



# History of Seismology

Seismic waves



## **Definition:**

Seismology is the science of seismic waves generated by earthquakes.

## **Objectives:**

To learn about, develop, and improve

1. the **structure of the earth** (direct observation is impossible)
2. the **physics of earthquakes**
3. societal measures against **earthquake risk**

## **Earthquake facts:**

**Every day:**

=> ~50 earthquakes strong enough to be felt locally

=> several of these produce **distant seismic waves measured globally**

**Every few days:**

=> An earthquake strong enough to damage structures.



## *Early attempts in Asia*

Since **780 BC**: every moderate to large earthquake recorded in China

**132 BC**: First “seismoscope” developed in China

**416 AD**: Japanese earthquake catalogue (patchy)

**1600+**: Japanese quake catalog complete



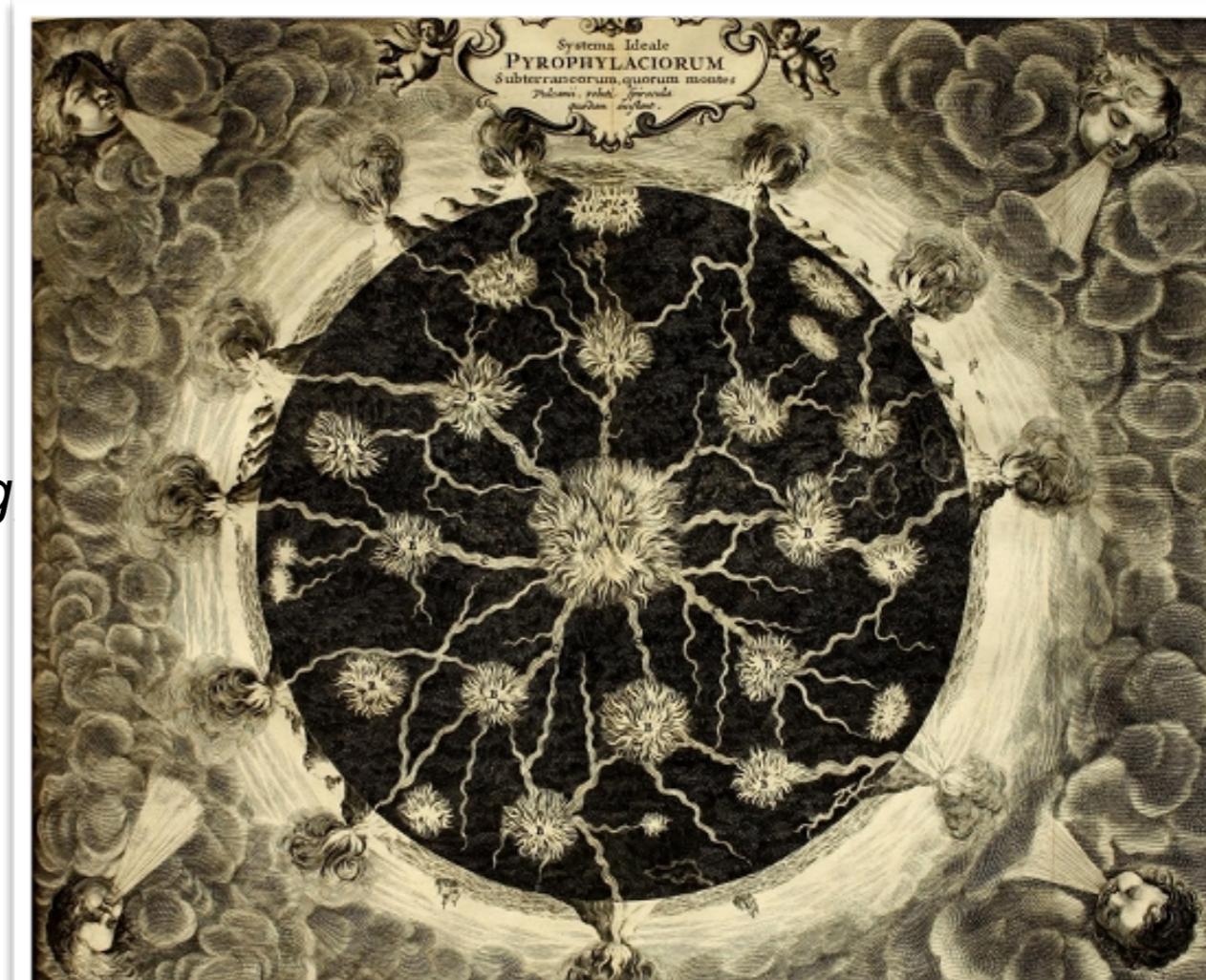
# *Early attempts in Europe*

Earthquakes produced by collision of subterranean winds  
[Aristotle, “Meteorologica”, ~340 BC]

*Diseased nature oftentimes breaks forth  
In strange eruptions; oft the teeming earth  
Is with a kind of colic pinch'd and vex'd  
By the imprisoning of unruly wind  
Within her womb; which, for enlargement striving  
Shakes the old beldam earth and topples down  
Steeple's and moss-grown towers.*

[Shakespeare, The First Part of Henry IV:  
Act 3, Scene 1, ~1597]

