Basic Seismology

Seismic Waves and Their Measurement

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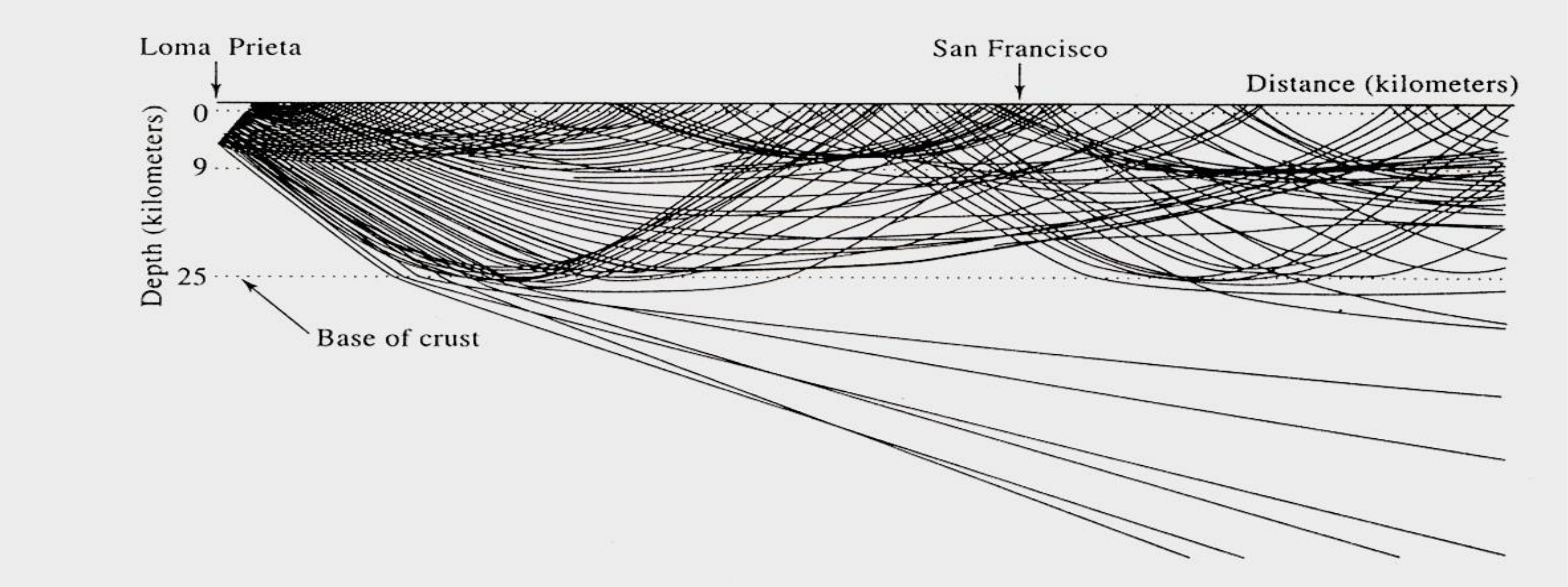
Seismic Waves

- Earthquakes generate many types of seismic waves in complex patterns.
- Some penetrate the earth and come to the surface in the same state, or slightly distorted. Others are reflected, or refracted, or bent by something or some zone of different density within the earth itself. Some travels round the circumference of the world and do not penetrate at all.

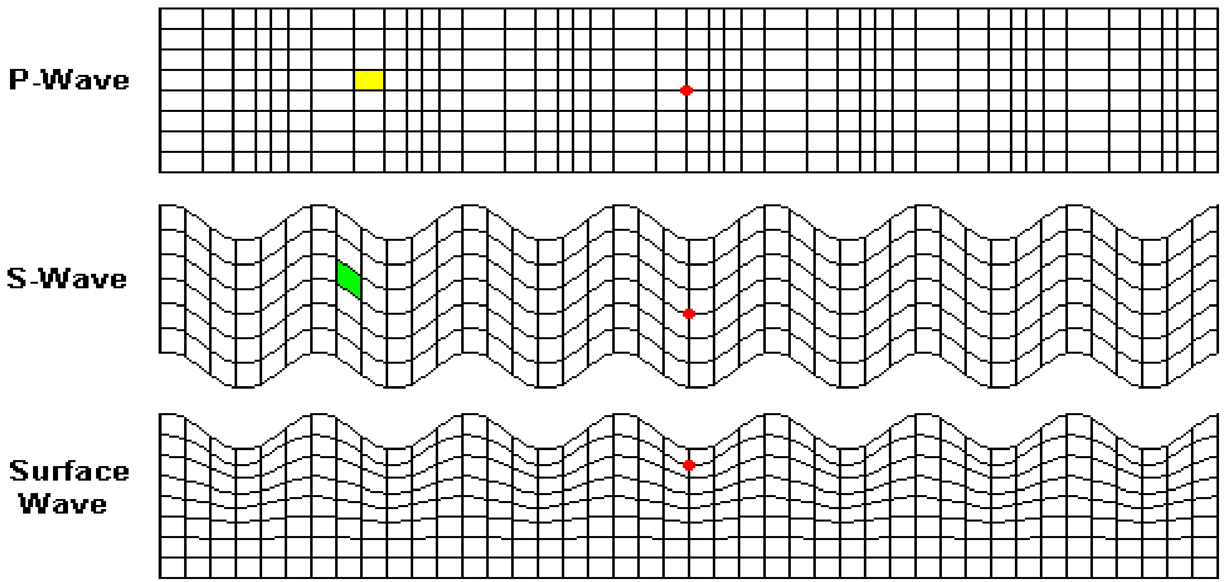


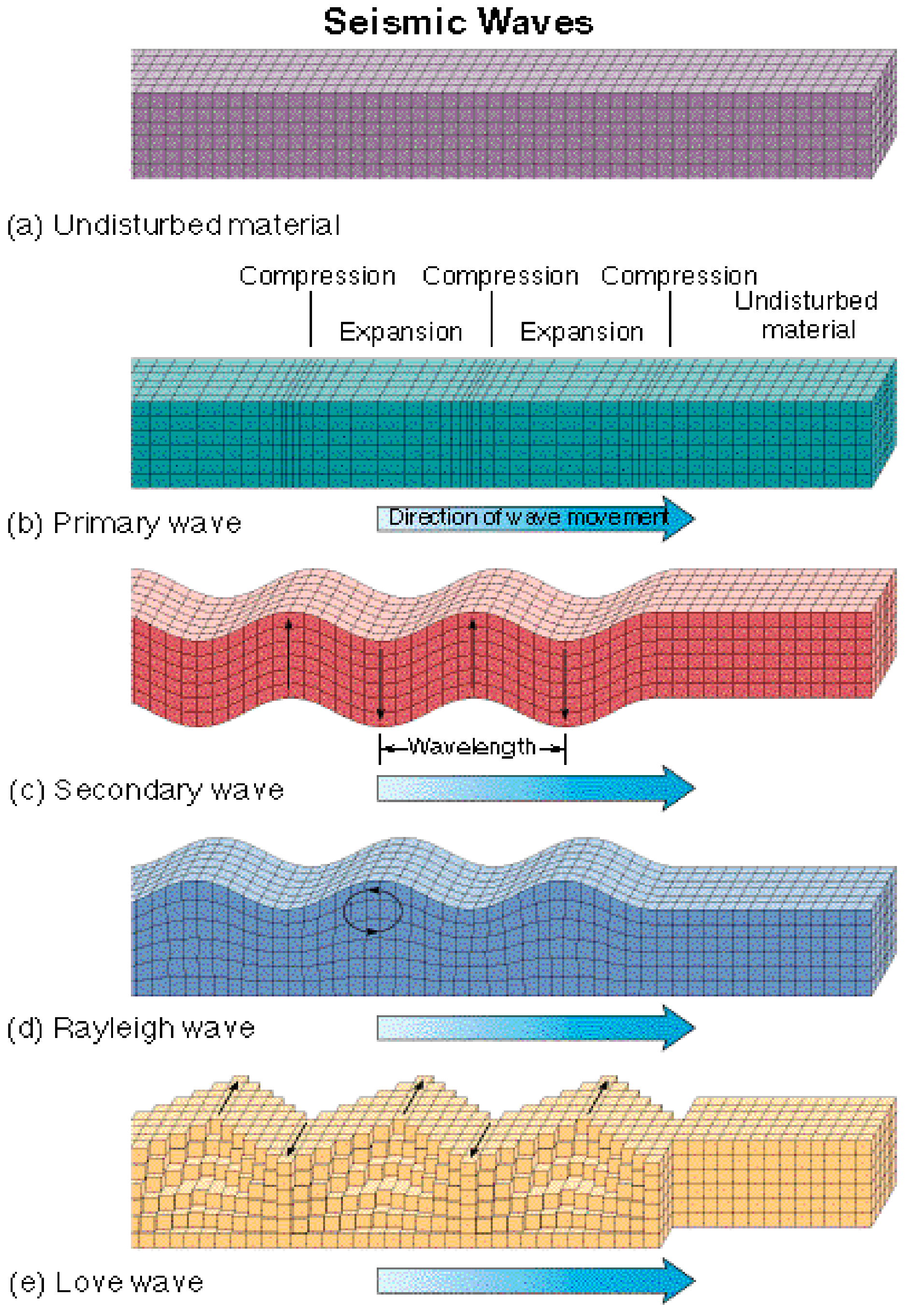
Rays of seismic shear waves from the focus of the 1989 Loma Prieta earthquake through the crust.

Seismic Waves

- There are 3 basic types of seismic waves:
  - **The primary (P) waves**
  - **The secondary (S) waves**
  - **The surface waves**
- **P waves** are compressional waves which exert a pull-push force.
  - The motion of a P wave is the same as that of a sound wave—as it spreads out, it alternately pushes (compresses) and pulls (dilates) the rock.
  - These P waves, just like sound waves, are able to travel through both solid rock and liquid material (such as volcanic magma or the oceans).
- **S waves** are shear waves.
- As it propagates through the body of rock, a shear wave shears the rock sideways at right angles to the direction of travel.
- S waves cannot propagate in the liquid parts of the earth, such as the oceans or magma.

Seismic Waves





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Body Waves

Surface Waves

Body Waves

- When the body waves (the P and S waves) move through the layers of the rock in the crust, they are reflected or refracted at the interfaces between rock types. Also, whenever either one is reflected or refracted, some of the energy of one type is converted to waves of the other type.

