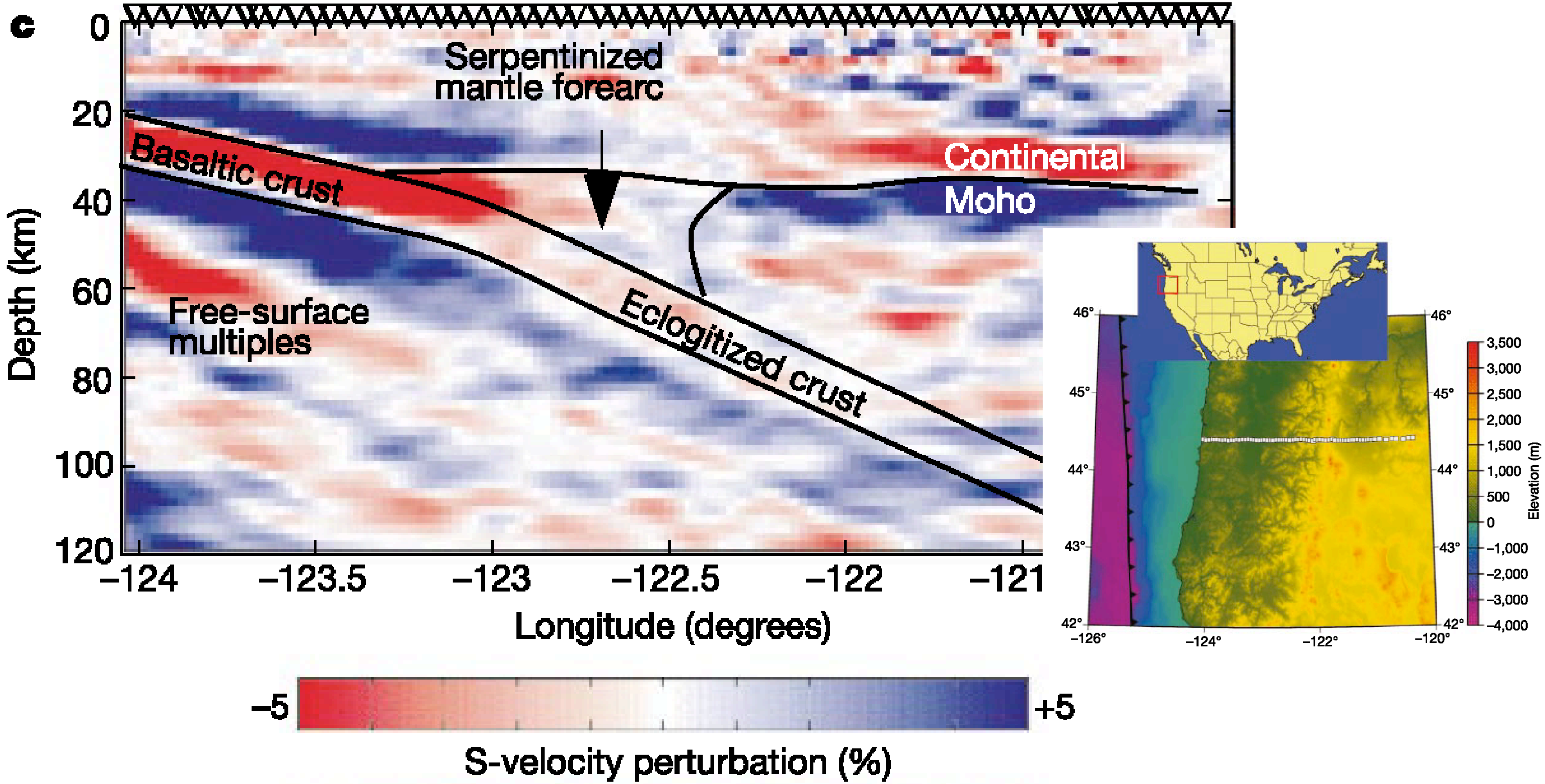




> seismic reflections/conversions originate from discontinuities in velocity/density