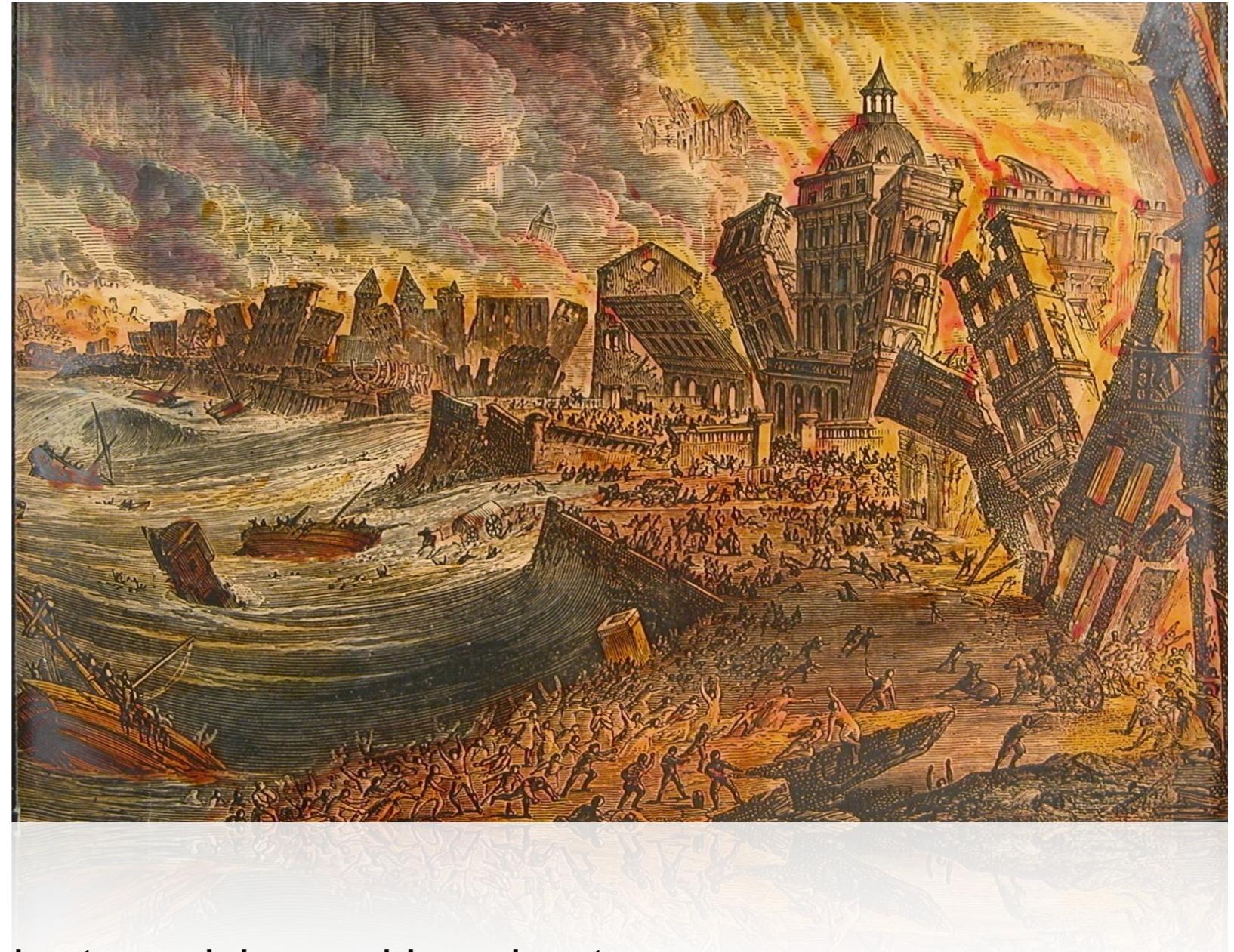
....wind/gas model lasts until ~1700's



Athanasius Kircher, *Mundus Subterraneus*, 1665



# Lisbon 1755



....kills >70,000 people

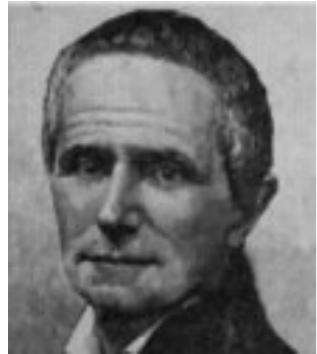
*Marquis* sent out questionnaire to parishes asking about aftershocks, earthquake duration, damage, well water, animal behavior, and aftershocks.

**1760:** Astronomer *John Mitchell* calculates velocity of seismic wave to be ~500 m/s (slow, but not impossible)



# **Seismology in the 19<sup>th</sup> century**

**1821-22:** Navier, Cauchy, Stokes derive **equations for elasticity** before observations



Filippo Cecchi