- P and S waves do not travel at the same speed, and these speeds vary with the substance through which the waves are passing. Broadly speaking, a P wave travels faster than an S wave.

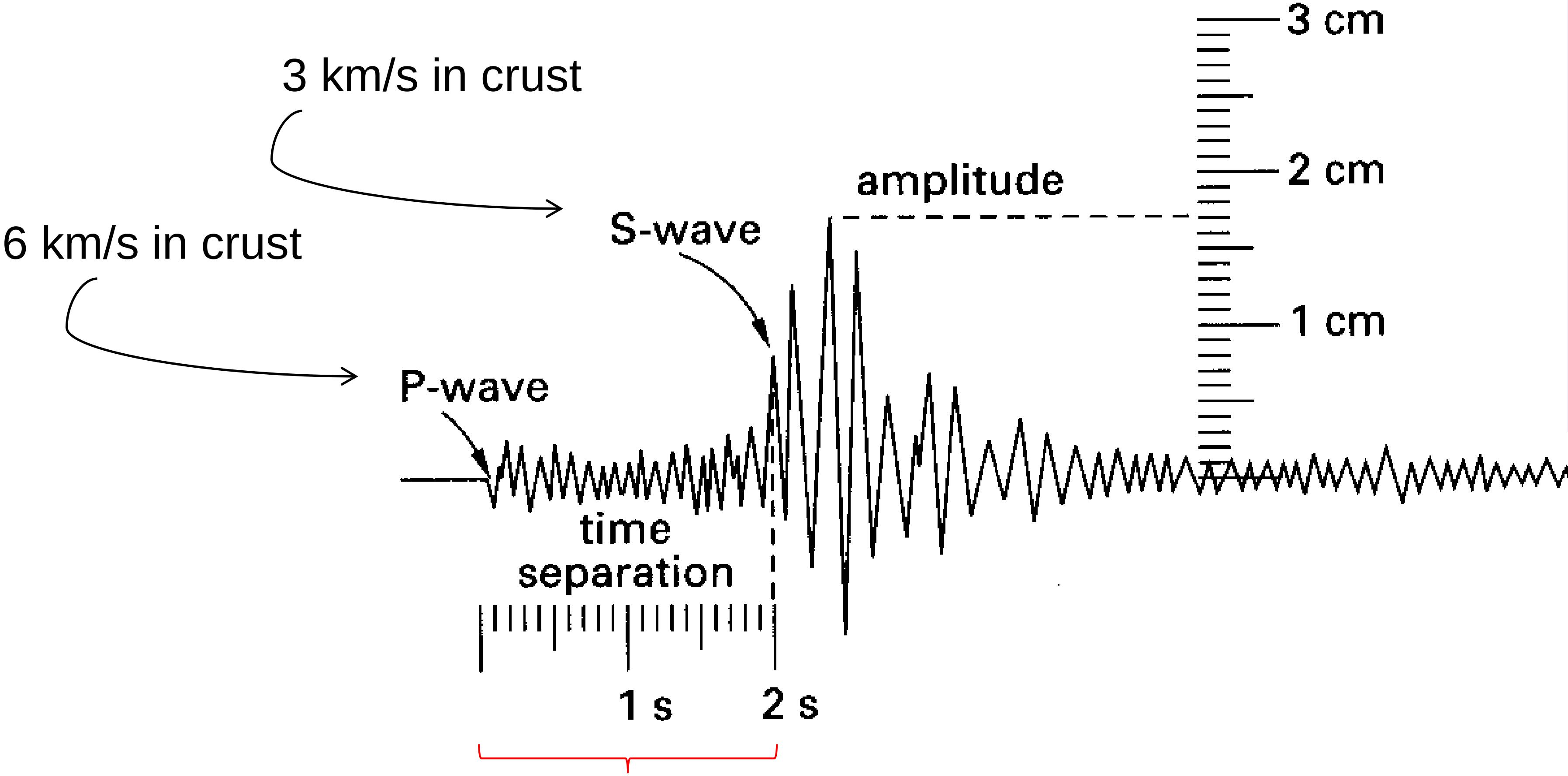
- Thus at any site, the P wave arrives first, and the S wave arrives later.

- The length of time between the arrival of the P and the S wave gives an indication of the distance an earthquake is away from an observer. By using 3 or more seismograph stations, it is possible to pinpoint where the earthquake occurred.

Surface Waves

- Surface waves have their motion restricted to near the ground surface. As the depth below this surface increases, wave displacements decrease.
- Surface waves travel more slowly than body waves.
- Surface waves in earthquakes can be further divided into 2 types:
- **Love wave** and **Rayleigh wave**.
- **The motion of a Love wave is essentially the same as that of S waves that have no vertical displacement.** It moves the ground from side to side in a horizontal plane but at right angles to the direction of propagation. Love waves do not propagate through water.
- Like rolling of ocean waves, the pieces of material disturbed by a **Rayleigh wave move both vertically and horizontally in a vertical plane** pointed in the direction in which the wave is travelling.

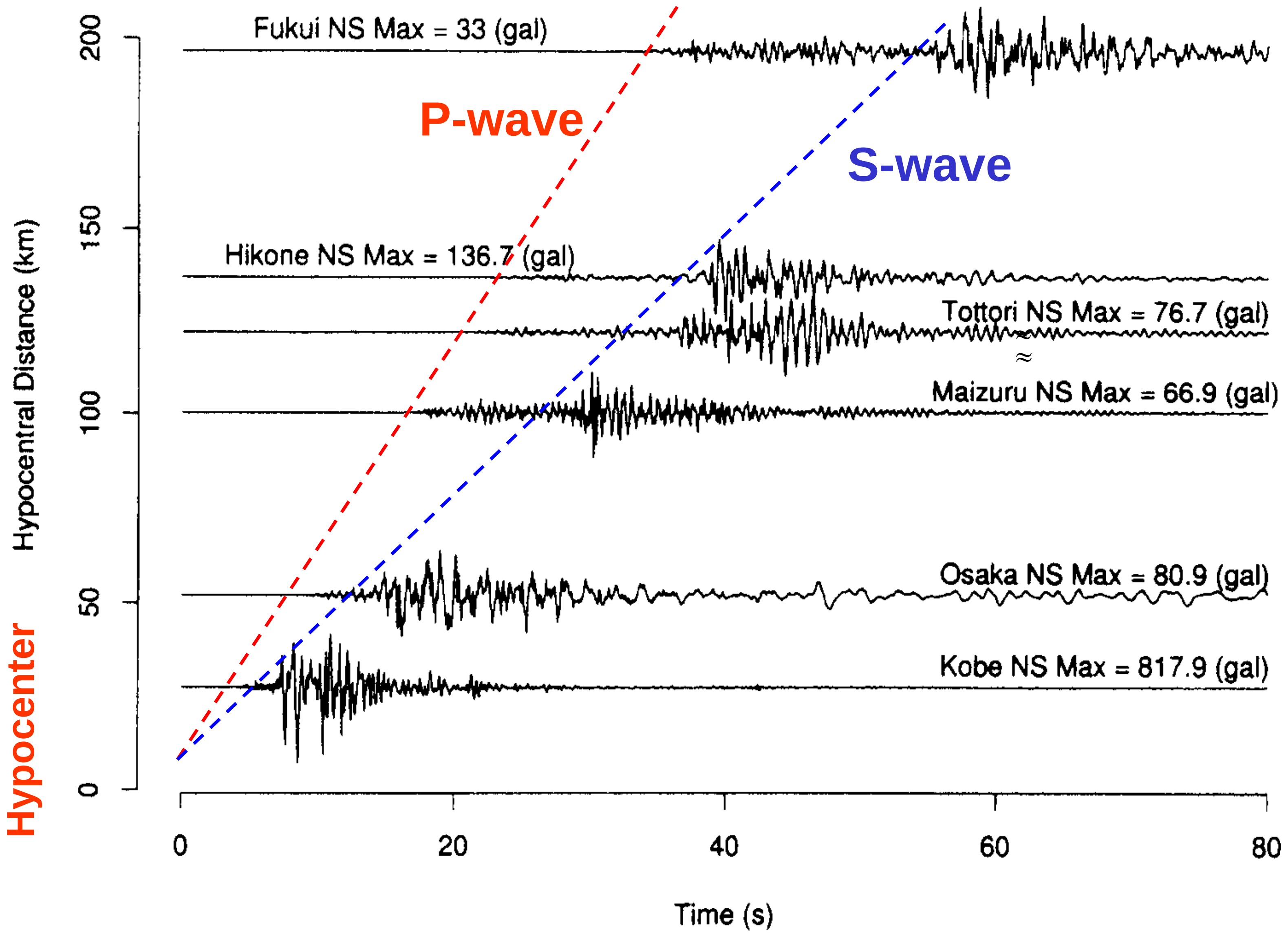
Instrumental Record at a Seismic Station

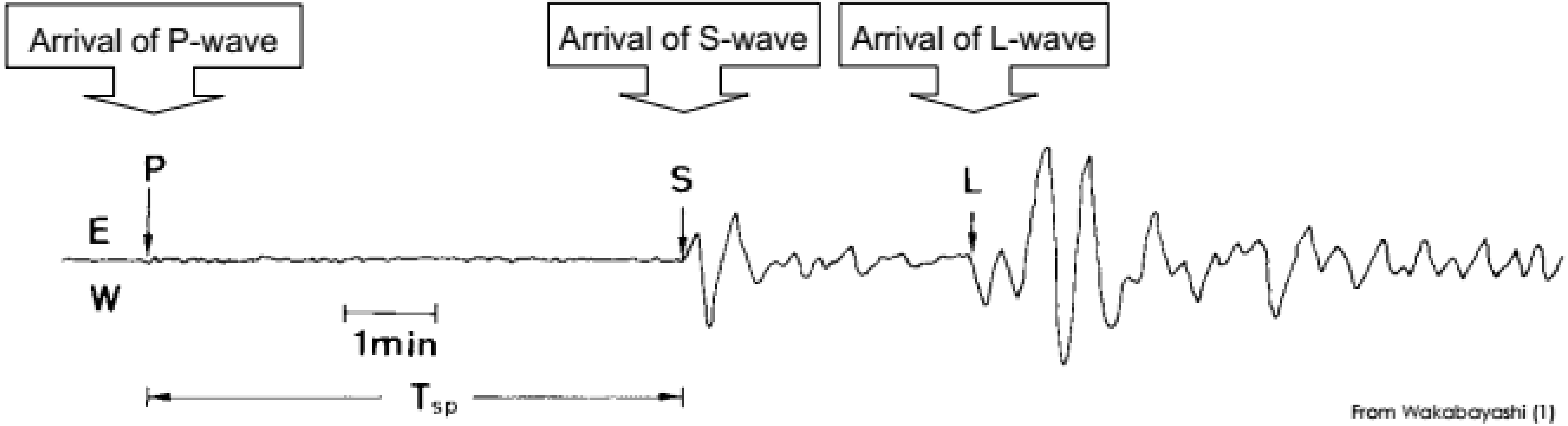


Difference in **arrival times between P and S waves**: measure of site-to-source distance