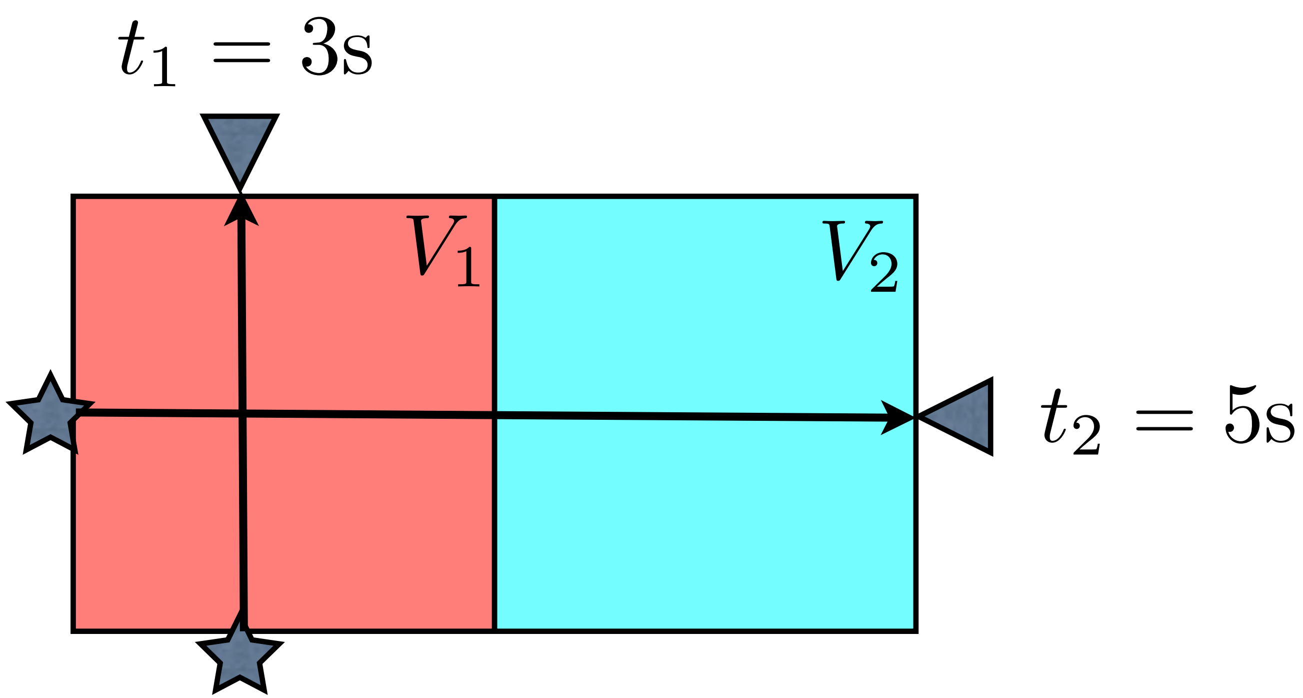
> primary tool for hydrocarbon exploration

TELESEISMIC IMAGING



> waves generated by earthquakes and scattered from discontinuities can be used to image e.g. subduction zones

TRAVELTIME TOMOGRAPHY



> 2 blocks (1 m X 1 m) with unknown velocities V_1, V_2

> 2 traveltime measurements t_1, t_2

> can you determine V_1, V_2?