**1830:** Poisson: only P and S waves travel through homogeneous solids

**1857:** Mallet: earthquakes radiate from focus, can be located by backprojection, proposes to monitor earthquakes: **starts era of observational seismology**

**1875:** Cecchi builds first seismometer (detects/records earthquake vibrations) in Italy



John Milne

**1878:** „Erdbebenkommission“ founded in Bern (before Italy, Japan)

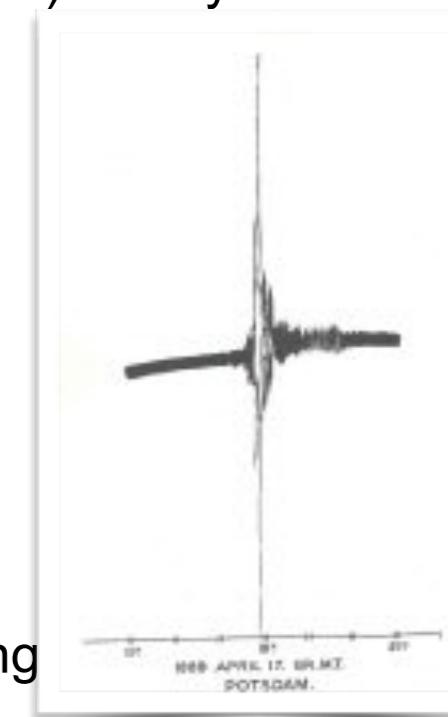
**1883:** G. K. Gilbert associates earthquakes with faults

