

EOSC 256 - January 9, 2012



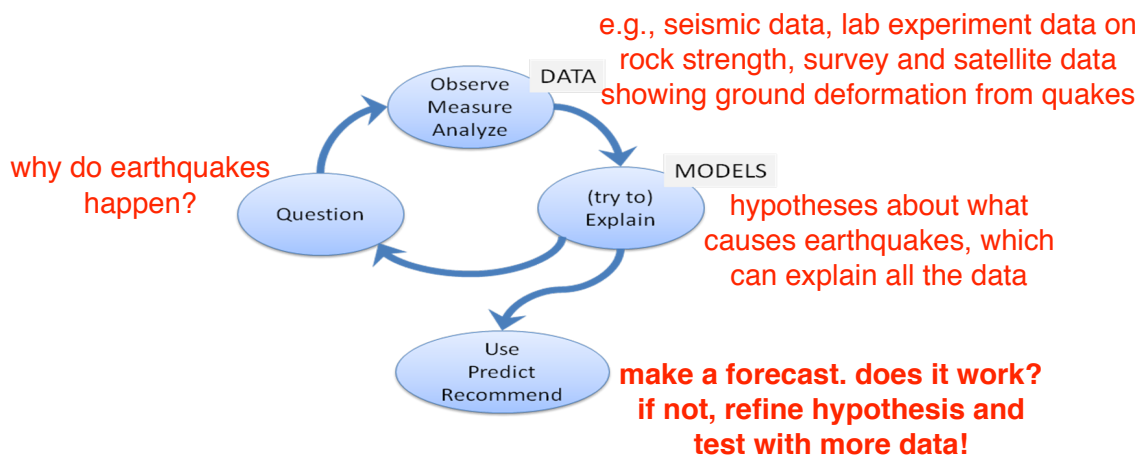
- Historic earthquake theories

- Learning goals:

understand that before 1900, there were scientific efforts to explain earthquakes (NOT just supernatural explanations)

understand the sorts of data on earthquake that people had to work with before the late 1800's

be able to list a few of the suggested earthquake causes (not ALL of them - I will touch on several)



What **data** would people have had in the past, without specialized instruments?

Observational challenge: earthquakes are not repeated, predictable phenomena like most astronomical events. Not as common as storms, and no obvious precursors.

What sorts of **explanations** did they come up with?

Shaking - no way to measure quantitatively until the late 1800's.



First seismometer ~ 132 AD. Indicated azimuth and the fact that shaking had occurred.
3000-year record of large earthquakes in China.
Japan and the Mediterranean region also have long records of large earthquakes.

North and South America - short records
(less writing going on)

Northern Europe - few large earthquakes
to write about.

Africa - both...

Some early descriptions note local strong shaking, and rolling felt over a larger region (with associated dizziness and nausea) as separate phenomena.

Data were time, duration, and strength of shaking (subjective), as well as damage.

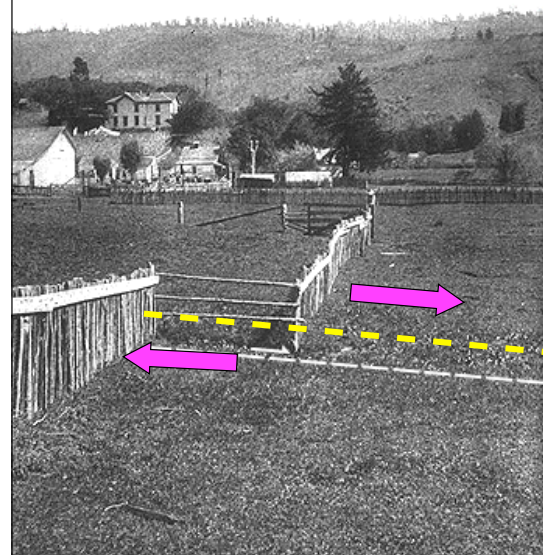
Surface cracks or discontinuities (not always seen!!)