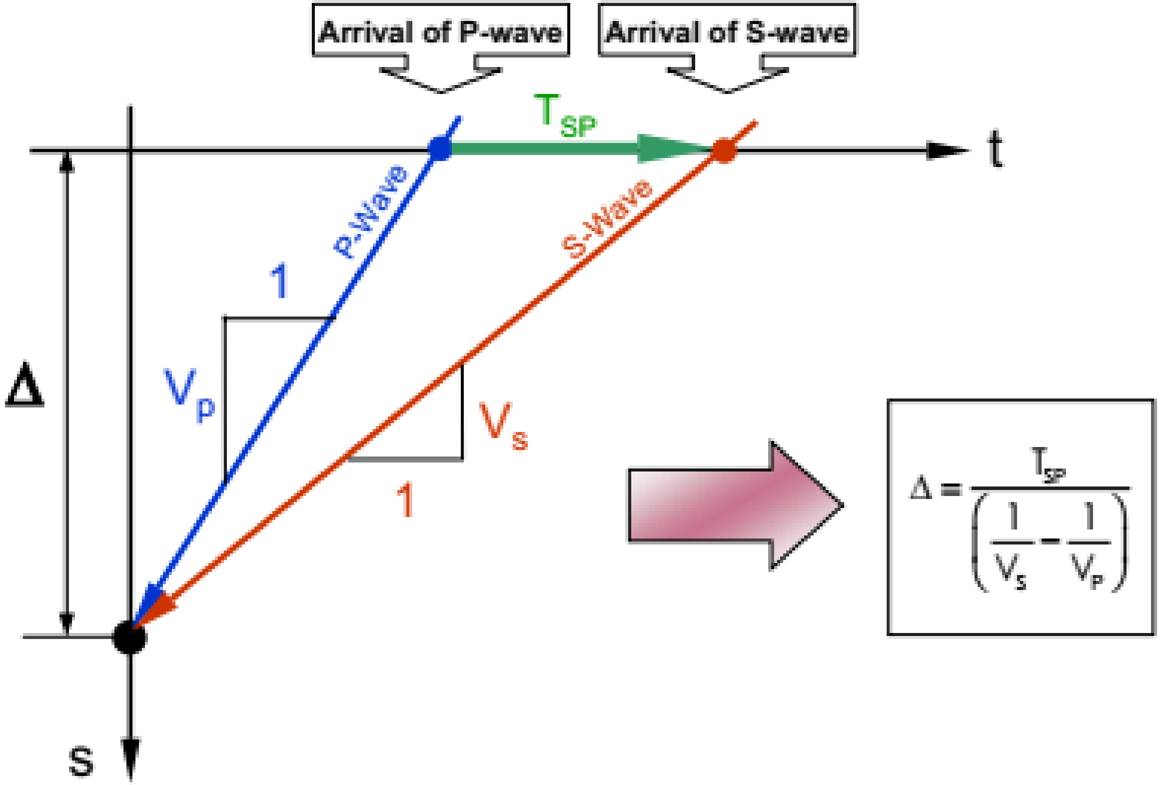
Seismic Wave Records at Several Seismic Stations

The 1995 Kobe Earthquake





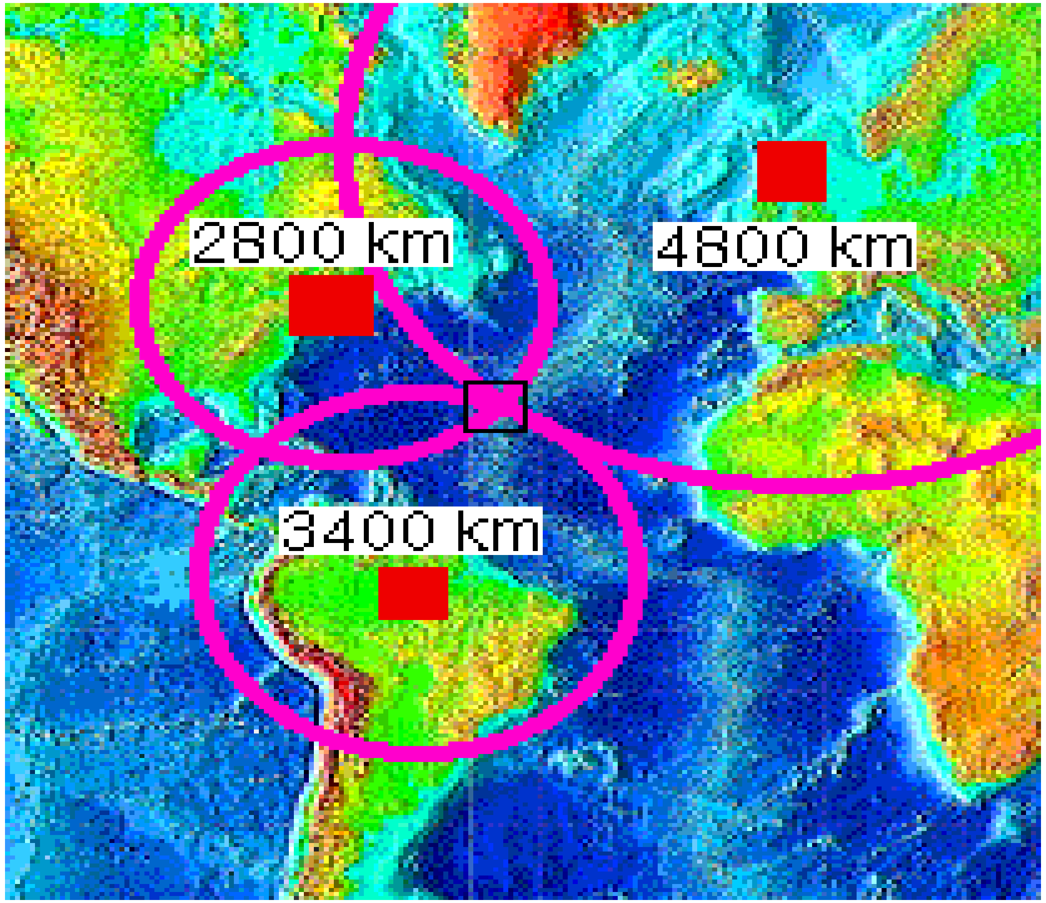
From Wakabayashi (1)



$$\Delta = \frac{T_{SP}}{\left(\frac{1}{V_S} - \frac{1}{V_P}\right)}$$

Locating Earthquakes

Although it is possible to infer a general location for an event from the records of a single station, it is most accurate to **use three or more stations**.



- A **measurement of the P-S time** at single station **gives the distance** between the station and the event.
- **Drawing a circle** on a map around the station's location, with a **radius equal to the distance**, shows all possible locations for the event.
- With the P-S time from **a second station**, the circle around that station will narrow the **possible locations down to two points**.
- It is only with a **third station's P-S time** that should identify which of the two previous possible points is **the real one**.