**1889:** first **teleseismic** recording of earthquake in Japan, recorded in Germany

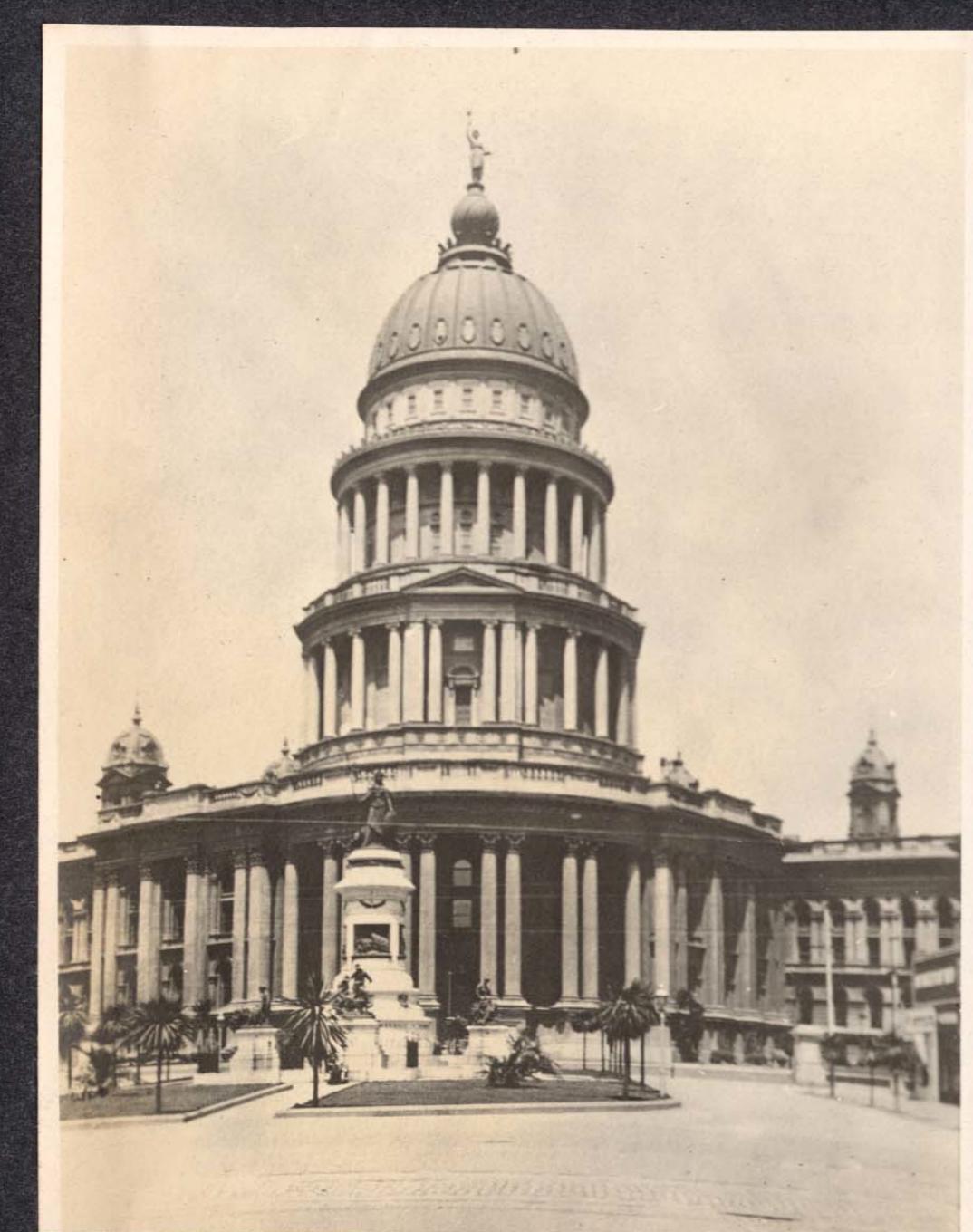
**1892:** Milne develops first portable: **starts era of global seismology**

**1897:** Wiechert (1<sup>st</sup> geophysics prof) develops 1<sup>st</sup> seismometer with damping

**1887, 1911:** Rayleigh and Love demonstrate existence of free surface waves



# *San Francisco 1906*



City Hall Tower before and after the Quake.



# *San Francisco 1906*



THE GREAT MEMORIAL ARCH AT STANFORD UNIVERSITY BEFORE AND AFTER THE EARTHQUAKE.