1891, Japan



<http://pubs.usgs.gov/gip/earthq3/along2.html>

1906, California



Deformation of the ground (uplift, subsidence, also landslides)

Alaska 1964: Exposed sea floor ... 33 ft of uplift!



noted often in long-ago earthquakes but not often measured quantitatively (mentioned by Greeks and Romans)

1835, South America:
3 meters of uplift recorded by Charles Darwin and others on the HMS Beagle

Damaged structures (presumably from shaking or permanent shift in ground surface)

Middle East, 749 AD



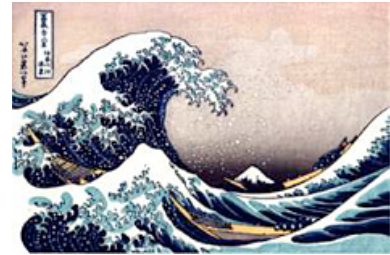
The fallen columns in Susita (Hypos) east of the Sea of Galilee from a magnitude ~7.5 earthquake on the Dead Sea transform fault in A.D. 749.
SOURCE: A. Nur, And the walls came tumbling down, *New Scientist*, 6, 45-48, 1991

Lisbon, Portugal 1755

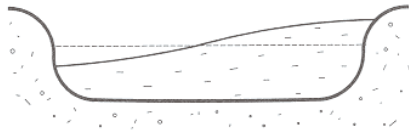


Tsunamis and seiches, sometimes located far from the quake

"The water also went into the pine trees of Ego. The receding water went out very fast, like a big river. It came in about seven times before 10 a.m. of that day and gradually lost its power...Because the way the tide came in was so unusual, and was in fact unheard of, I advised the villagers to escape to Miho Shrine...It is said that when an earthquake happens, something like large swells result, but there was no earthquake in either the village or nearby."

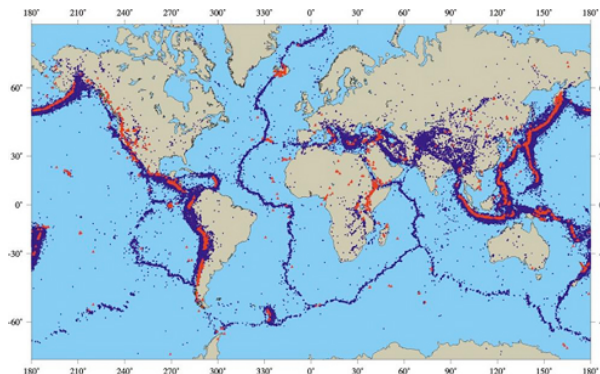


Satake et al. "Time and size of a giant earthquake in Cascadia inferred from Japanese tsunami records of January 1700." Nature, Vol. 379, 18 January 1996, pp.246-248.



seiches were seen in Scotland and Sweden (lakes and canals) due to the 1755 Lisbon earthquake

Who was witnessing these phenomena, trying to explain earthquakes, and writing things down before the late 1800's?



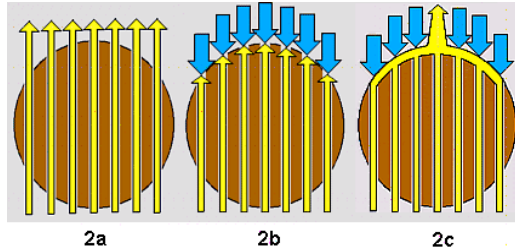
lots of seismicity in eastern Mediterranean, China, Japan

not much seismicity in Northern Europe

What the Greeks thought

Classical Elements (Earth, Water, Air, Fire, and Aether)

Prior to fully modern theories of electromagnetism, many scientists applied the term "aether" to the pervasive medium through which they thought light must propagate. That is, this substance filled the otherwise 'empty' parts of the universe.