http://www.seismo.unr.edu/ftp/pub/louie/class/100/seismic-waves.html

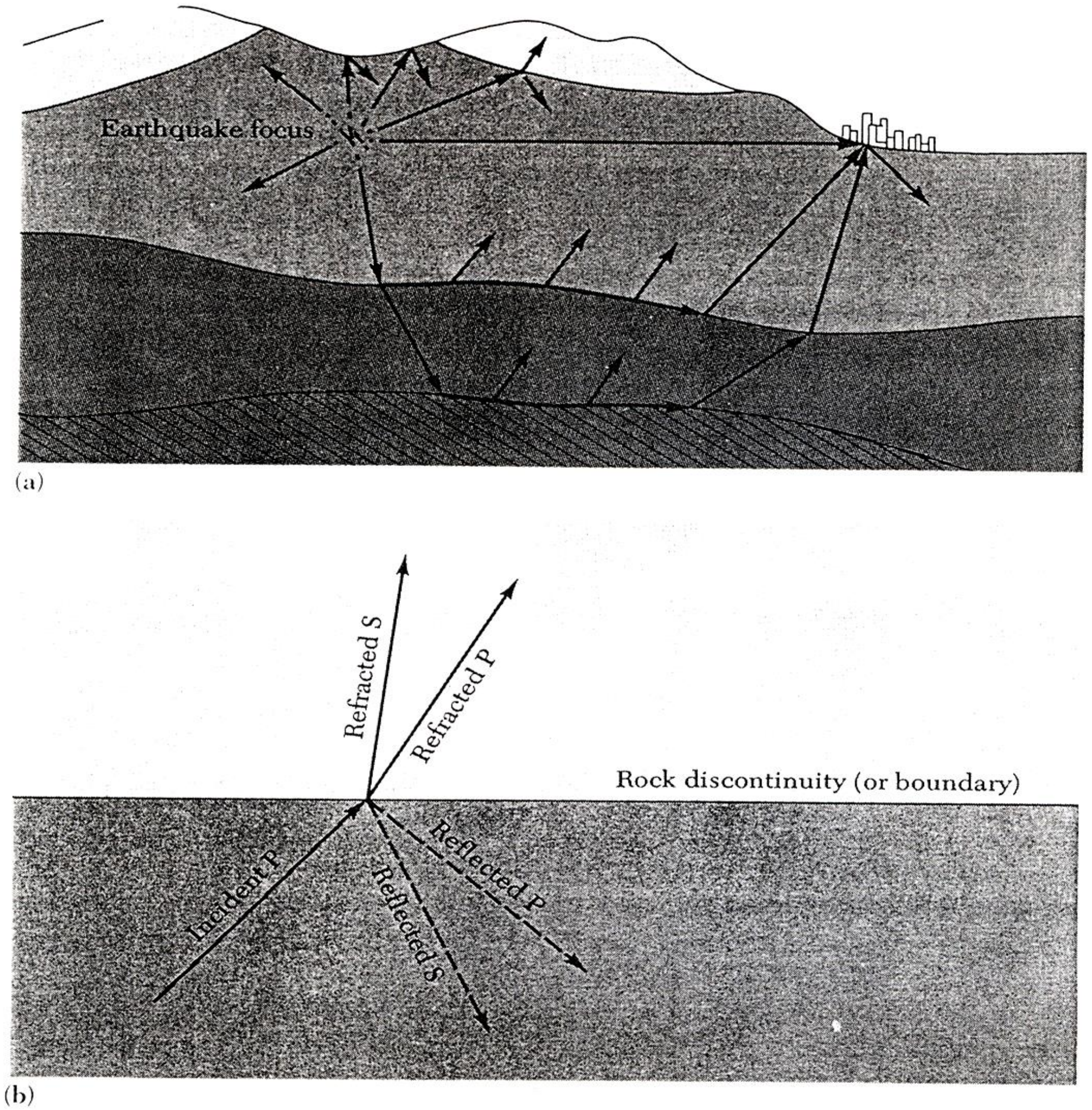
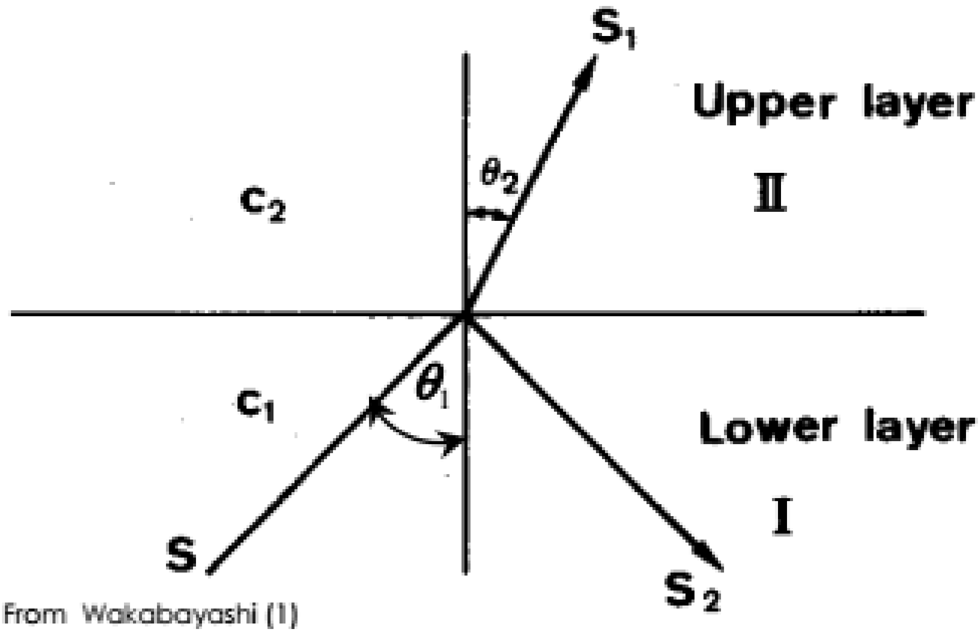


Figure 1.10 (a) A simplified picture of the paths of seismic P or S waves being reflected and refracted in rock structures of the Earth's crust. (b) The reflection and refraction of a longitudinal (P) wave in an earthquake after it hits a boundary between two types of rock. [From Bruce A. Bolt, *Nuclear Explosions and Earthquakes: The Parted Veil* (San Francisco: W. H. Freeman and Company. Copyright 1976).]

Reflection and refraction of waves

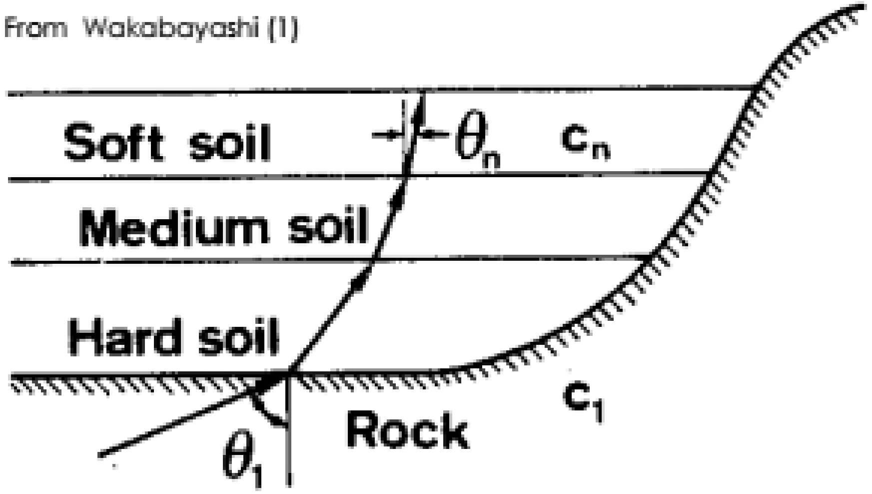


From Wakabayashi (1)

$$\frac{\sin\theta_1}{C_1} = \frac{\sin\theta_2}{C_2}$$

Refraction of waves in the surface of layers

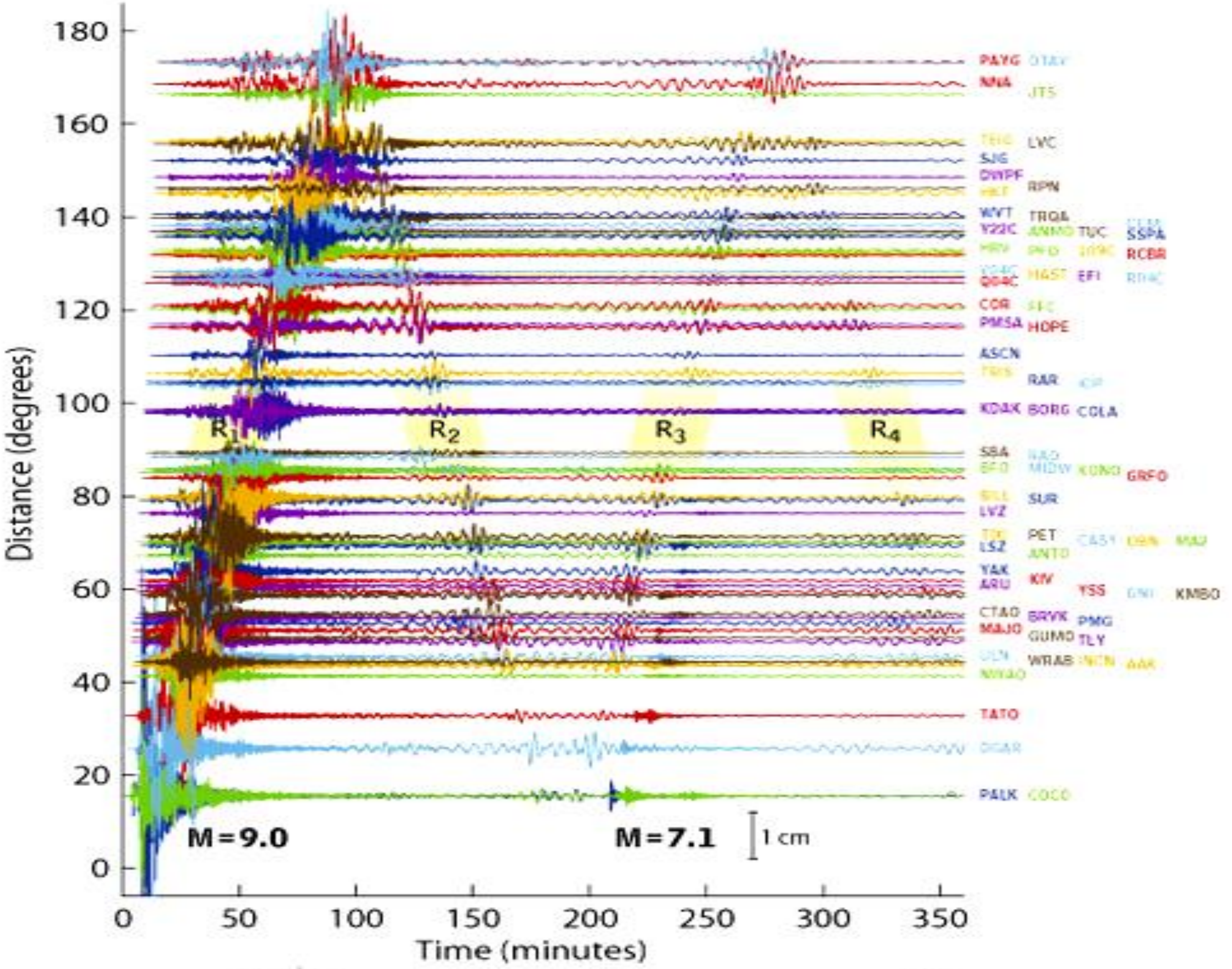
From Wakabayashi (1)



$$\sin\theta_n = \frac{C_n}{C_1} \cdot \sin\theta_1$$

Sumatra - Andaman Islands Earthquake (M_w=9.0)

Global Displacement Wavefield from the Global Seismographic Network



IRIS National Science Foundation USGS UCSD

Seismoscopes

In the year A.D. 136, a Chinese called **Choko** (also called Chang Heng) invented an instrument for indicating earthquakes.

It consisted of a spherically formed copper vessel (about 2.4 m in diameter). In the inner part of this instrument a column was so suspended that it can move in 8 directions.

When an earthquake occurs, the vessel is shaken, the dragon instantly drops the ball, and the frog which receives it vibrates vigorously; anyone watching this instrument can easily observed earthquakes.

Once upon a time a dragon dropped its ball without any earthquake being observed, and people therefore thought the instrument of no use, but after 2 to 3 days a notice came saying that an earthquake had taken place in Rosei. Hearing of this, those who doubted the use of this instrument began to believe in it again.