SOLUTION

1. Solve for V_1 using t_1 : $\quad V_1 = 0.3333\,\mathrm{m/s}$

2. Insert in solve for V_2 : $\quad V_2 = 0.5\,\mathrm{m/s}$

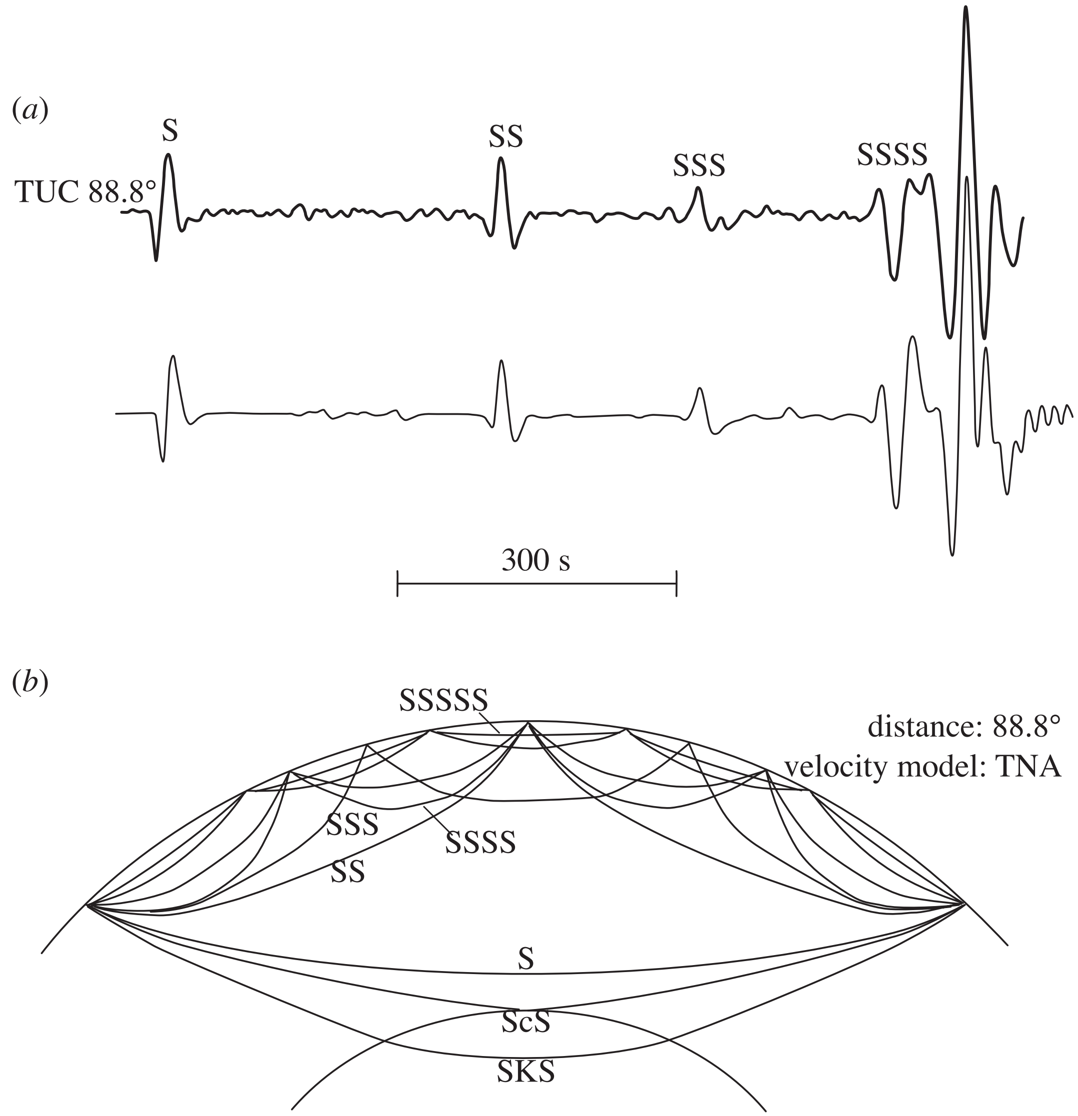
OR

Solve matrix equation

$$\begin{bmatrix} t_1 \\ t_2 \end{bmatrix} = \begin{bmatrix} 3 \\ 5 \end{bmatrix} = \begin{bmatrix} 1 & 0 \\ 1 & 1 \end{bmatrix} \begin{bmatrix} \frac{1}{V_1} \\ \frac{1}{V_2} \end{bmatrix}$$