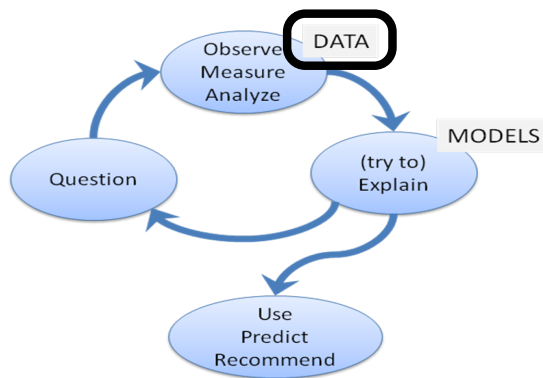
*ARISTOTLE's understanding of
ANAXAGORAS' theories —
speculation*

- "Aether" forces its way down through pores in the Earth.
 - The pores are plugged up by rain water.
 - Aether builds up pressure, forcibly generates an exit, and escapes.
- This process is associated with an earthquake.

ARISTOTLE (384-322 B.C.) criticized the above theory as primitive ("silly"). His idea: the damp earth is being heated up by internal heat and by the sun, creating winds which can pass through the solid earth. This theory was "in play" through the 1700's.

main sources: Erhard Oeser, 1992 and
Christopher Liner, 1997

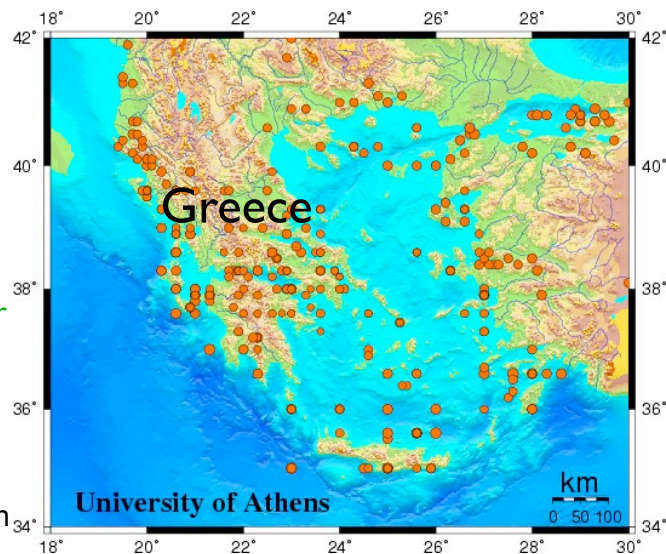
Aristotle's data



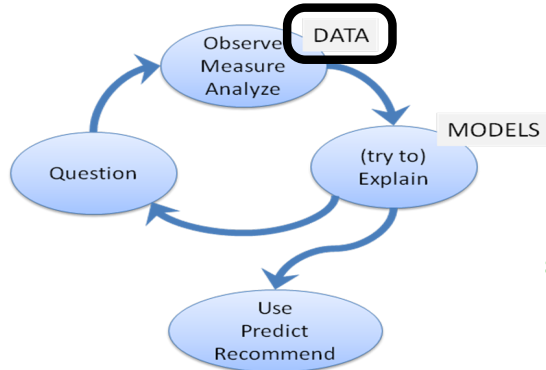
- more quakes in fall and spring (false)
- more quakes at night or mid-day (false)
- more intense shaking in areas with soft sediments ("porous subsoil") (true)

- more earthquakes in or near the ocean ("where the sea is full of currents" and fewer "on islands far out at sea" (true around Greece)

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- sun becomes "misty and dim" before an earthquake (false)

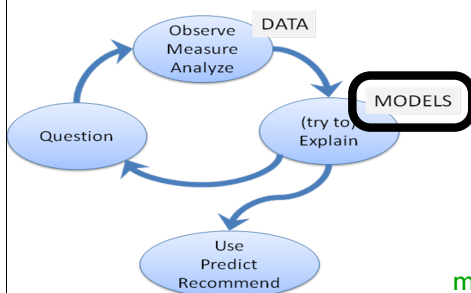
- noises precede earthquake (immediately: P-wave?)

- large ocean waves occur with some earthquakes (true: tsunamis)

from his book, "Meteorologica"

"Our own view is that the same natural substance causes wind on the earth's surface, earthquakes beneath it, and thunder in the clouds; for all these have the same substance, the dry exhalation. If it flows in one way it is wind, in another it causes earthquakes..."