After this ingenious instrument had been invented by Choko, the Chinese government wisely appointed a secretary to make observations on earthquakes.

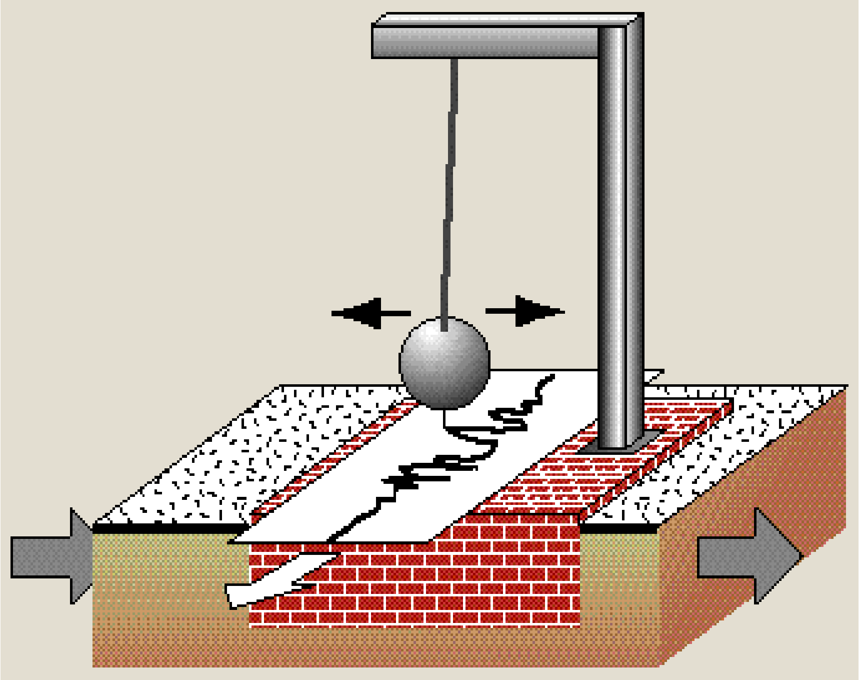
Seismographs

The earliest modern seismographs was invented by **John Milne** around 1880s during when he was Professor of Geology and Mining at the Imperial College of Engineering in Tokyo (University of Tokyo).

The principal problem for constructing precise earthquake measuring devices during that time was **how to produce a body which would remain stationary**, and detached from the world around in order to record the relative movement of the ground on which it actually rested.

They decided to make use of **the mechanical principle of inertia— in essence the tendency of a heavy body to stay put**.

Thus their seismographs relied on using a freely swinging pendulum whose movements were marked by pin or pen on a revolving drum of smoked glass, and later paper.



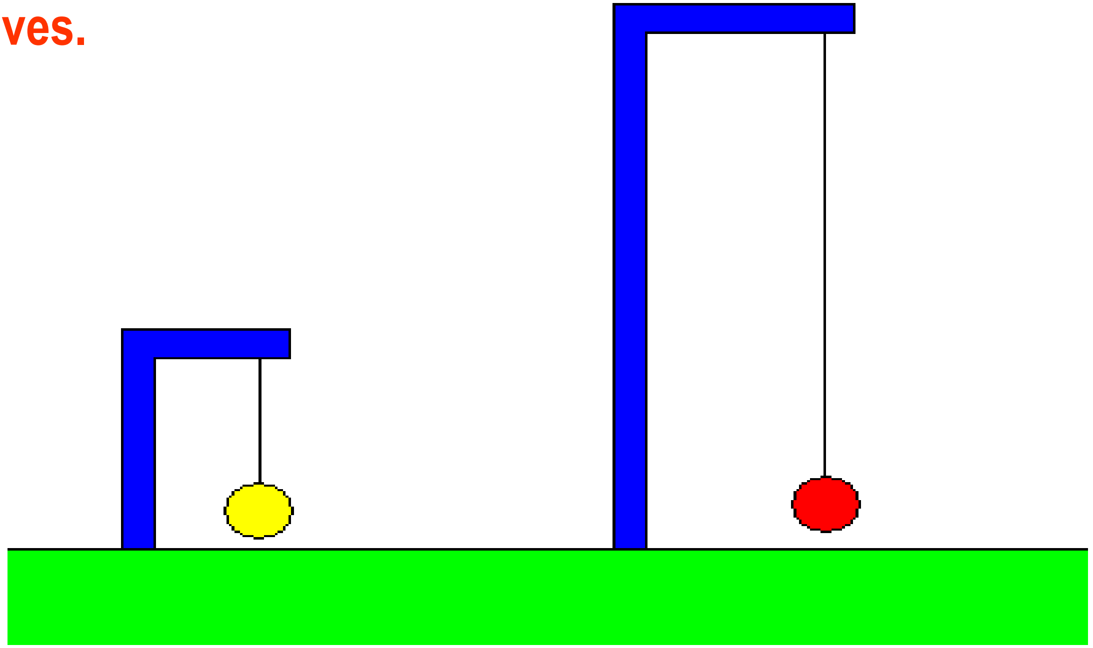
Mechanism of Seismograph

An earthquake does not make the pendulum swing. Instead, **the pendulum remains fixed as the ground moves beneath it.**

A pendulum with a short period (left) moves along with the support and registers no motion. **A pendulum with a long period (right) tends to remain in place while the support moves.**

The boundary between the two types of behavior is the natural period of the pendulum. **Only motions faster than the natural period will be detected; any motion slower will not.**

“Seismograph” usually refers a displacement-type seismometer.

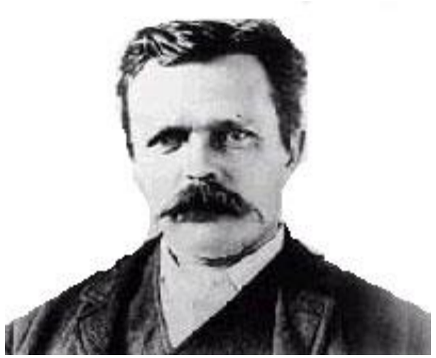


http://www.uwgb.edu/dutchs/202ovhds/quakes.htm

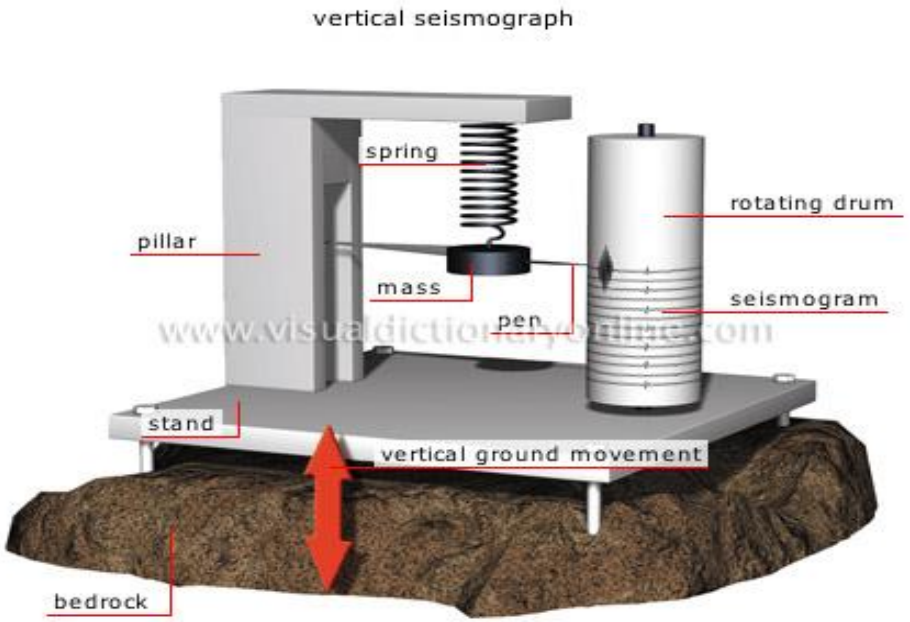
Seismographs

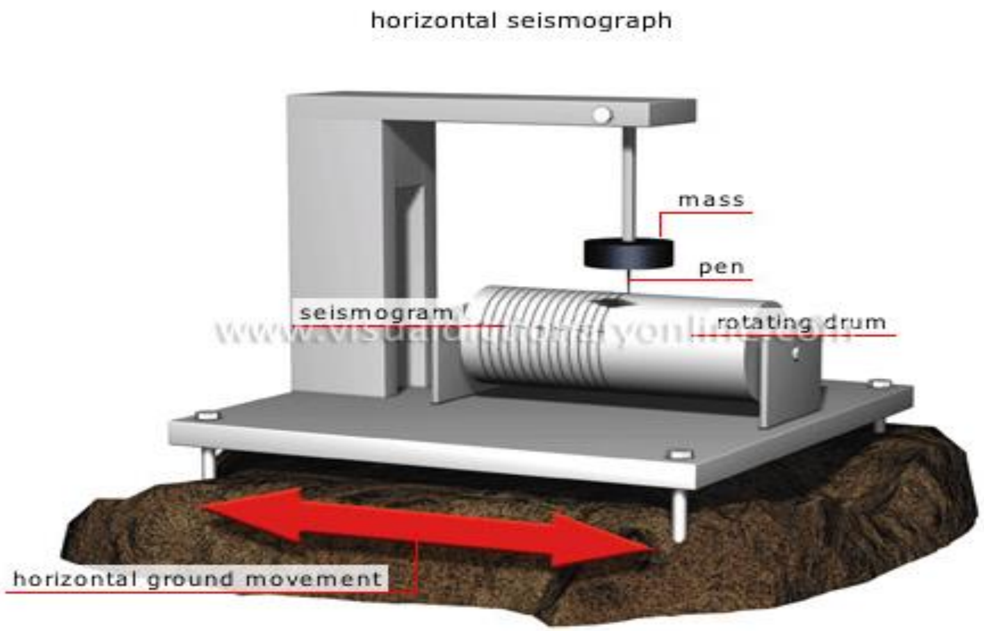
The damping of the pendulum was also added to suppress the free vibration response and to improve the performance of the seismographs.

