Principles of Seismology
Part I

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Introduction

- *Every* day there are about fifty earthquakes worldwide that are strong enough to be felt locally , and every few days an earthquake occurs that is capable of damaging structure.
- *Each* event radiates seismic waves that travel throughout Earth , and several earthquakes per day produce distant ground motions that , although too weak to be felt , are readily detected with modern instruments anywhere on the globe.

Introduction

- *Seismology* is the science that studies these waves and what tell us about the structure of Earth and the physics of earthquakes.
- *Seismology* is the primary means by which scientists learn about Earth's deep interior, where direct observations are impossible.
- **Seismology** occupies an interesting position within the more general fields of geophysics and Earth sciences.

Brief History of Seismology

- – *Seismology* is a comparatively young science that has only been studied quantitatively for about 100 years.
- ***Historical perspective***:
- ***1678 – Hooke*** , Hooke’s Law $\sigma = E\epsilon$
- ***1760 – Mitchell*** , Recognition that ground motion due to earthquakes is related to wave propagation.

Brief History of Seismology

- 1821 – ***Navier*** , Equation of motion
- 1828 – ***Poisson,*** Wave equation
  →P & S – waves
- 1885 – ***Rayleigh*** , Theoretical account surface waves
  → Rayleigh & Love waves
- 1892 – ***Milne*** , First high – quality seismograph →being of observational period

Brief History of Seismology

- 1897 – ***Wiechert*** , Prediction of existence of dense core (based on meteorites → Fe-alloy
- 1900 – ***Oldham***, Correct identification of *P* , *S* and surface waves
- 1906 – ***Oldham***, Demonstration of existence of core from seismic data
- 1906 – ***Galitzin*** , First feed-back broadband seismograph
- 1909 – ***Mohorovičić*** , Crust –mantle boundary

Brief History of Seismology

- 1911 – ***Love***, Love waves (surface waves)
- 1912 – ***Gutenberg***, Depth to core – mantle boundary : 2900 km
- 1922 – ***Turner***, Location of deep earthquakes down to 600km
- 1928 – ***Wadati***, Accurate location of deep earthquakes

→ Wadati – Benioff zones

Brief History of Seismology

- 1936 – *Lehman,* Discovery of inner core
- 1939 – ***Jeffreys & Bullen***, First travel-time tables

  → 1D Earth model
- 1948 – ***Bullen,*** Density profile
- 1977 – ***Dziewonski & Toksöz*** , First 3-D global model

Observations:

- 1964 *ISC* (International Seismological Centre)- travel times and earthquake locations
- 1960 ***WWSSN*** (Worldwide Standardized Seismograph Network) – (analog records)

Brief History of Seismology

- 1978 *GDSN* (Global Digital Seismograph Network) – (digital records)
- 1980 *IRIS* (Incorporated Research Institutes for Seismology)

Stress and Strain

- The seismic waves basically result from the balance between stress and strain.

Stress

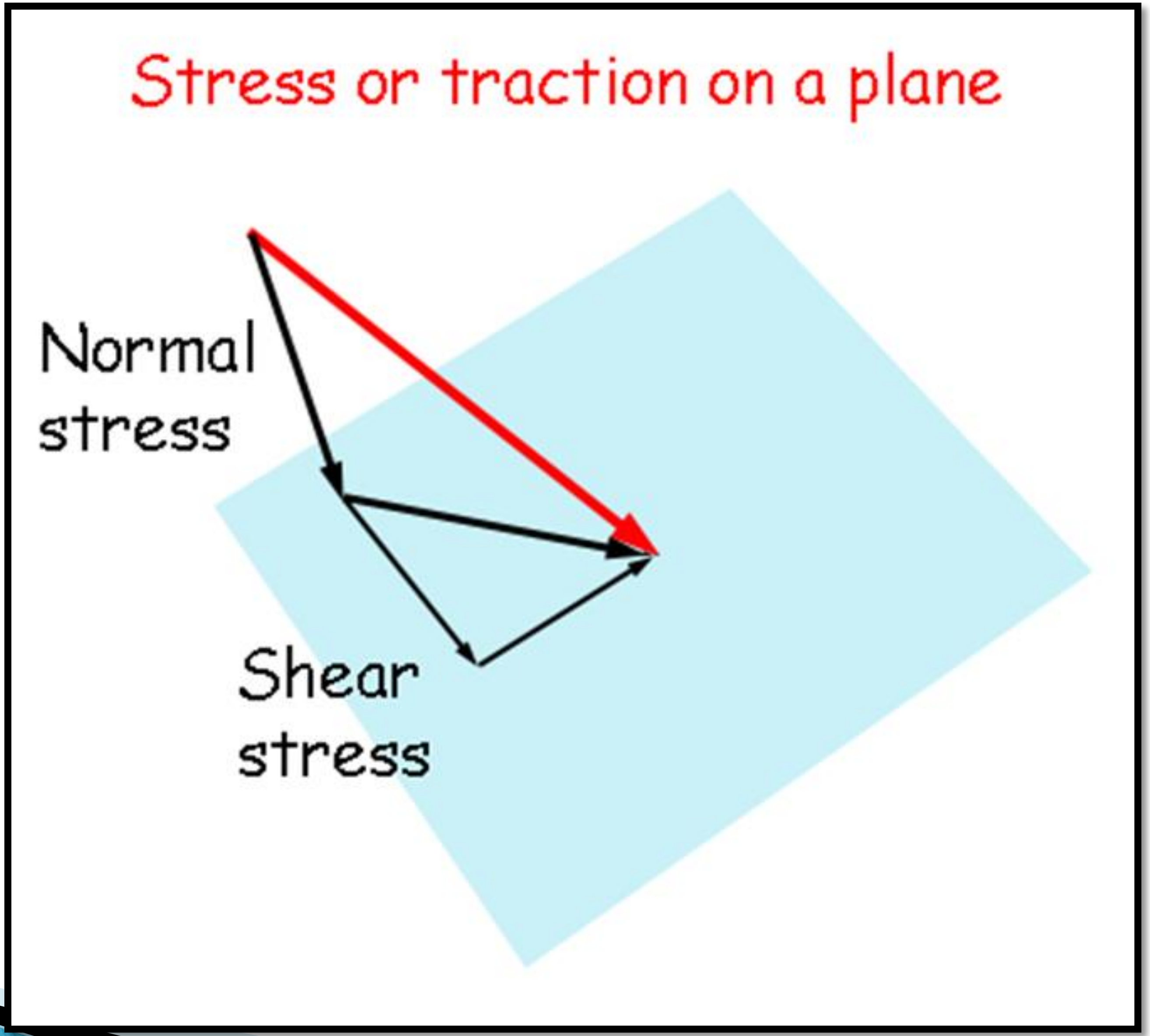
-***Stress*** is force per unit area , and the principle unit is Newton per square meter (Nm^{-2}) or *Pascal* ($1Nm^{-2} = 1$ Pa).

- There are two types of Stress (Fig. 1):

1. ***Normal stress*** (**σ_n**) : It is the force F per unit area that is perpendicular to the plane or the surface

element (δS) .

Figure 1



Stress and Strain

2. Shear stress(τ) : It is the force per unit area that is parallel to plane or the surface element *δS*.

- For stress we define the ***traction*** as a vector that represents the total force per unit area on *δS*.
- Units of stress : Nm-2 or Pa.

Stress and Strain

Strain

- Strain is defined as extension per unit length.
- Strain = extension / original length
- Strain has no units because it is a ratio of lengths.
- Figure 2 shows the types of shear strain.