# *San Francisco 1906*

San Francisco Trolley Car Ride - 1906  
Market Street



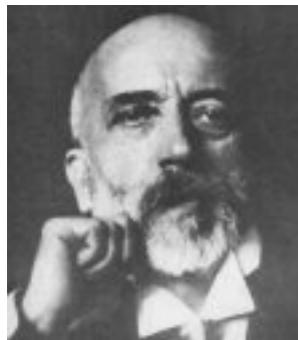
Miles Brothers Footage - April 14, 1906  
Four Days Before the Earthquake



Aftermath of Earthquake and Fire - 1906  
Newsreel Footage - Producer Unknown



# **Seismology in the 20<sup>th</sup> century**



Andrija Mohorovičić

**1906:** Reid uses offsets from SF quake to develop elastic rebound theory

**1906:** Oldham discovers the core

**1907:** Zoeppritz: teleseismic traveltimes and first 1D earth model

**1909:** Mohorovičić discovers the crust-mantle boundary

**1935:** Richter: “Richter scale” to measure strength of Californian earthquakes

**1936:** Lehmann discovers the inner core

**1960:** Chile earthquake, first recording of Earth's free oscillations

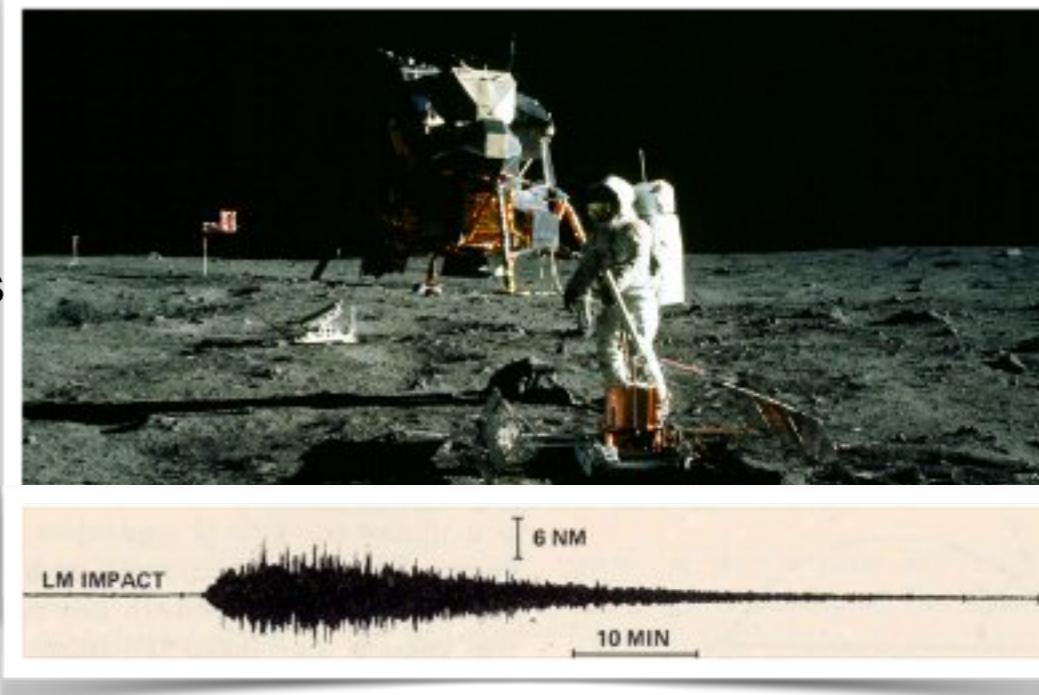
**1960's:** Plate tectonic theory confirms earthquakes confined to plate boundaries  
Computers routinely used for earthquake locations, inverse problems, synthetics

**1970s:** Digital seismometers developed and installed, centralized data archiving

**1977:** Kanamori proposes moment magnitude scale



Inge Lehmann



Apollo mission (1969-1972)



# ***Seismology in the 21<sup>th</sup> century***

**Global tomography:** 3D earth models agree for large-scale structure

**Numerical wave propagation:** accurately predicts ground motion, uses full seismograms for tomography, improves resolution for seismic imaging

**Ambient noise:** Diffuse wavefields from scattering or ocean-continent interaction, cross-correlated to obtain ballistic seismic signals