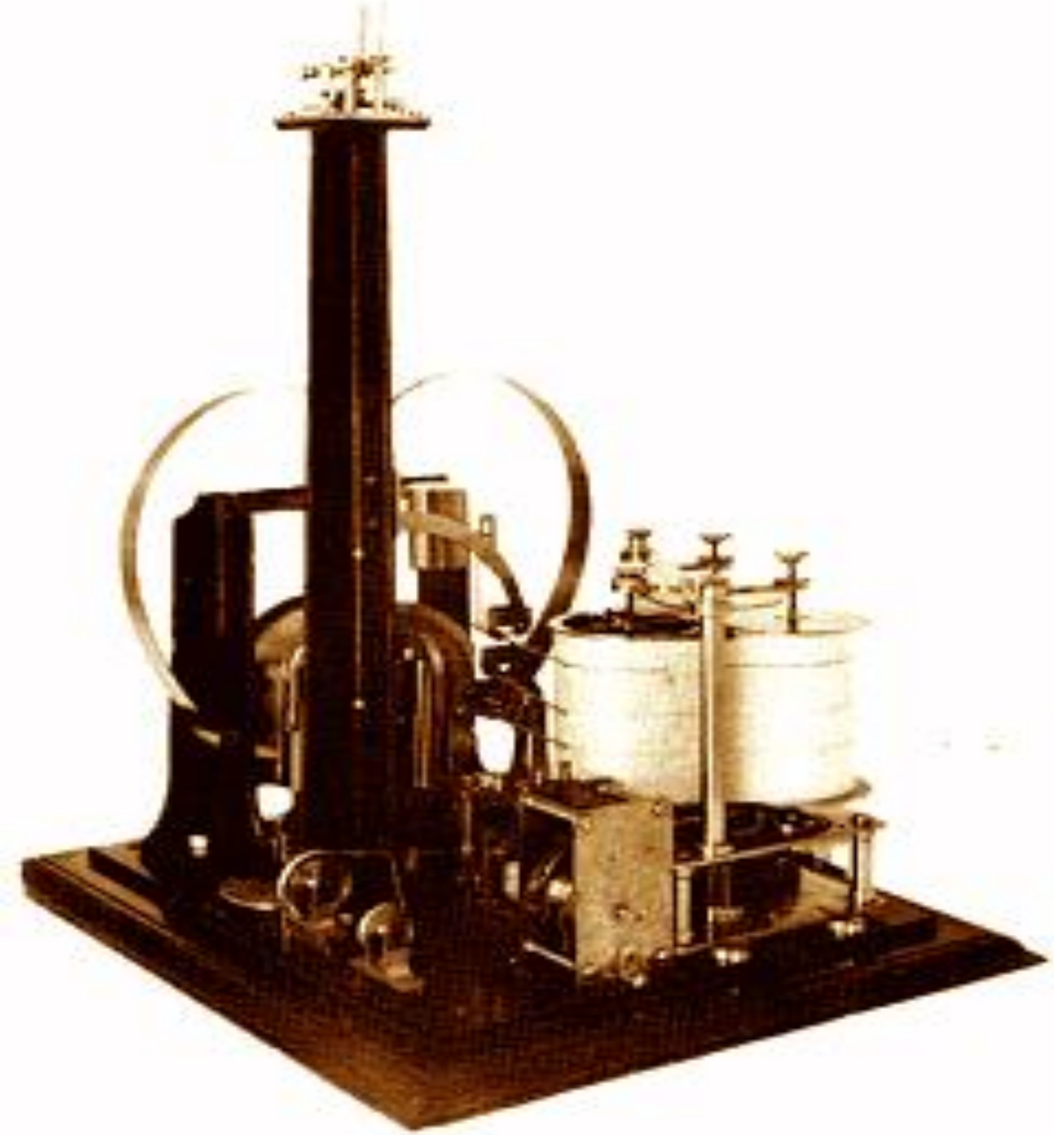
The Milne seismographs employed 3 devices, one for each component of ground motion (up-down, north-south, east-west components).



John Milne







After his arrival in Japan, John Milne was responsible for the invention of a number of seismographs. This is one he produced with his colleague Gray.

Crown Copyright, Science Museum, London

Modern Seismographs

- The general principle behind the early seismographs is still the basic idea behind the designs of present-day seismographs.
- In modern seismographs the relative motion between the pendulum and frame produces an electrical signal that is magnified electronically thousands or even hundreds of thousands of times before it is recorded.
- The electrical signals can be recorded on to magnetic tapes, papers, or converted into equivalent digital signals and stored in computer memory.

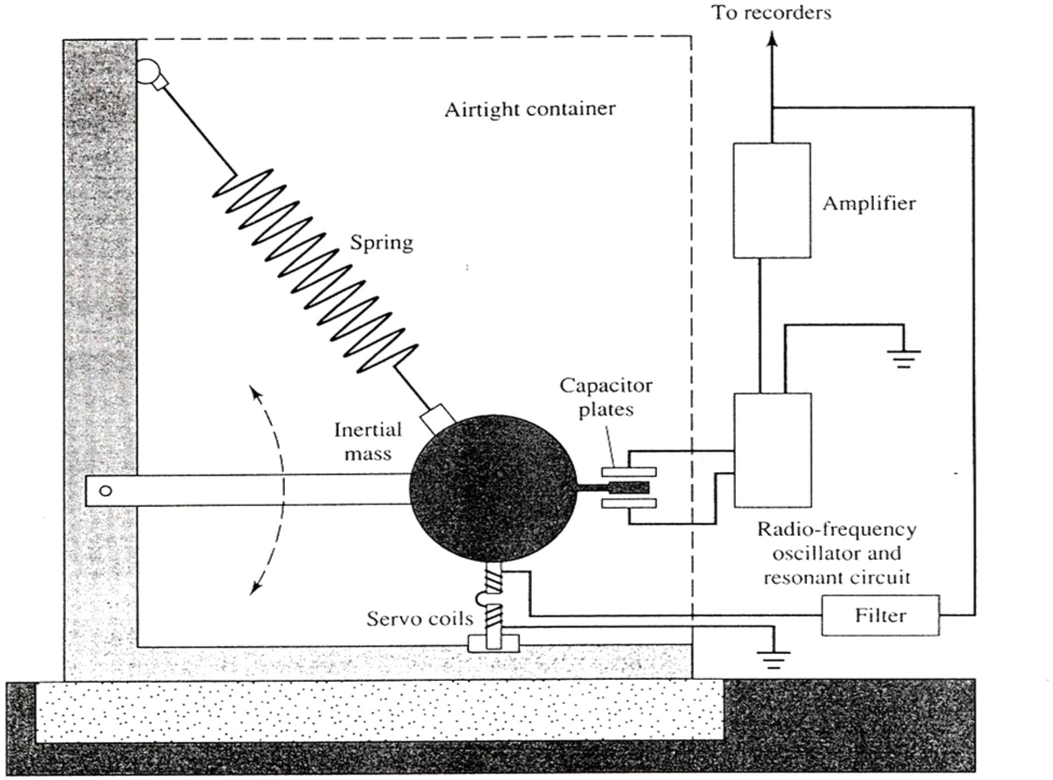


Figure 3.3 Principle of the vertical pendulum seismograph. The mass tends to remain stationary as the Earth moves. Relative motion at the capacitor plates generates an electrical signal that is fed to an analog or digital recorder. The filter feeds back spurious signals, representing undesirable ground motions, to coils that keep the mass centered. (From B. A. Bolt *Inside the Earth*.)

Modern Seismographs

Short-period Seismograph

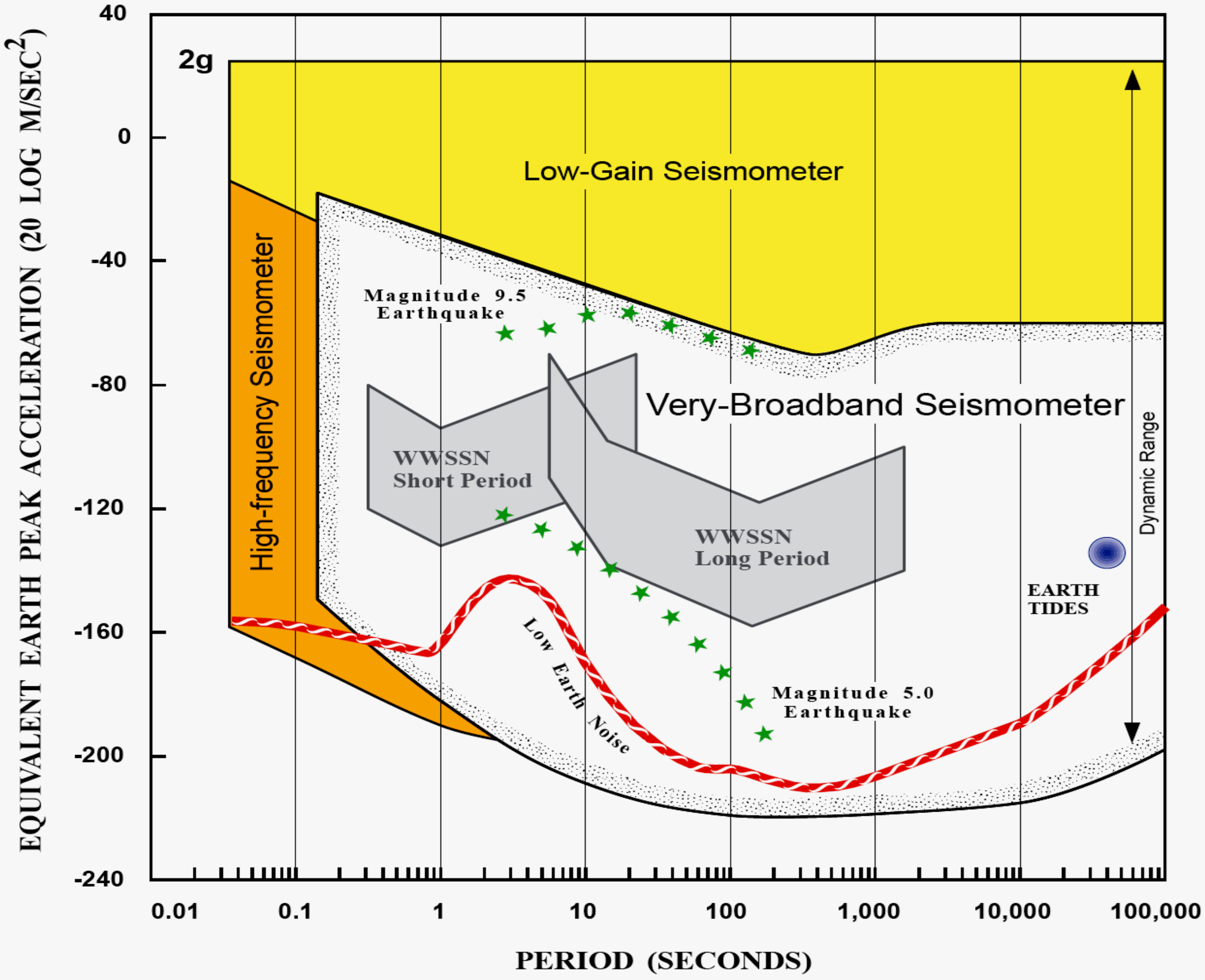
Natural Period = 1 sec

Broadband Seismograph

Natural Period = 120 sec

Most seismographs around the world are designed to detect small-amplitude motions (weak motions) and are very sensitive "ears on the world". They can detect and record earthquakes of small size from very great distances (>1000 km).