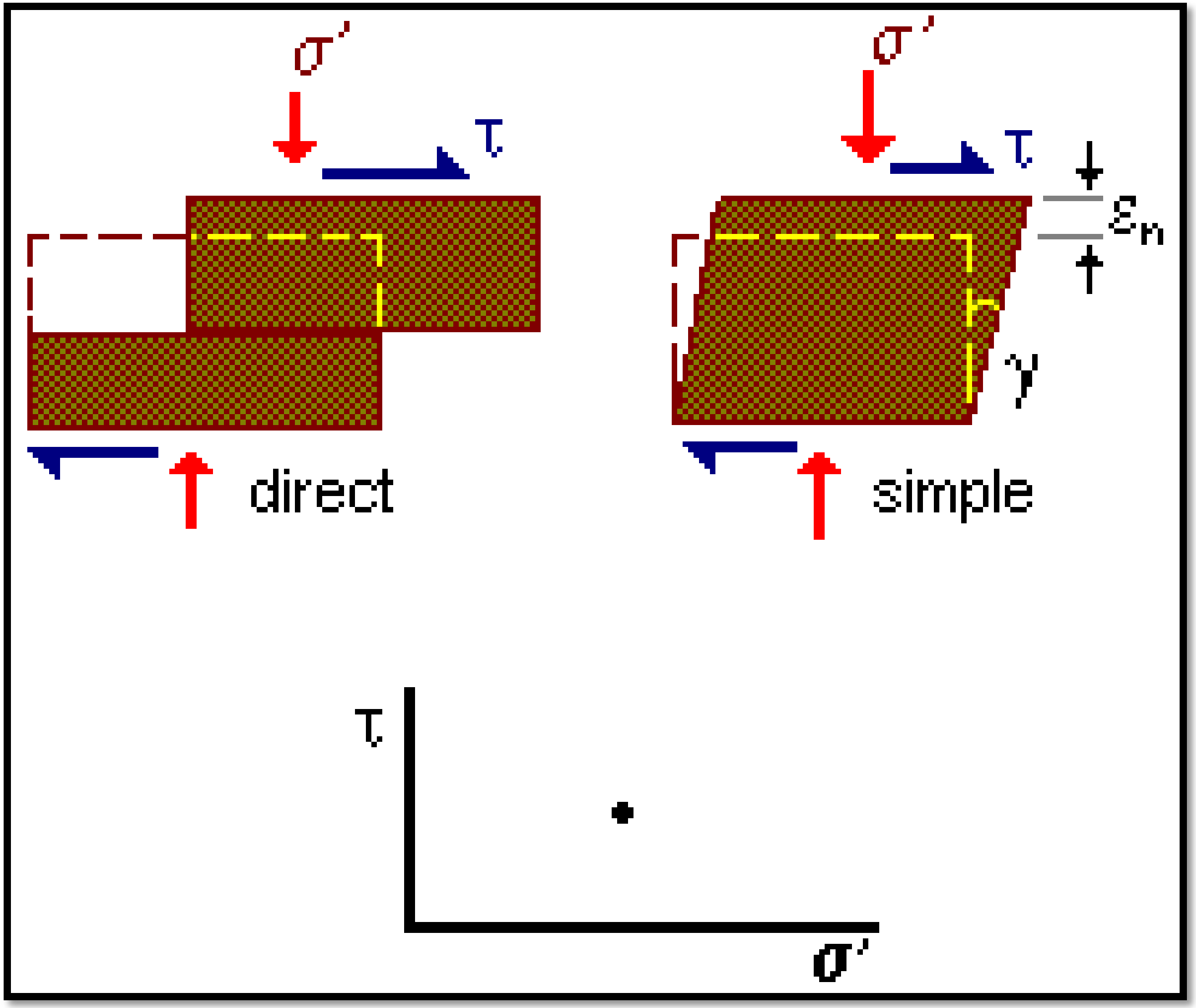
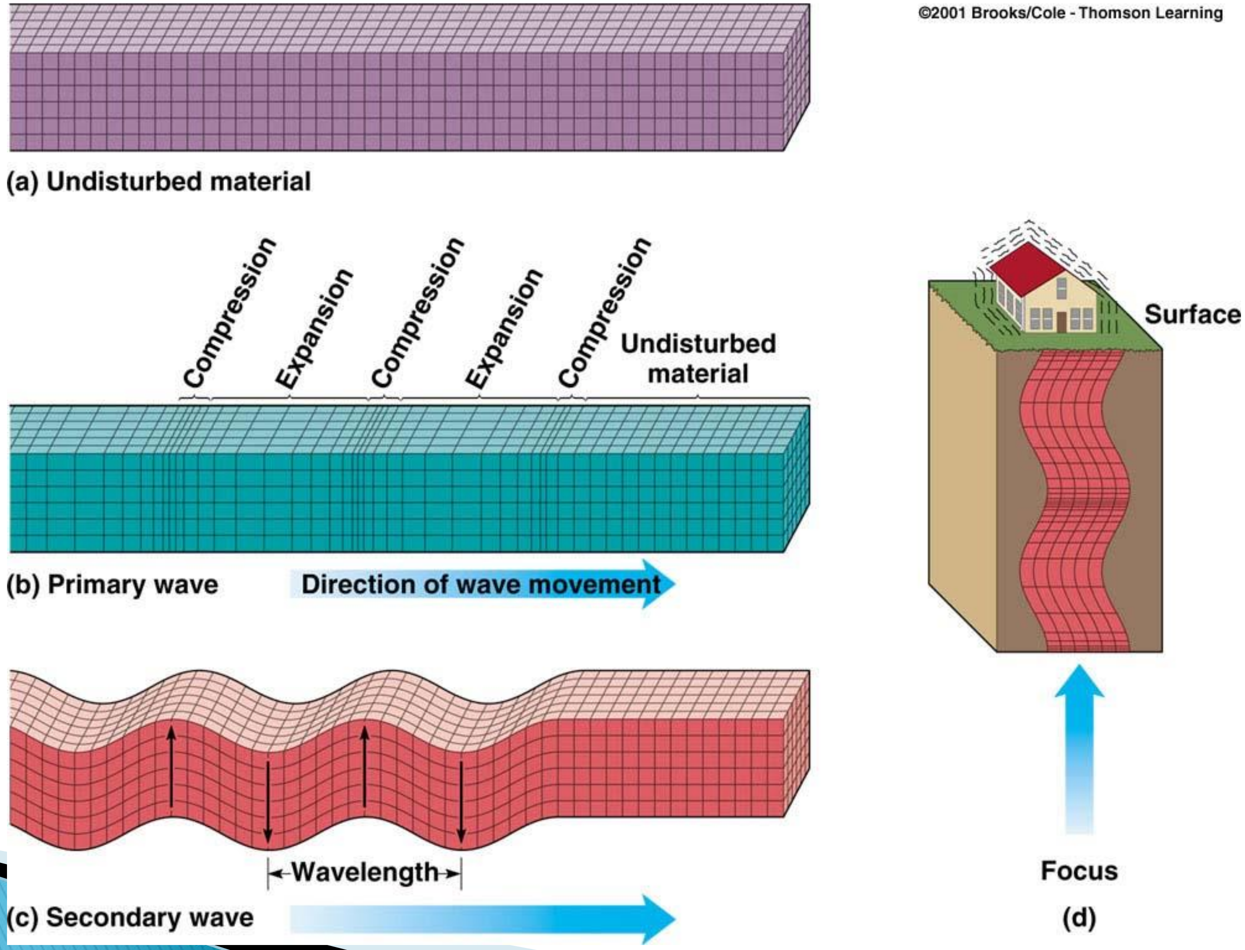