TRAVELTIMES OF MAJOR PHASES

> modern global tomography incorporates information from many phases including CMB/ surface reflections



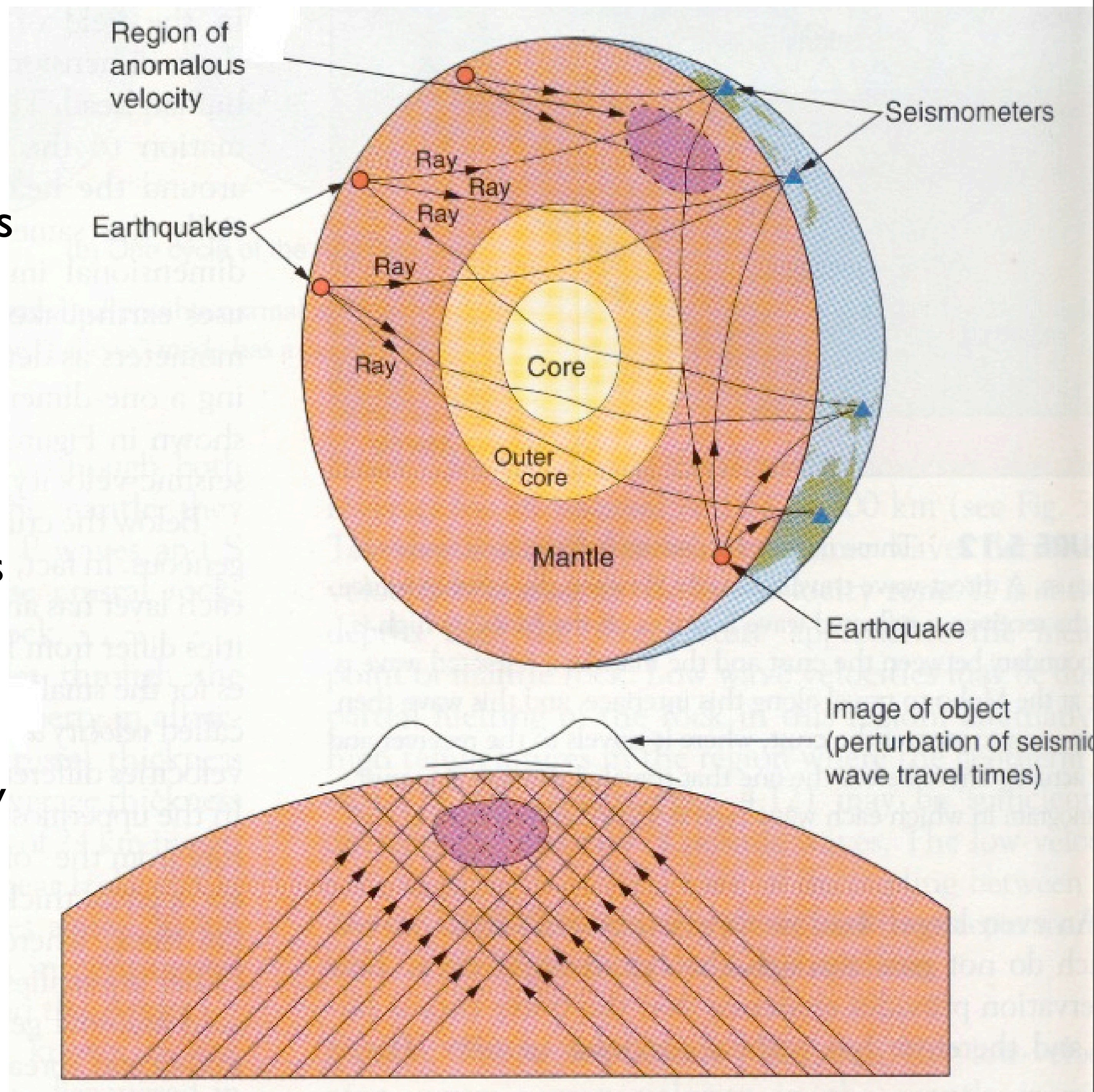
GLOBAL SEISMIC TOMOGRAPHY

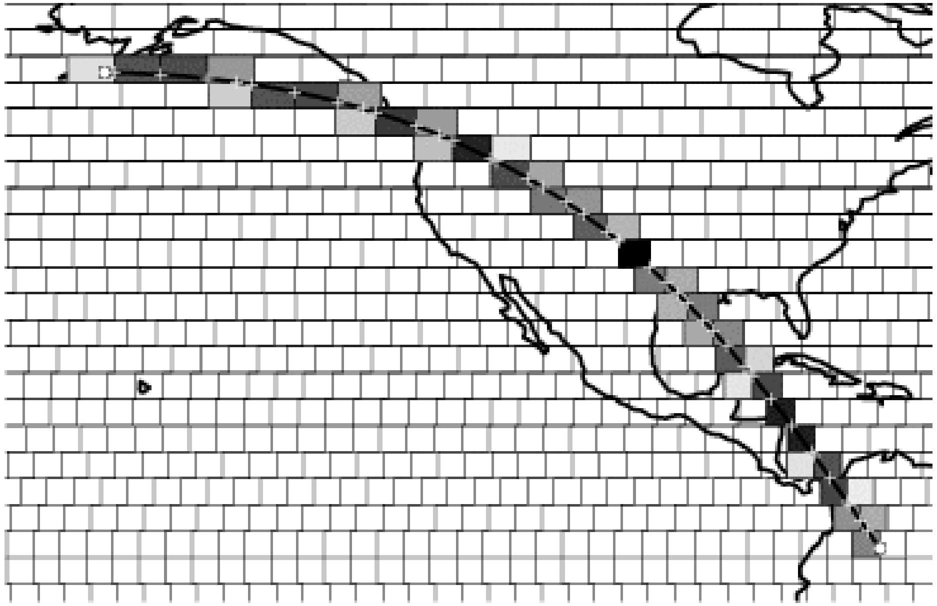
> model Earth as many constant velocity elements

> each measured time represents a ray and an equation