IRIS GSN SYSTEM

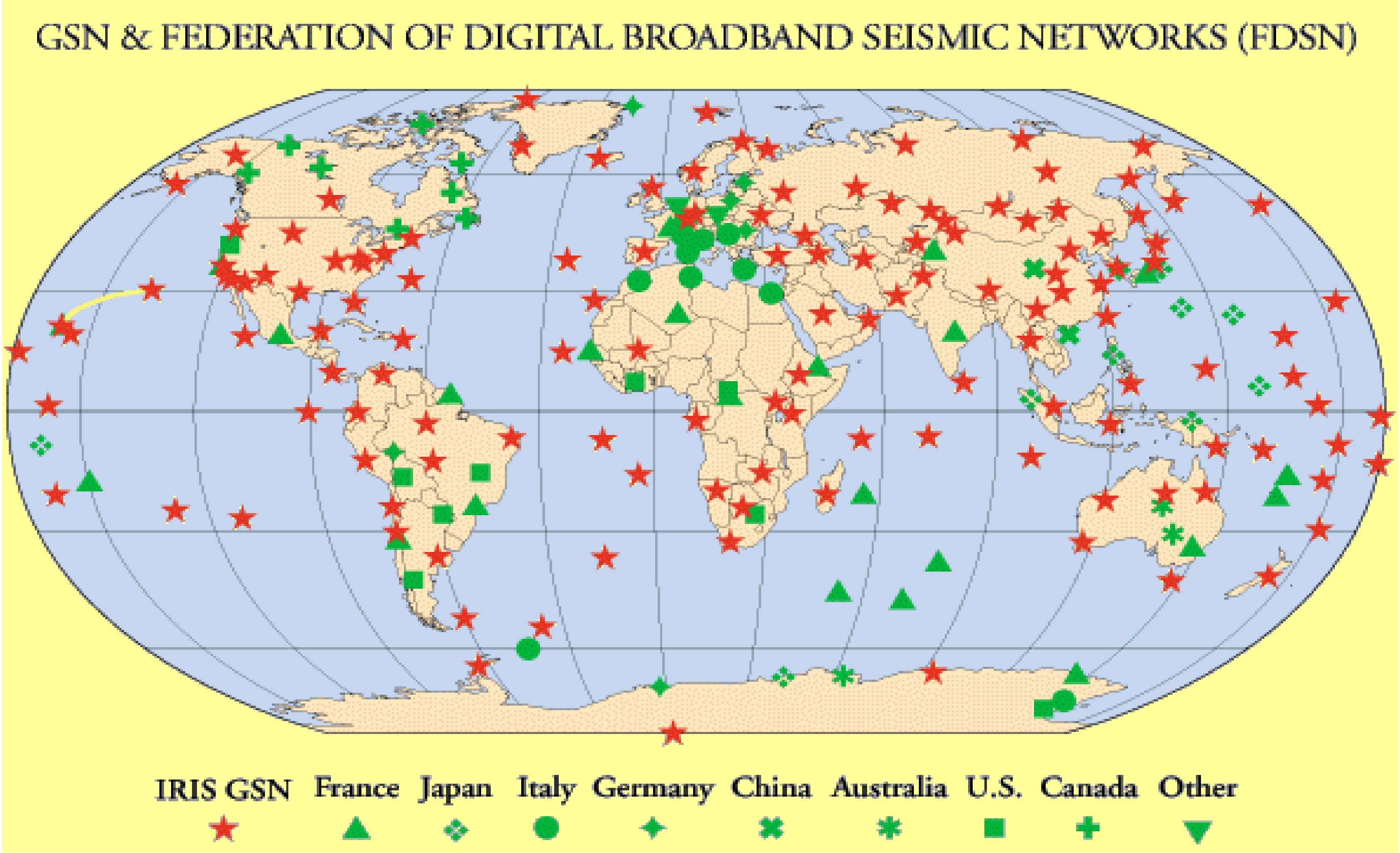


The IRIS Global Seismographic Network (GSN)

The goal of the GSN is to deploy 128 permanent seismic recording stations uniformly over the earth's surface.

IRIS: Incorporated Research Institutions for Seismology

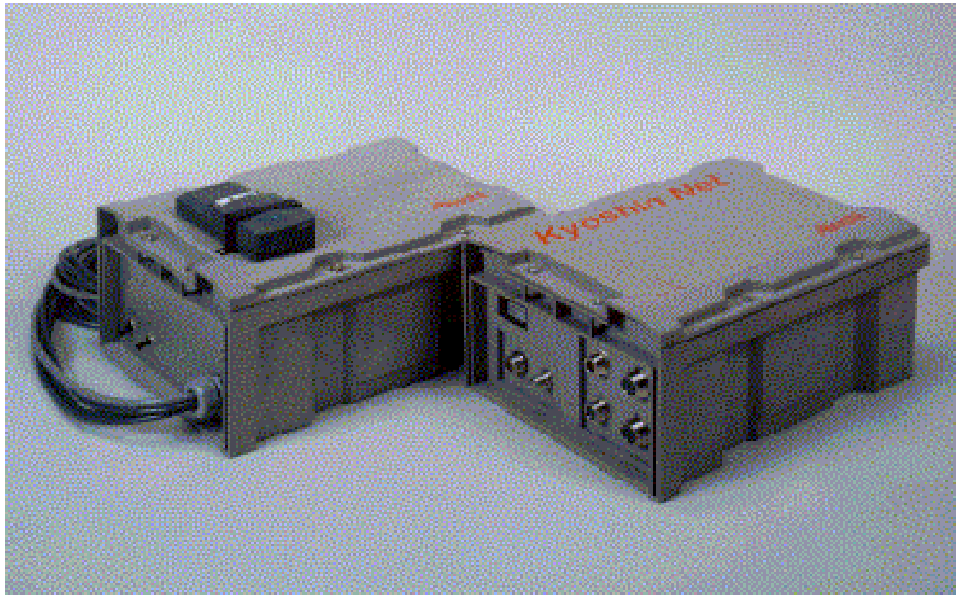
http://www.iris.edu/



Strong-motion Seismographs

Strong-motion seismographs are specially designed to record the strong shaking of the ground in such a way that the records obtained can be directly read as acceleration of the ground.

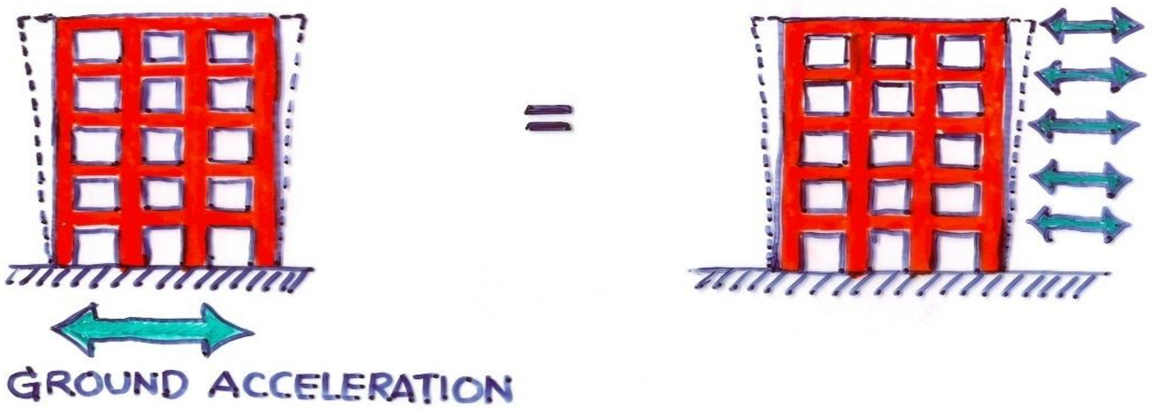
They are usually capable of recording acceleration of the ground greater than that of gravity.