Figure 2

Seismic waves-Body waves

- **Longitudinal waves:**
  - They are faster than transversal waves and thus arrive first.
  - The particles oscillate in the direction of spreading of the wave.
  - Compressional waves
  - P-waves
- **Transversal waves:**
  - The particles oscillate in the direction perpendicular to the spreading direction.
  - Shear waves - they do not propagate through liquids (e.g. through the outer core).
  - S-waves

Seismic waves-Body waves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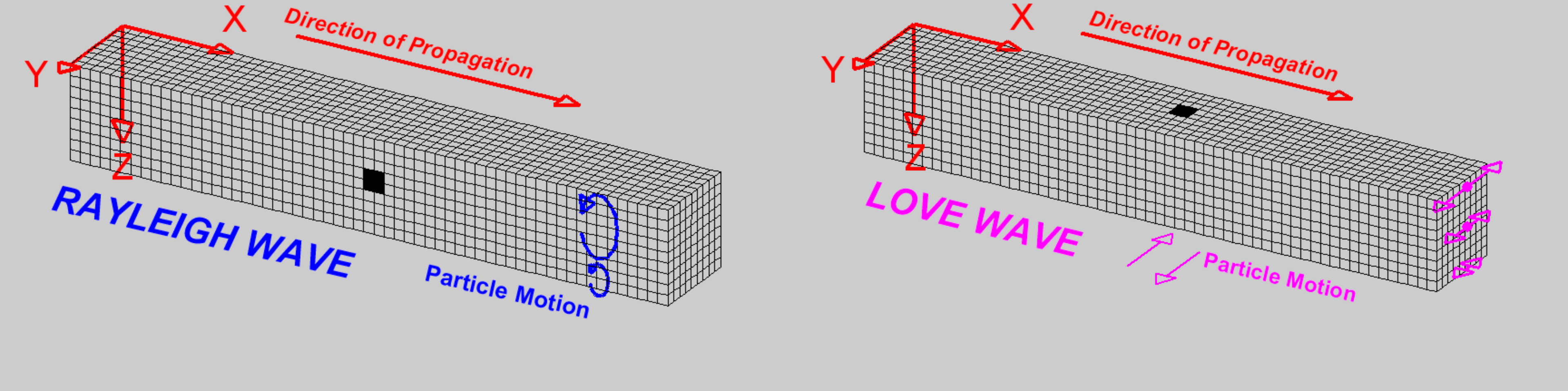
Seismic waves – surface waves

Surface waves: Rayleigh and Love waves

- Their amplitude diminishes with the depth.

-They have large amplitudes and are **slower** than body waves.

- These are dispersive waves (large periods are faster).



Velocity of Seismic Waves

- –The main factors that determine seismic wave velocity are :

1. *Density*
2. *Elastic properties of the Earth*. These vary with *depth*, *location* and *composition*.
3. *Frequency of the seismic energy*
4. *Number, orientation and shape of cracks or other voids in the ground.*

Velocity of Seismic Waves

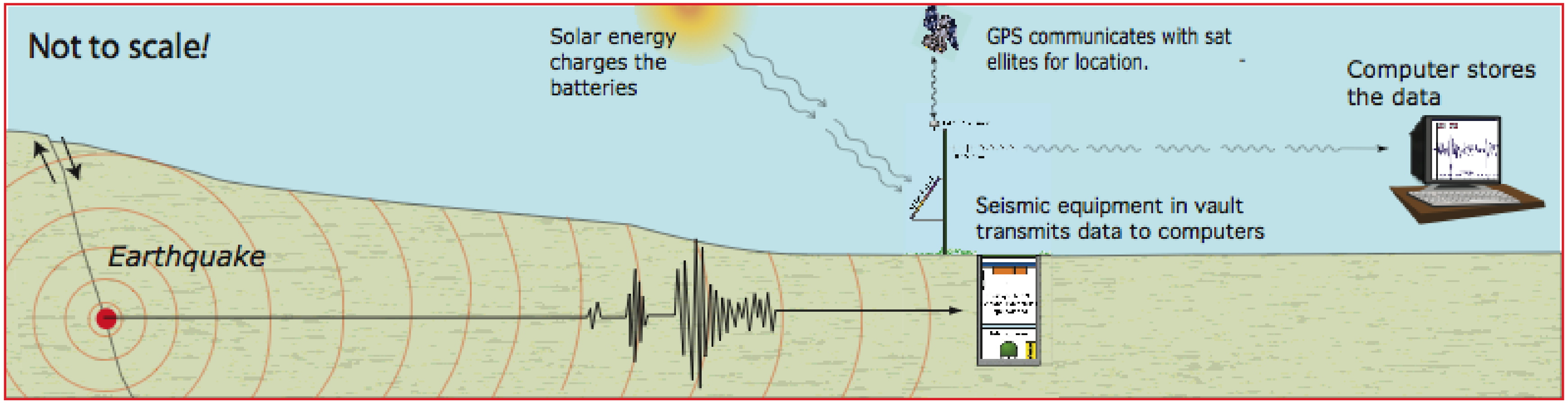
$$V_p = \sqrt{\frac{\kappa + \frac{4}{3}\mu}{\rho}}$$

$$V_s = \sqrt{\frac{\mu}{\rho}}$$

$$V_R = \sqrt{\frac{E}{\rho}}$$

Where:
ρ is the density
κ is the bulk modulus
μ is the shear (or rigidity) modulus
E is Young's modulus

Detection of Earthquakes

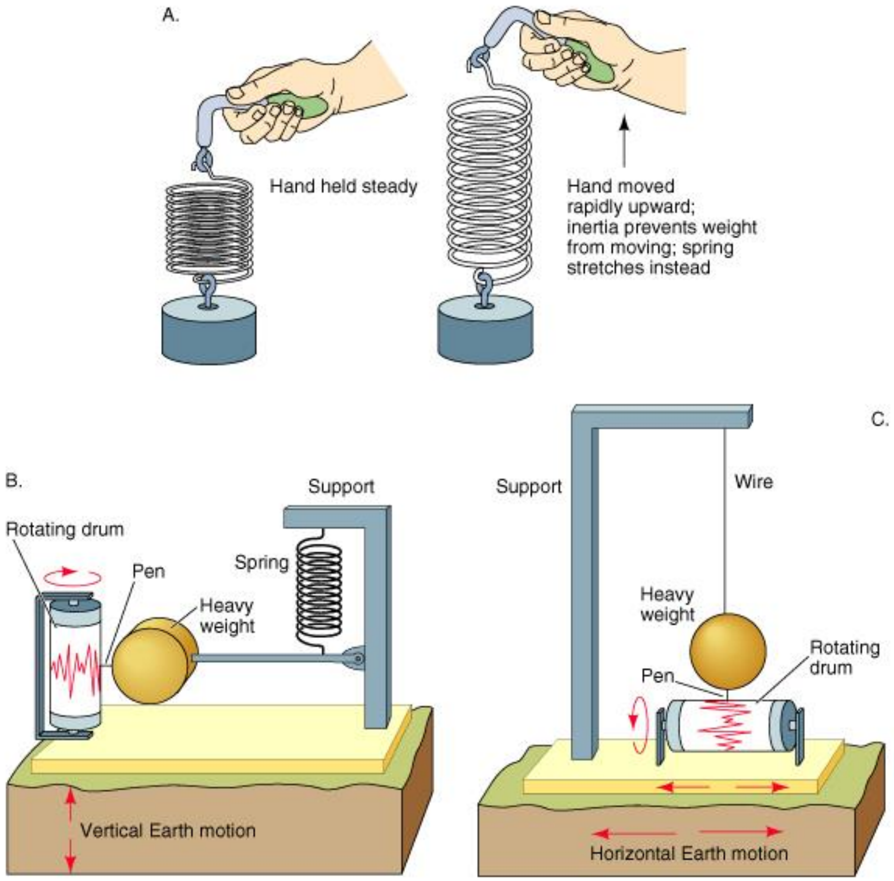


When an earthquake occurs the seismic waves travel through the Earth to the seismic station where the information is transmitted to distant computers.