How Aristotle's model (theory) explains the available observations



- more quakes in fall and spring (false)

- more quakes at night or mid-day (false)

because of a greater total supply of wind and during calm conditions, a greater percentage of the total wind supply is available to cause earthquakes

- more intense shaking in areas with soft sediments ("porous subsoil") (true)

it's easier for winds to pass through porous sediments

- more earthquakes in or near the ocean ("where the sea is full of currents" and fewer "on islands far out at sea" (true around Greece)

pressure under deep water suppresses the wind. near the coast, high currents (also due to the wind) transfer wind into the Earth

- sun becomes "misty and dim" before an earthquake (false)

"the sun is necessarily misty and dim when the wind which dissolves and breaks up the air begins to retreat into the Earth"

- noises precede earthquake (immediately: P-wave?)

sound of the wind moving in the Earth before it escapes

- large ocean waves occur with some earthquakes (true: tsunamis)

water is piled up where the winds released by the quake collide with winds blowing in the opposite direction

More ideas: fires, explosions, etc.

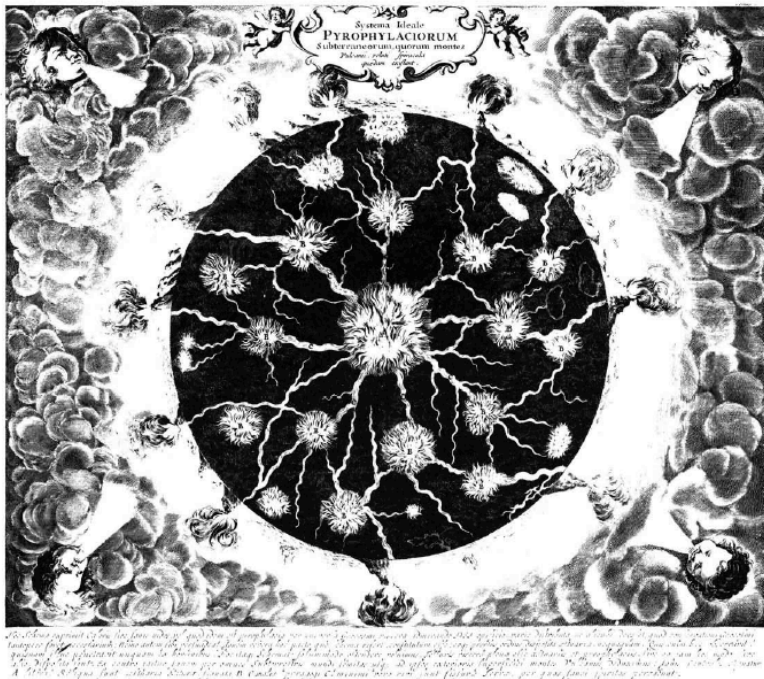
GREEKS (including ARISTOTLE) were convinced that there existed "fire streams" and "fire hearths" inside the earth. Only their causes were disputed.

collapse

- a smoldering subterranean fire expands to neighbouring parts of the earth, scorching and damaging them. These parts crumble, destroying the surface via collapse (leading to earthquakes). There were several other theories involving collapse of underground caves (ANAXIMENES, DEMOCRITUS).

positive
pressure

- fires inside the earth make subterranean water boil, producing vapour, which in turn moves winds through the earth looking for an exit. This leads to vibrations and eruptions. (ARISTOTLE)



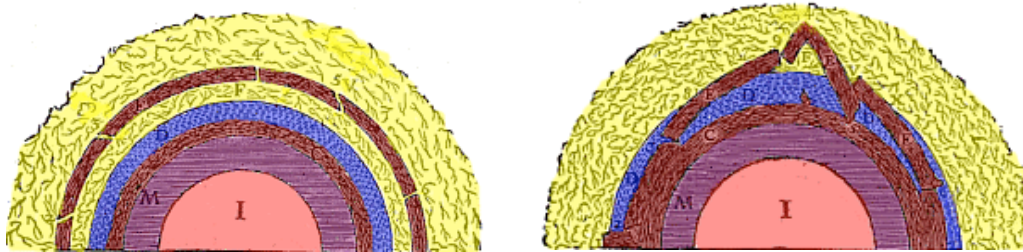
one model of
the Earth's
interior, 1685

During the Middle Ages no new concepts about earthquake mechanisms and causes were developed. Christian authors of this era wrote that God is the first supernatural cause of earthquakes, while the natural causes presented by ARISTOTLE were only secondary.