**Exotic seismic sources:** Tremors, slow-slip events, landslides, glacial calving, meteorite impacts

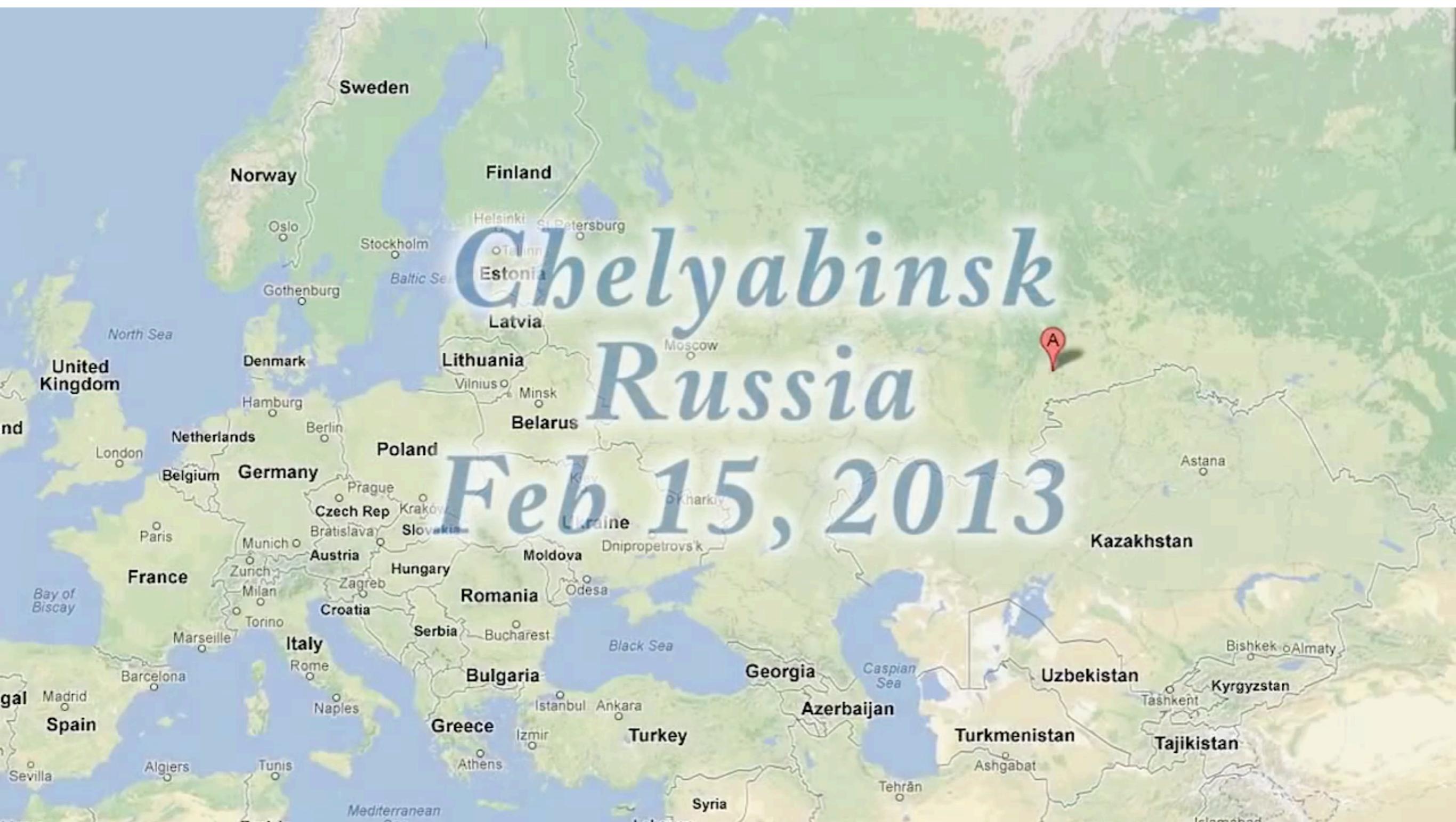
**Instrumentation:** Floating hydrophones, large arrays, GPS, laptop accelerometers, fibre optics