> 1,000,000's of equations in 100,000's of elements

> solve enormous matrix system for Earth's velocity structure





Discretization: model earth as a mesh of small elements each with constant seismic velocity

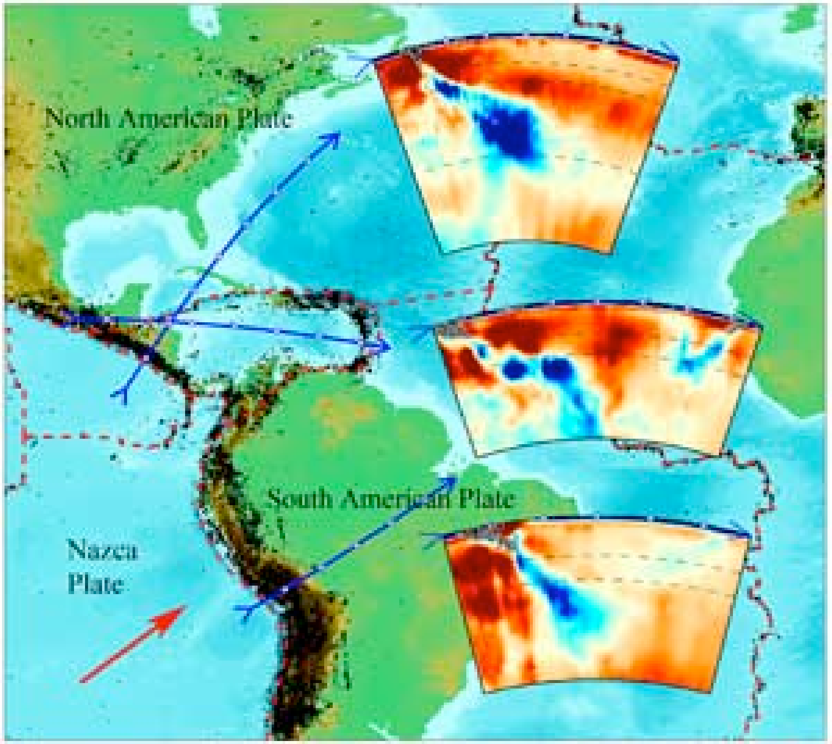
$$\delta t_i = L_{ij}\delta s_j \quad \text{or} \quad \boldsymbol{\delta}\mathbf{t} = \mathbf{L}\cdot\boldsymbol{\delta}\mathbf{s}$$