Detection of Earthquakes

- The ***"seismometer***" is the instrument that is supersensitive to ground motions and therefore can detect the minute ground motions produced by a distant earthquake.
- Some ***seismometers*** record horizontal movement (N-S or E-W) while other seismometers record vertical movement (up-down).

Detection of Earthquakes



Detection of Earthquakes

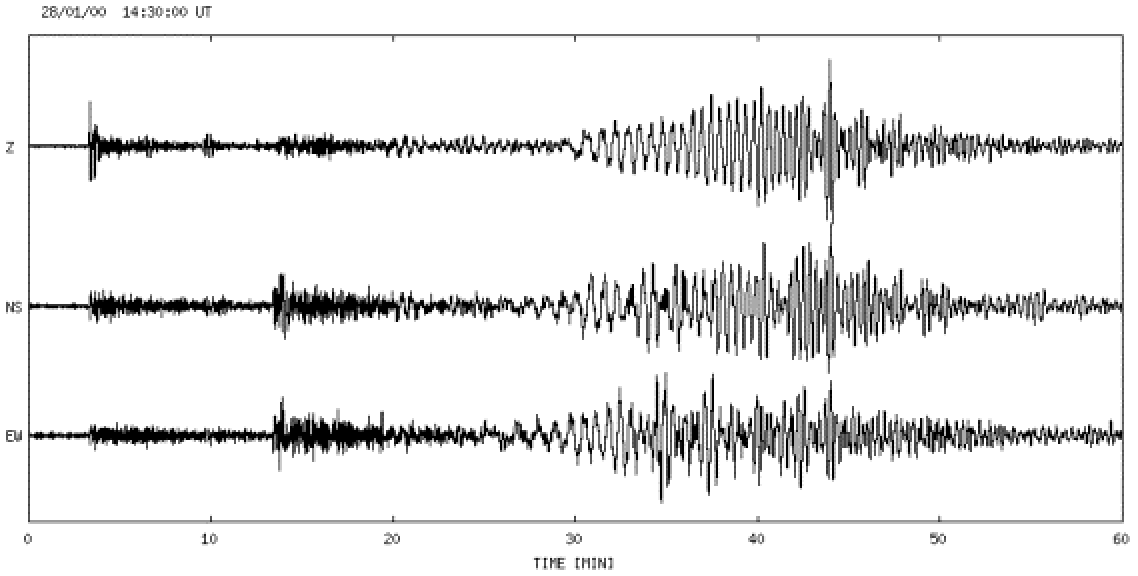
- A ***“seismogram”*** is the graphical representation that the seismometer makes of a particular earthquake.
- As seen on the seismograph in the bottom figure, the order of arrival of seismic waves is: P wave, then S wave, then surface waves.
- When interpreted for us, a seismogram looks pretty simple. In actuality, it takes a trained eye to spot the arrivals of different kinds of seismic waves on the seismogram.

Detection of Earthquakes

Earthquake in Japan

Station in Germany

Magnitude 6.5



Detection of Earthquakes

- Modern digital broadband seismographs are capable of recording almost the whole seismological spectrum (50 Hz – 300 s).
- Their resolution of 24 bits (high dynamic range) allows for precise recording of small quakes, as well as unsaturated registration of the largest on

Detection of Earthquakes

The Seismometer

The seismograph

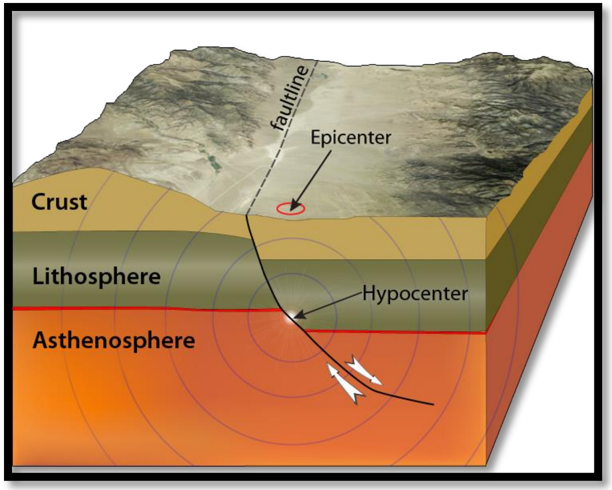
Epicenter & Focus of Earthquakes

- ***Epicenter:***

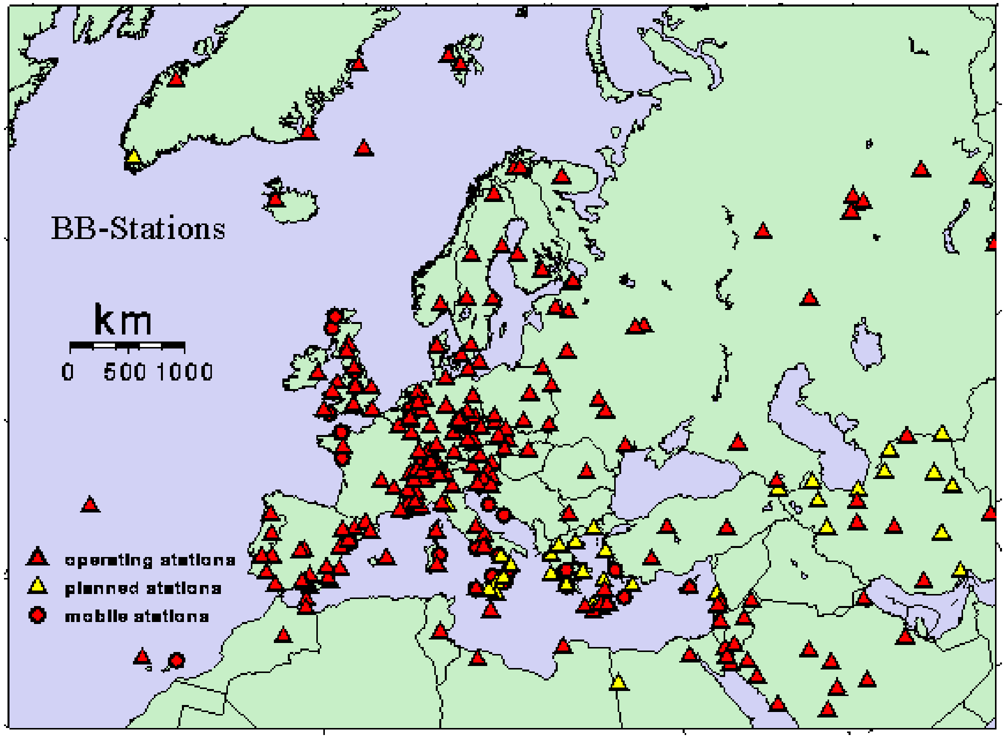
Location *on* Earth's surface directly *above* the hypocenter.