More speculation from famous people: fires, explosions, etc.

According to **RENE DESCARTES** (1596 - 1650) the fire-fluid and sunlike core of the earth is surrounded by a spherical shell of metals. This solid shell is enclosed by another one consisting of water and another one consisting of air. Beyond this last shell there is the freely floating earth crust which, however, is broken in several pieces. Thereby mountains and seas have been formed. As for earthquakes as well as eruptions of volcanoes they are caused by an *accidental spark which is inflamed by sulphuric vapour in crevices and caves of the earth's crust*. Thus the walls of the caves are shaken:

The earth model by RENÉ DESCARTES



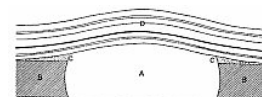
(based on what?)

Ideas from the 1700's (Europeans and Americans, *motivation: Newcomen steam engine*)

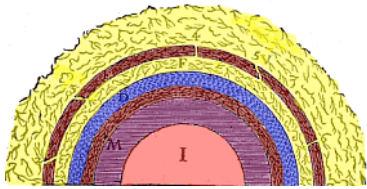
explosion!

- Spontaneous ignition of a mixture of iron and sulphur: the heat of the sun produces such deep fissures that the air can penetrate into the interior of the earth, allowing this chemical reaction (i.e. explosion) to occur. Immanuel Kant's recipe: 2 parts vitriol, 8 parts water, and 2 parts iron = steam explosion.

- The outer crust of the earth contains a stream of very hot "stones and minerals in burning canals". Cold water mixes with this stream of hot rock, leading to explosions, steam pressure buildup, etc. This idea can explain "everything that can be noticed during an earthquake, starting with the noise that may be heard before an earthquake even begins, and ranging to elevations, repeated jerks and shocks and tremors of the ground" (F. Jacobi)



Subterranean fire hearth and strata lying above it according MICHELL (1760)



More hypothetical layered-Earth models

BENJAMIN FRANKLIN: the core of the earth consists of an air sphere highly compressed (and hence dense). In his opinion the crust of the **earth is swimming on this air sphere**, with the atmosphere being above the crust. **Due to the rotation of the earth around its axis, the inner fluid changes its shape so that the crust could burst.** In addition wave-like movements (undulations) originate below the crust, due to the expansion of vapours putting pressure on the inner fluid. These undulations are distributed over wide areas and may cause tremors over large regions.

CHARLES DARWIN: earthquakes are the consequences of a phenomenon analogous to volcanic eruptions. **A layer of liquid magma is postulated to lie beneath the crust and an earthquake is a failed volcanic eruption.**

"In a primary volcanic outburst, we know the cause to be the explosion of liquid and aeriform matter, first through solid strata, and afterwards through a nearly open passage; hence we are led to conclude, that the cause of the simple earthquake, with its secondary shocks, are explosions of a similar nature, which, however, do not open a passage, but rend successively portions of the superincumbent masses."

Japan and China - earthquakes due to 'imbalances in the 5 Yin and Yang forces' (similar to the five Greek elements).



Namazu (in Japan) = myth or symbol more than a serious explanation

China and Japan - detailed catalogues of earthquakes going back hundreds to thousands of years

Seismology as a quantitative science started in Japan in the late 1800's



Gravity is 'discovered' and then...