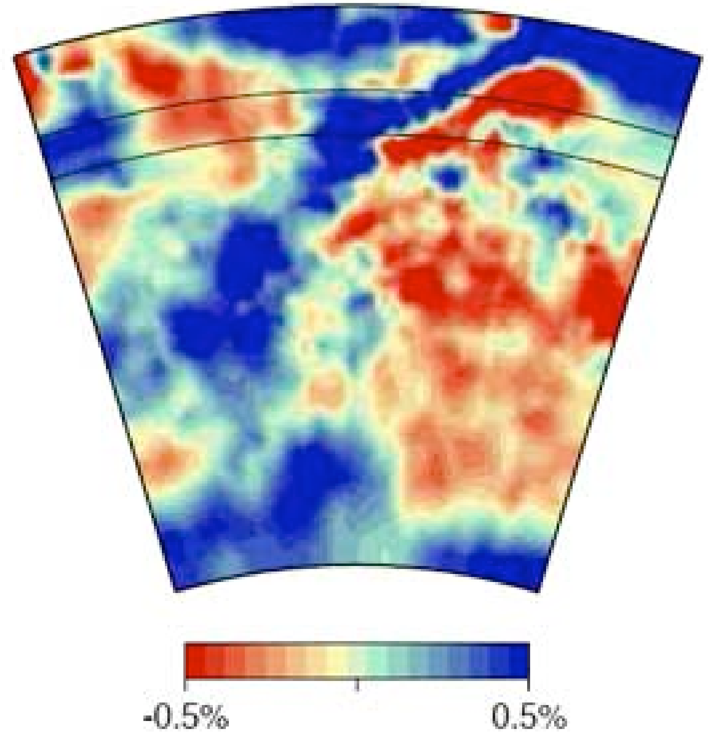
$$\text{M travel-time anomalies} \begin{bmatrix} \vdots \\ \delta t_i \\ \vdots \end{bmatrix} = \begin{bmatrix} & \vdots & \\ \ldots & L_{ij} & \ldots \\ & \vdots & \end{bmatrix} \times \begin{bmatrix} \vdots \\ \delta s_j \\ \vdots \end{bmatrix} \text{N slowness perturbations}$$