- ***Focus (or hypocenter):***

Location *within* the Earth where the earthquake occurred.



Observational Seismology



Broad-band seismological stations in Europe

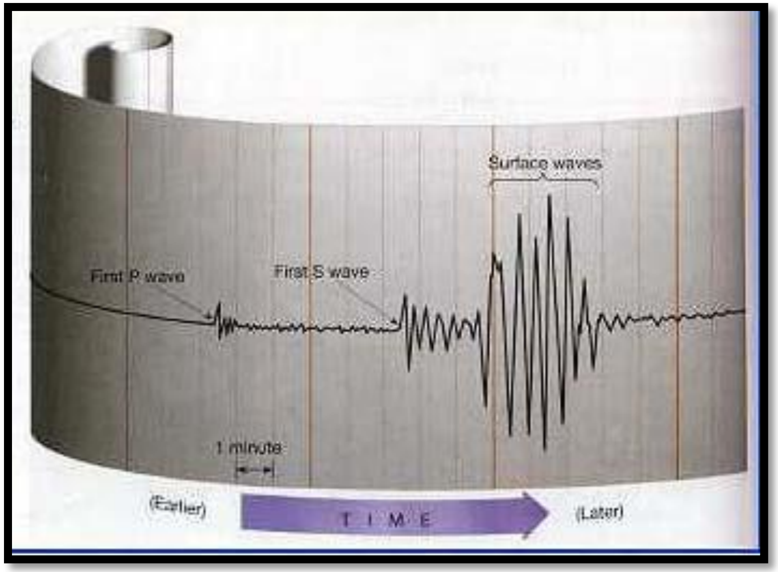
Observational Seismology

- We are now equipped to start recording and locating earthquakes. For that we need a seismic network of as many stations as possible.
- -Minimal number of stations needed to locate the position of an earthquake epicentre is three.

Observational Seismology

Locating Earthquakes

- To locate an earthquake we need precise readings of the times when P- and S-waves arrive at a number of seismic stations.
- Accurate absolute timing (with a precission of 0.01 s) is essential in seismology!



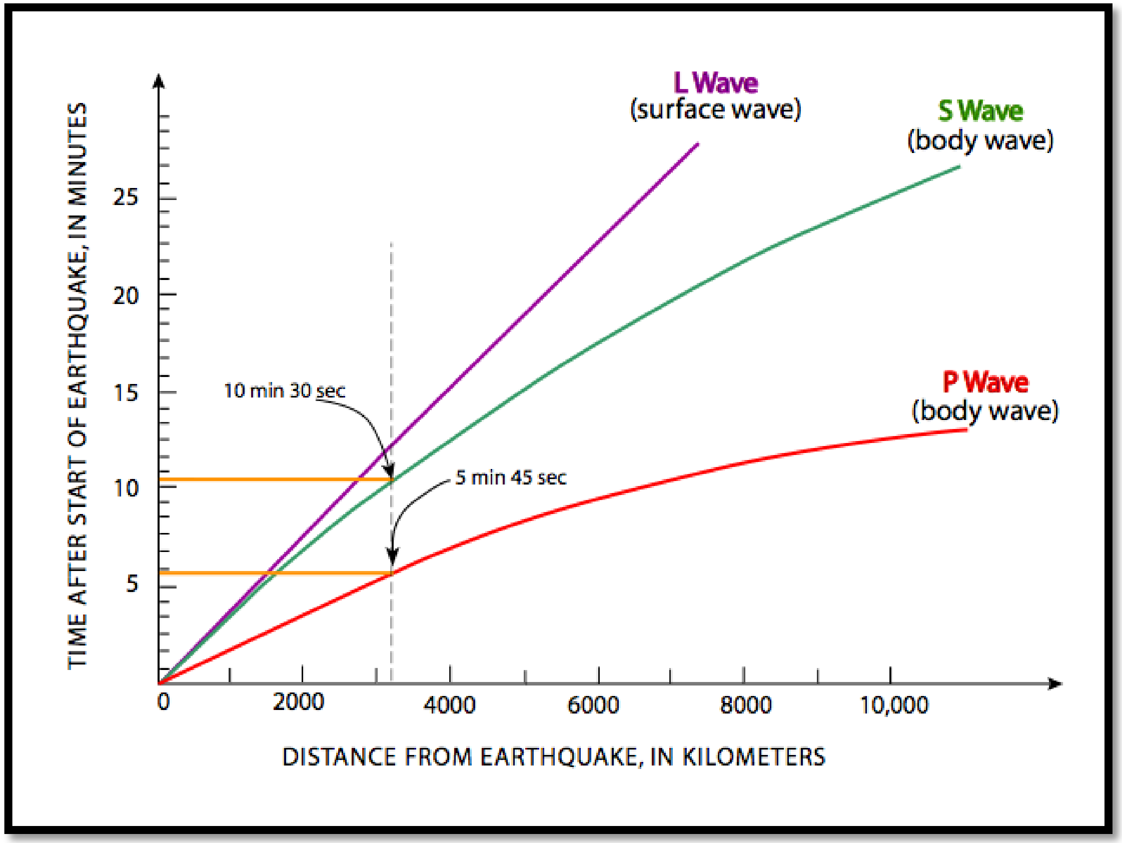
Observational Seismology

Locating Earthquakes

- ✓ Knowing the difference in arrival times of the two waves, and knowing their velocity, we may calculate the distance of the epicentre.
- ✓ This is done using the travel-time curves which show how long does it take for P- and S-waves to reach some epicentral distance.

Observational Seismology

Locating Earthquakes

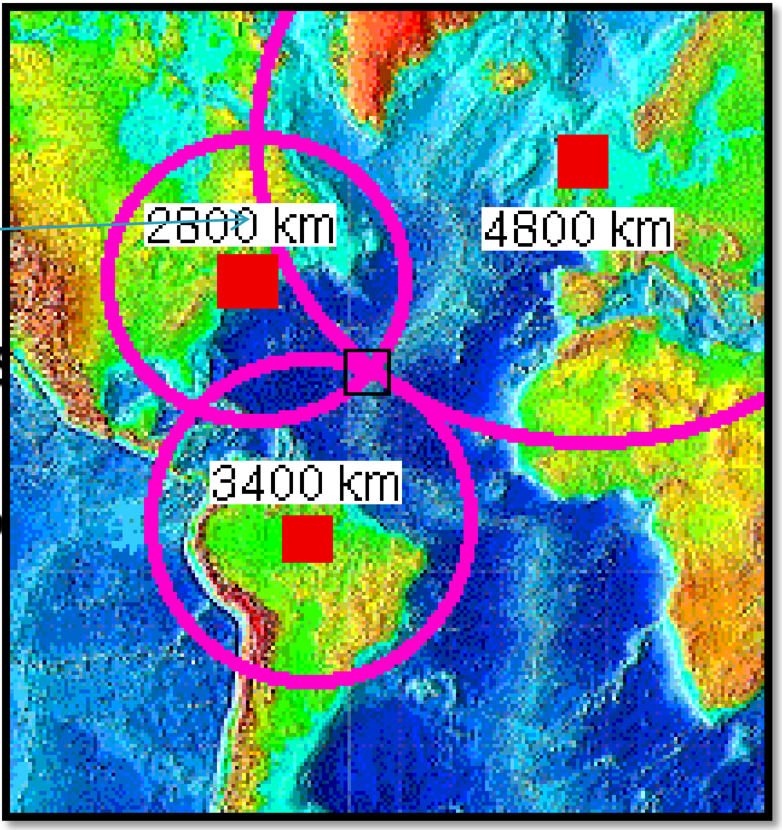


The travel-time curves.