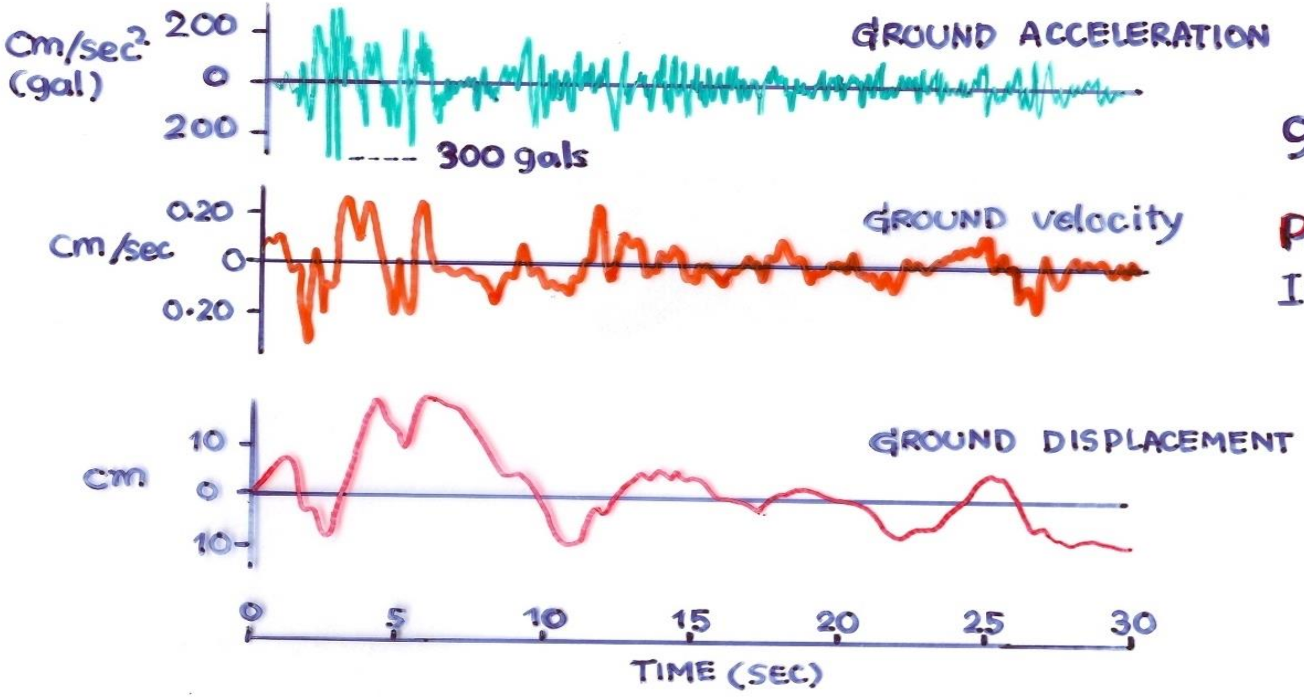


STRONG MOTION SEISMOGRAPH
Type K-NET95

Most strong-motion accelerometers do not record continuously but are triggered into motion by the first waves of the earthquake to arrive.

FORCE = MASS x ACCELERATION



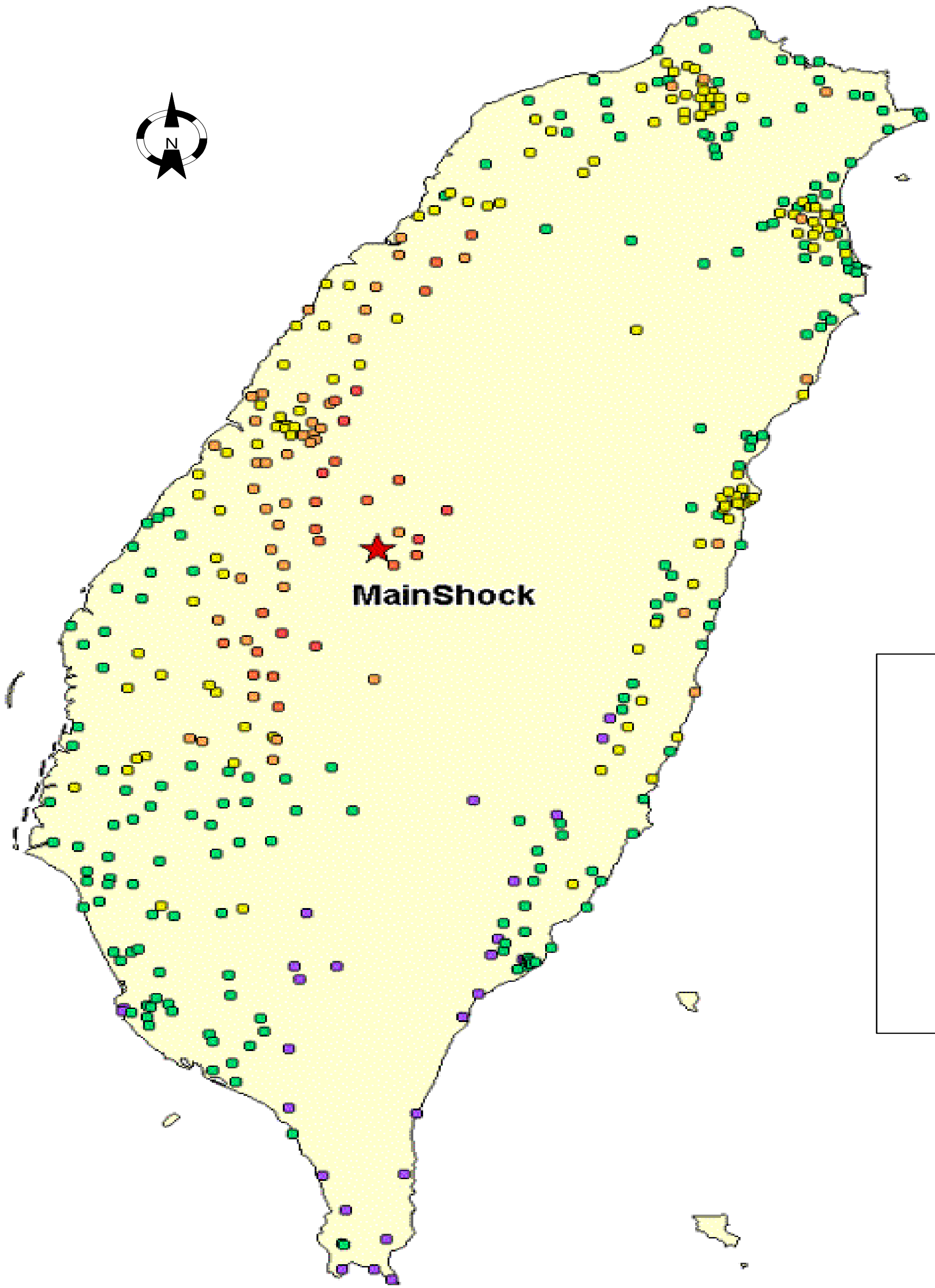


980 gals= 1 G

Peak Ground Acceleration:

Index of Seismic Loading

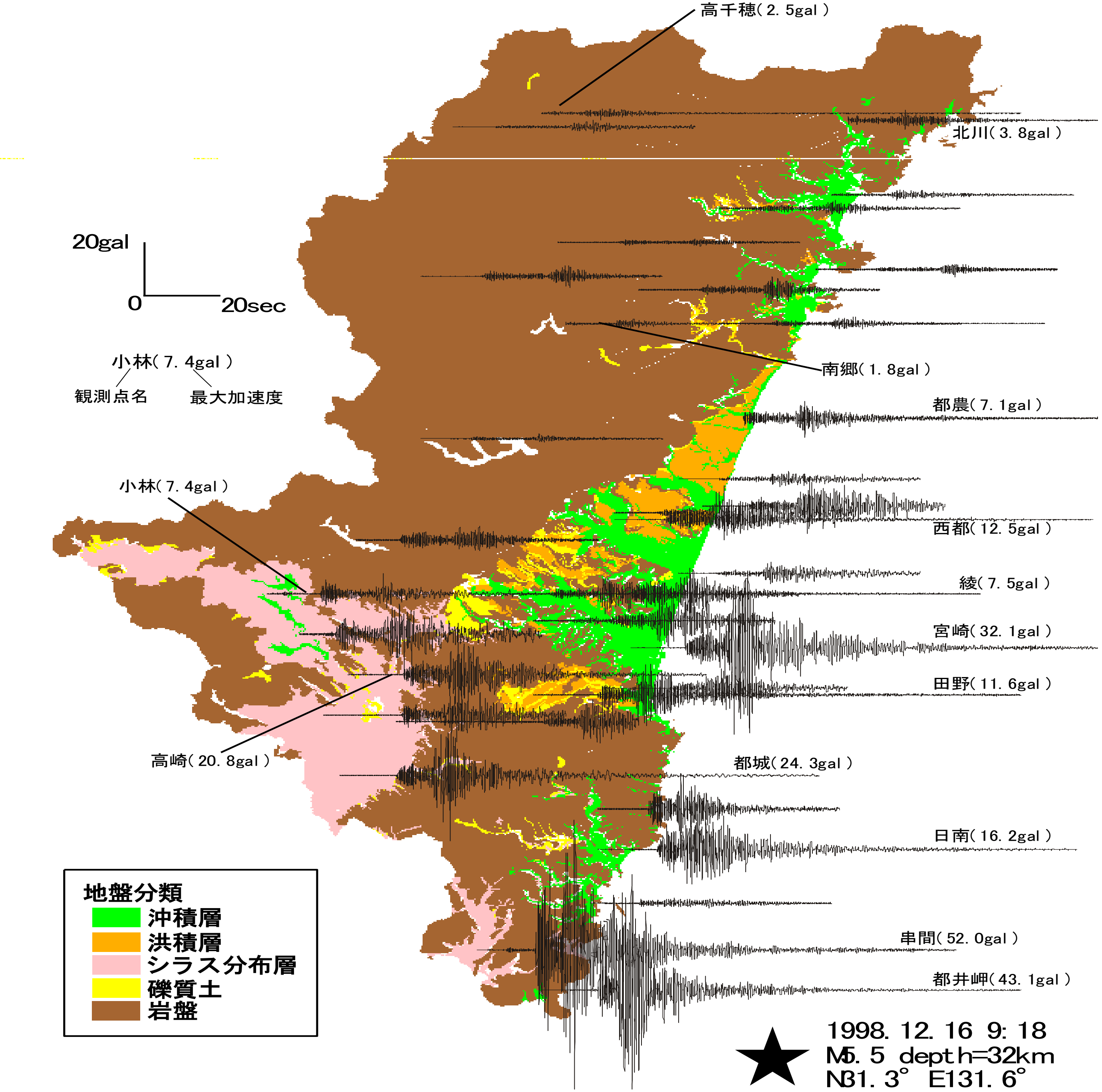
Strong Motion Stations in Taiwan and Distribution of the JMA seismic intensity for the 1999 Chi-Chi EQ



Instrumental Intensity

🔴 6 +
🟠 6 -
● 5 +
🟡 5 -
🟢 4
🟣 3

Note: JMA seismic intensity is calculated from a three-component acceleration record.



Strong-motion Records
In Yokohama, Japan

Magnitude-5 Earthquake
December 16, 1998
Depth 32 km

An Example – September 24, 2019 Mirpur Earthquake (M 5.4)

USGS Event Page:
https://earthquake.usgs.gov/earthquakes/eventpage/us60005mqp/executive

IRIS Event Page:
http://ds.iris.edu/ds/nodes/dmc/tools/event/11121410

Time History Data from Wilber 3 (IRIS):
http://ds.iris.edu/wilber3/find_stations/11121410

Thank you for your attention