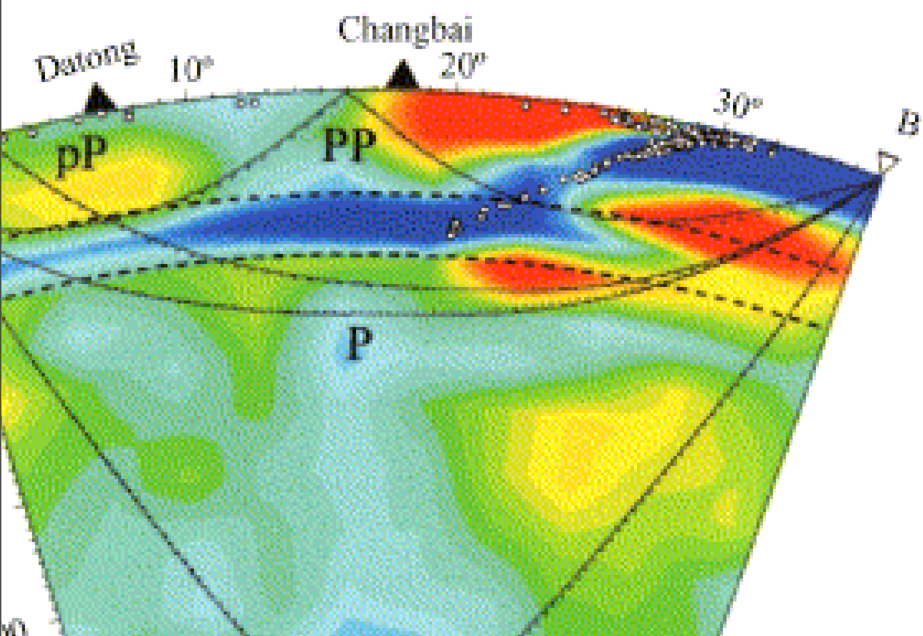
M×N **sensitivity matrix**

WHAT DOES TOMOGRAPHY TELL US ABOUT PLATE BOUNDARIES AND MAJOR FAULTS?

TOMOGRAPHIC IMAGES







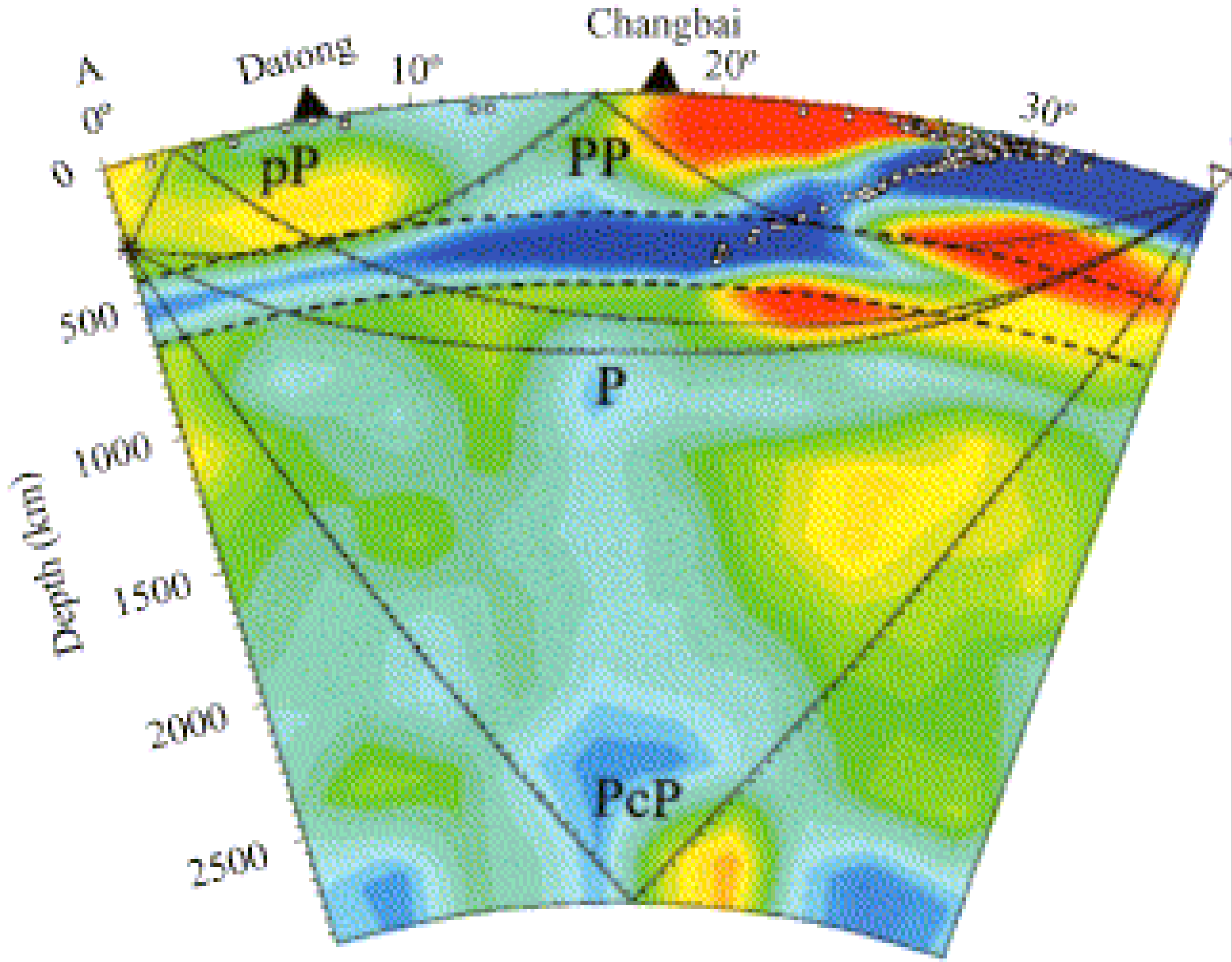
on zones as high-velocity
ough the mantle to the CMB