Observational Seismology

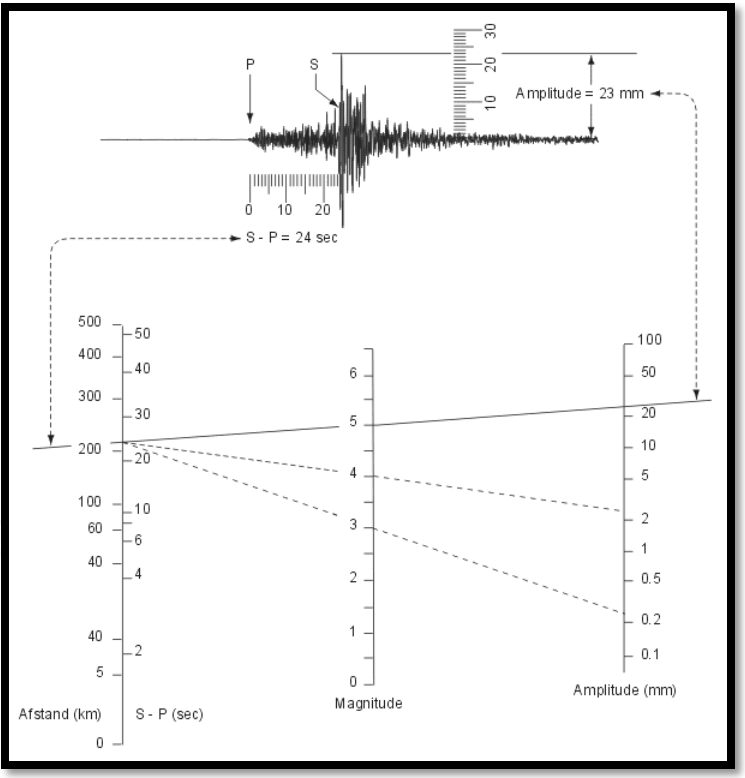
Locating Earthquakes

- After we know the distance of epicentre from at least three stations we may Like this find the epicentre
- There are more sofisticated methods of locating positions of earthquake foci. This is a classic example of an *inverse problem.*



Observational Seismology
Magnitude determination

- Besides the position of the epicentre and the depth of focus, the earthquake magnitude is another defining element of each earthquake.
- Magnitude (defined by **Charles Richter** in 1935) is proportional to the amount of energy released from the focus.



Observational Seismology
Magnitude determination

- -Magnitude is calculated from the amplitudes of ground motion as measured from the seismograms. You also need to know the epicentral distance to take attenuation into account.

Formula:

$$M = \log(A) + c_1 \log(D) + c_2$$

where A is amplitude of ground motion, D is epicentral distance, and c_1, c_2 are constants.

Observational Seismology Magnitude determination

- There are many types of magnitude in seismological practice, depending which waves are used to measure the amplitude: M_L, m_b, M_c, M_s, M_w, ...
- Increase of 1 magnitude unit means ~32 times more released seismic energy!

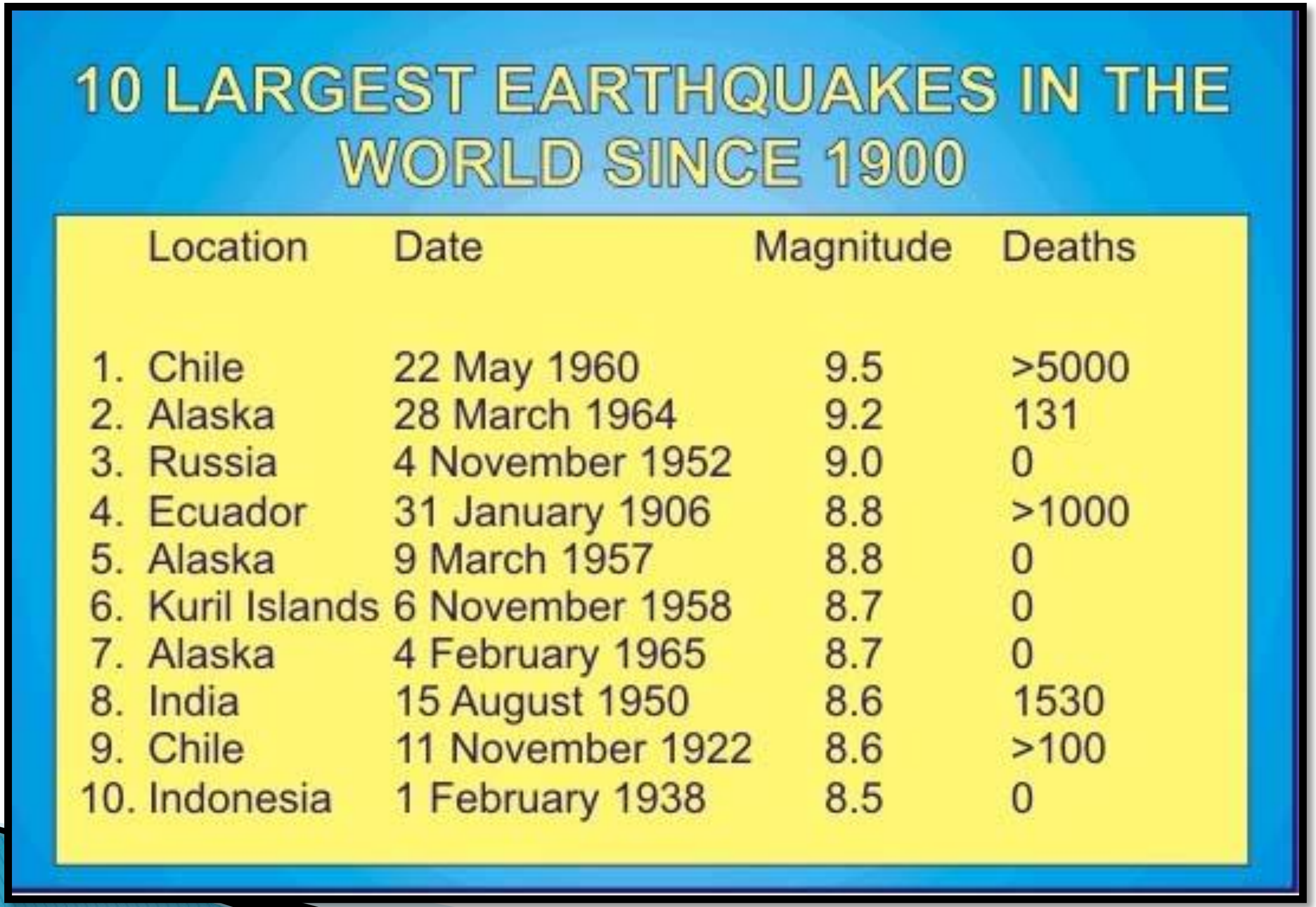
Observational Seismology some statistics

Magnitude	Effects	Number per year
Less than 2	**Not felt by humans. Recorded by instruments only**	Numerous
2	**sensitive. Felt only by the most Suspendedobjects swing**	> 1000000
3	**Felt by some people. Vibration like a passing heavy vehicle**	100000
4	**Felt by most people. Hanging objects swing. Dishes and windows rattle and may break**	12000
5	**Felt by all; people frightened. Chimneys topple; furniture moves**	1400
6	**Panic. Buildings may suffer substantial damage**	١٦٠
7–8	**Widespread panic. Few buildings remain standing. Large landslides; fissures in ground**	20
8–9	**Complete devastation. Ground waves**	~2