"It either happens due to a real vibration of the ground or not"

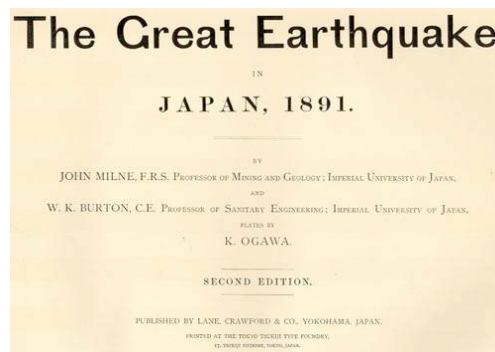
On 18 February 1756 between 8 and 8.30 Germany and the Netherlands were affected by an earthquake. Both in Göttingen, where TOBIAS MAYER was director of the observatory, and in Hannover, where Friedrich Jacobi was writing his treatise on earthquakes in (response to the 1755 Lisbon earthquake), the earth shocks could be noticed. Both scientists reported the dizziness they felt during the earthquake.

Their theoretical explanation of these phenomena was totally different. While TOBIAS MAYER tried to explain this dizziness by a **change of gravity with the ground of the earth not moving at all**, JACOBI attributed them to real movements of the ground.

...short-time local change in the direction of gravity, with the ground itself remaining unmoved and the objects on it moving around. According to this hypothesis the term "earthquake" was not really correct, like in astronomy the terms "sunset" and "sunrise":

This hypothesis did explain collapsing houses, strange movements of water masses that were far away, and the subjective feeling of dizziness that is similar to sea-sickness.

Detailed surveys, seismograms, and photographs showed that the ground really does move...



Part of a table from the Lawson Report (1906 California earthquake)

Table 1. — Displacements of 1906

Table 1: Displacements of 1906																				
Station	Latitude After 1868			Latitude 1906-07			Longitude After 1868			Longitude 1906-07		Southward Component of Displacement	Eastward Component of Displacement	Direction of Displacement	Amount of Displacement		Relation to Fault			Degree of Certainty
Group 1.										Meters	Meters				Meters	Feet	Km.	Miles	Dir.	
Rocky Mound	37°	52'	57.253"	57.262"	122°	14'	30.507"	30.515"	- 0.28	- 0.20	145°	0.34	1.1	32	20	E	Doubtful.			
Red Hill	37	33	04.730	04.738	122	05	40.982	40.975	- 0.25	+ 0.17	215	0.30	1.0	19	12	E	Doubtful.			
Sierra Morena	37	24	38.266	38.305	122	18	28.006	28.054	- 1.20	- 1.18	136	1.68	5.5	4.3	2.7	W	Certain.			
Mount Tamalpais	37	55	27.507	27.492	122	35	45.242	45.228	+ 0.46	+ 0.34	324	0.58	1.9	6.4	4.0	E	Certain.			
Farallon Lighthouse	37	41	58.250	58.277	123	00	03.605	03.669	- 0.83	- 1.57	118	1.78	5.8	37	23	W	Certain.			
Pt. Reyes Light-house	37	59	45.458	45.572	123	01	20.577	20.618	- 0.43	- 1.00	113	1.09	3.6	19	12	W	Doubtful.			

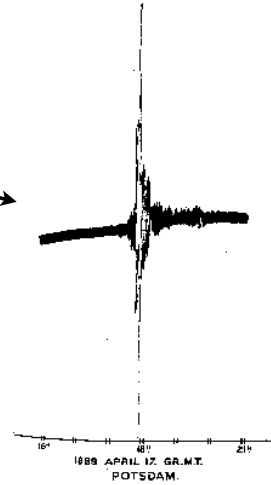
Late 1800's: development of seismometers quantify and record shaking

1875 First “useful” seismometer built in Italy

1889 Japan earthquake recorded in
Germany

1890's John Milne, working in Japan, invents
better, portable seismometers (big cat fight
over who invented what, when)

1906 San Andreas earthquake recorded by
dozens of seismographs worldwide



1875: In Italy, Luigi Palmieri invented an electromagnetic seismograph, one of which was installed near Mount Vesuvius and another at the University of Naples. These seismographs were the first seismic instruments capable of routinely detecting earthquakes imperceptible to human beings.

The foregoing work set the stage for the late 1800s and early 1900s, when many fundamental advances in seismology would be made. In Japan, three English professors, John Milne, James Ewing, and Thomas Gray, working at the Imperial College of Tokyo, invented the first seismic instruments sensitive enough to be used in the scientific study of earthquakes