ocity?

TOMOGRAPHY & WADATI-BENIOFF ZONES

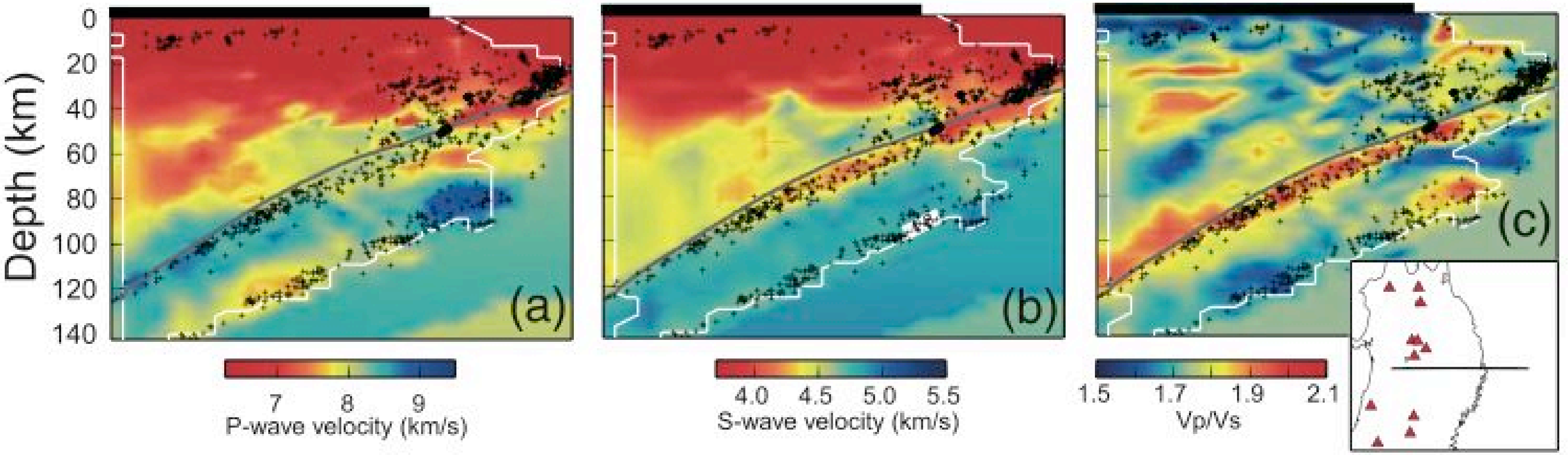
> most subduction zones have W-B zones extending to <700 km depth

> seismicity related to mineral reactions



(a)

DOUBLE BENIOFF ZONES



> example from NE Japan

> 2 lines of seismicity, one near plate boundary, the other 40 km below

> thought to be due to dehydration reactions

CASCADIA SEISMICITY

> Cascadia not as active as some s.z.'s

> still controversy over exact position of downgoing plate

> W-B seismicity restricted to above 100 km