Observational Seismology some statistics

Equivalent Magnitude	Event	Energy (tons TNT)
2	Large quary blast	1
2.5	Moderate lightning bolt	٥
3.5	Large ligtning bolt	75
4.5	Average tornado	5100
6	Hiroshima atomic bomb	20000
7	Largest nuclear test	32000000
7.7	Mt. Saint Helens eruption	100000000
8.5	Krakatoa eruption	1000000000
9.5	Chilean earthquake 1960	32000000000

Observational Seismology some statistics



10 LARGEST EARTHQUAKES IN THE WORLD SINCE 1900

Location	Date	Magnitude	Deaths
1. Chile	22 May 1960	9.5	>5000
2. Alaska	28 March 1964	9.2	131
3. Russia	4 November 1952	9.0	0
4. Ecuador	31 January 1906	8.8	>1000
5. Alaska	9 March 1957	8.8	0
6. Kuril Islands	6 November 1958	8.7	0
7. Alaska	4 February 1965	8.7	0
8. India	15 August 1950	8.6	1530
9. Chile	11 November 1922	8.6	>100
10. Indonesia	1 February 1938	8.5	0

Observational Seismology some statistics

10 WORLD EARTHQUAKES CAUSING THE LARGEST NUMBER OF FATALITIES

	Location	Date	Deaths	Magnitude
1.	Shaanxi, China	23 January 1556	830,000	8.0
2.	Antioch, Syria	13 December 0115	260,000	7.5
3.	Tangshan, China	27 July 1976	255,000	7.9
4.	Azerbaijan	25 September 1139	230,000	7.0
5.	Shanxi, China	17 September 1303	200,000	8.0
6.	Ningxia, China	16 December 1920	200,000	8.6
7.	Qumis, Iran	22 December 0856	200,000	7.9
8.	Kanto, Japan	1 September 1923	143,000	8.3
9.	Aleppo, Syria	15 October 1138	130,000	7.5
10.	Messina, Italy	28 December 1908	80,000	7.5

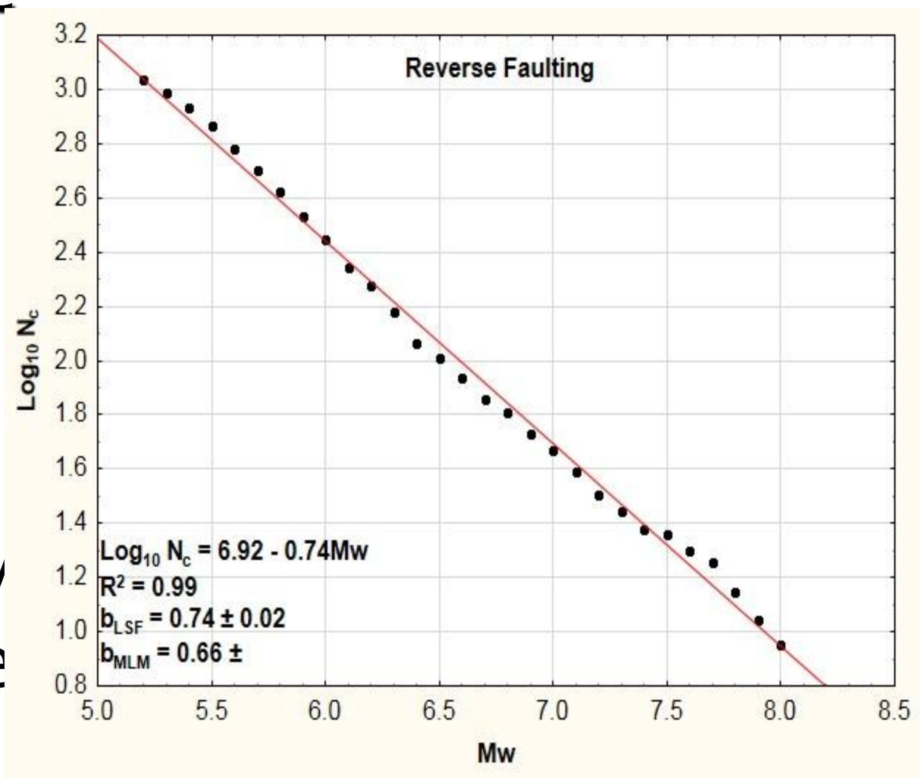
Observational Seismology
some statistics

- **Gutenberg-Richter frequency-magnitude relation:**

$\log N = a - bM$

$-b$ is approximately constant, $b = 1$ world-wide → there are ~10 more times M

than M=6 earthquake



Observational Seismology
Macroseismology

- MACROSEISMOLOGY deals with effects of earthquakes on humans, animals, objects and surroundings.
- The data are collected by field trips into the shaken area, and/or by questionaires sent there.
- The effects are then expressed as earthquake INTENSITY at each of the studied places.
- Intensity is graded according to **macroseismic scales** – Mercalli-Cancani-Sieberg (**MCS**), Medvedev-Sponheuer-Karnik (**MSK**), Modified Mercalli (**MM**), European Macroseismic Scale (**EMS**).
- This is a subjective method.

أخي المواطن الكريم وصفك الدقيق للهزة يساعدنا في التحديد المبكر لحجم الأضرار ولرسم خارطة الشدة الزلزالية فلا تبخل علينا بمعلوماتك ونكون شاكرين لك إذا زودتنا بصور موقعية أوفديو توثق الحدث

1- هل شعرت بالهزة .... اذكر الوقت ... : ... : ... ، إذكر فترة تعرضك للهزة... ؟

2- حدد موقعك في المدينة ....القضاء............

3- طبيعة الارض ترابية ....، صخرية....، أهوار ...، منحدرة...

4- اذكر نوع البناية كونكريت ...، طابوق ... ، طين ...، خشب ...، كرفان ...

5- عمر البناء حديث ...، قديم ...

6- عدد الطوابق في بنايتك ....،في أي طابق كنت .... ؟

7- هل شعر أحد غيرك بالهزة في المنزل او منطقتك ؟

8- هل أيقظتك الهزة من النوم ... ؟

9- هل شعرت بالخوف .... وهل هربت خارج المنزل ...؟

10- هل شعرت بالدوار... وهل سقطت أرضاً ...؟

11- هل سمعت قرقعة الشبابيك والأبواب أوصرير البناية ... ؟

12- هل سمعت ضجيج الأرض كصوت رعد ...،هل شممت رائحة غريبة... ؟

13- هل لاحظت اهتزاز الأشجار والمركبات...،أو تأرجح المراوح السقفية....، ما إتجاه هذا التأرجح...؟

14- هل لاحظت تحرك الاثاث ... أو الاثاث السميك ...، ما إتجاه حركة الأثاث ..؟

15- هل تكسر زجاج النوافذ ...أوسقطت أشياء من فوق الرفوف ... ؟

16- هل حدث تشقق بالجدران .... أو اللبخ ...،هل سقط احد الدور ...، ما عددها... ؟

17- هل شاهدت تدحرج صخورمن سفح الجبل ...، أو تصاعد غبار من الجبل ...

18- هل شاهدت تشققات أوصدوع في الأرض ...، سصحية ...، عميقة ...، ما إتجاهها......؟

19- هل هناك بنايات عالية مضطجعة ...، بنايات مدمرة...؟

20- هل يوجد جرحى...، ماعددهم.....، هل يوجد قتلى ...، ماددهم....؟

Observational Seismology Macroseismology

European Macroseismic Scale (EMS 98)

1. Not felt	Not felt, even under the most favorable circumstances.
2. Scarcely felt	Vibration is felt only by individual people at rest in houses, especially on upper floors of buildings.
3. Weak	The vibration is weak and is felt indoors by a few people. People at rest feel a swaying or light trembling.
4. Largely observed	The earthquake is felt indoors by many people, outdoors by very few. A few people are awakened. The level of vibration is not frightening. Windows, doors and dishes rattle. Hanging objects swing.
5. Strong	The earthquake is felt indoors by most, outdoors by few. Many sleeping people awake. A few run outdoors. Buildings tremble throughout. Hanging objects swing considerably. China and glasses clatter together. The vibration is strong. Top heavy objects topple over. Doors and windows swing open or shut.
6. Slightly damaging	Felt by most indoors and by many outdoors. Many people in buildings are frightened and run outdoors. Small objects fall. Slight damage to many ordinary buildings; for example, fine cracks in plaster and small pieces of plaster fall.

European Macroseismic Scale (EMS 98) (continued)

7. Damaging	Most people are frightened and run outdoors. Furniture is shifted and objects fall from shelves in large numbers. Many ordinary buildings suffer moderate damage: small cracks in walls; partial collapse of chimneys.
8. Heavily damaging	Furniture may be overturned. Many ordinary buildings suffer damage: chimneys fall; large cracks appear in walls and a few buildings may partially collapse.
9. Destructive	Monuments and columns fall or are twisted. Many ordinary buildings partially collapse and a few collapse completely.
10. Very destructive	Many ordinary buildings collapse.
11. Devastating	Most ordinary buildings collapse.
12. Completely devastating	Practically all structures above and below ground are heavily damaged or destroyed.

Observational Seismology Macroseismology

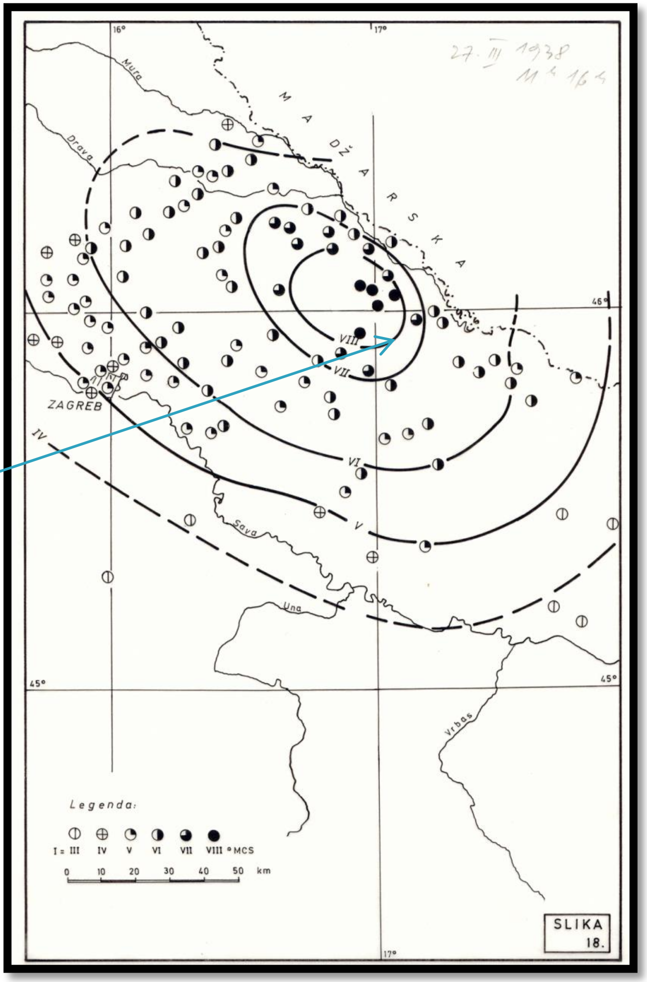
-Results of macroseismic surveys are presented on **isoseismal maps.**

-Isoseismals are curves connecting the places with same intensities.

-DO NOT CONFUSE INTENSITY AND MAGNITUDE!

- Just approximately, **epicentral intensity** is: $I_0 = M +$

-One earthquake has just one magnitude,
but many intensities!



Earthquakes Belts

- *Circum-Pacific belt*

About 95 percent of the energy released by earthquakes originates in a few relatively narrow zones. The greatest energy is released along a path surrounding the Pacific Ocean known as the **circum-Pacific belt.** Included in this zone are regions of great seismic activity such as Japan, the Philippines, and Chile. Areas of the United States that are part of the circum-Pacific belt lie adjacent to California’s San Andreas Fault and along the western coastal regions of Alaska, including the Aleutian Islands.

Earthquakes Belts (continued)

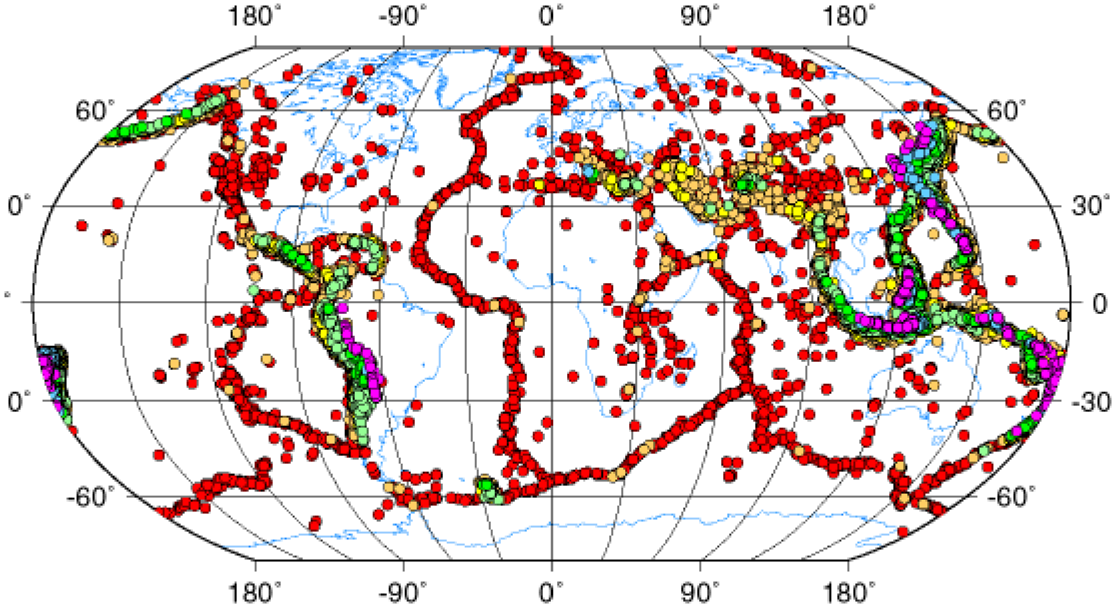
- ***Alpine-Himalayan belt***

Another major concentration of strong seismic activity runs through the mountainous regions that flank the Mediterranean Sea and extends through Iran and on past the Himalayan Mountains. This zone of frequent and destructive earthquakes is referred to as the **Alpine-Himalayan belt.**

- \- ***Mid - Ocean Ridge Belt***

This belt extends for thousands of kilometers through the world's oceans. This zone coincides with the oceanic ridge system, which is an area of frequent but low-intensity seismic activity.

Earthquakes Belts (continued)



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