Tristan volcano, ocean-bottom seismograph survey



# Seismology in the 21<sup>th</sup> century: Exotic sources

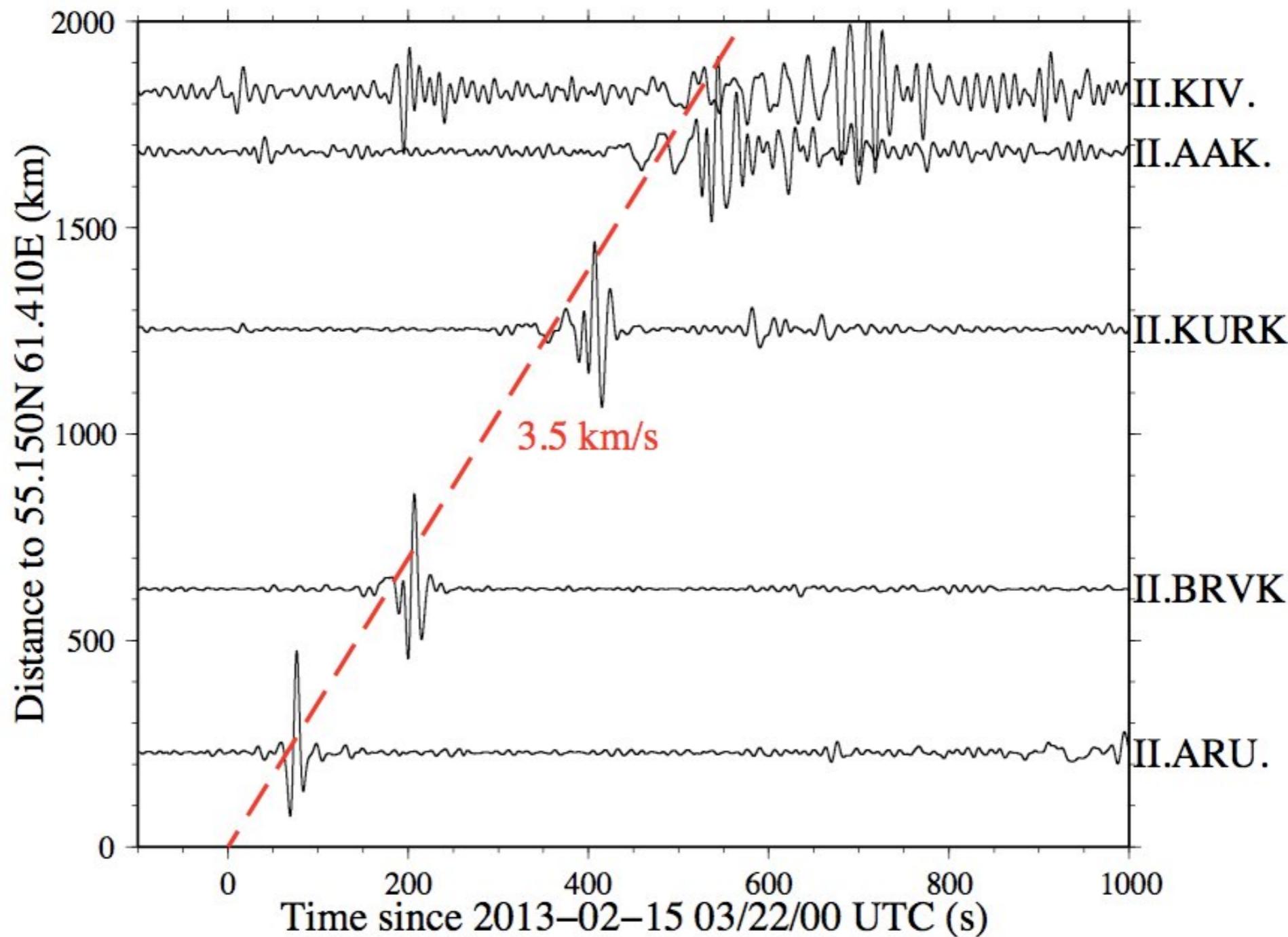


Meteorite impact, Chelyabinsk 2013

Seismic waves



# Seismology in the 21<sup>th</sup> century: Exotic sources

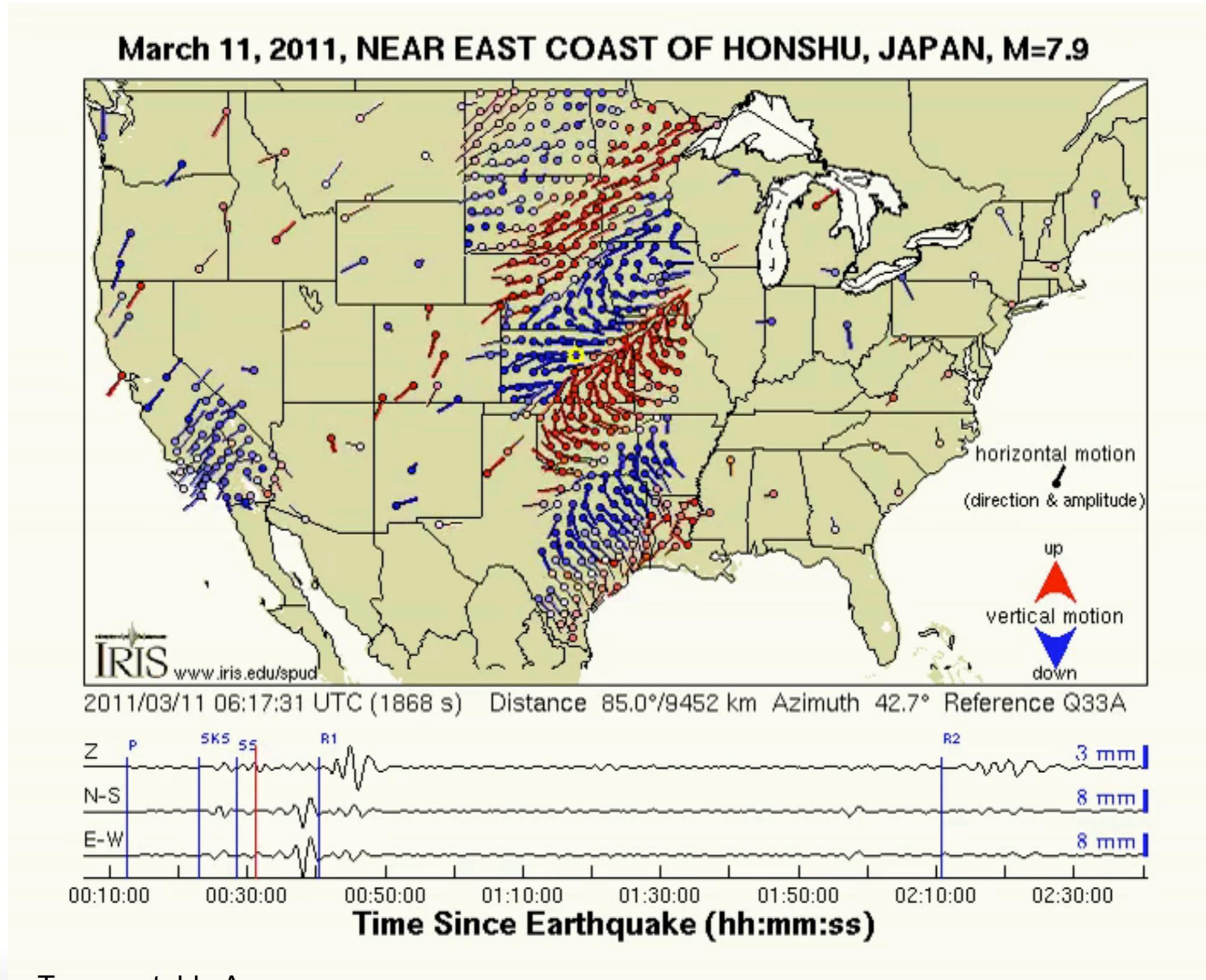


Meteorite impact, Chelyabinsk 2013

Surface waves generated by the Russia meteor explosion and recorded by the Global Seismic Network. The seismograms are band-pass-filtered between 10 to 100 s, and show clear Rayleigh waves recorded up to 2000 km



# Seismology in the 21<sup>th</sup> century: Seismic Arrays



USArray, Transportable Array  
Station spacing of ~70 km

Seismic waves



# **10 open questions in the Earth Sciences:**

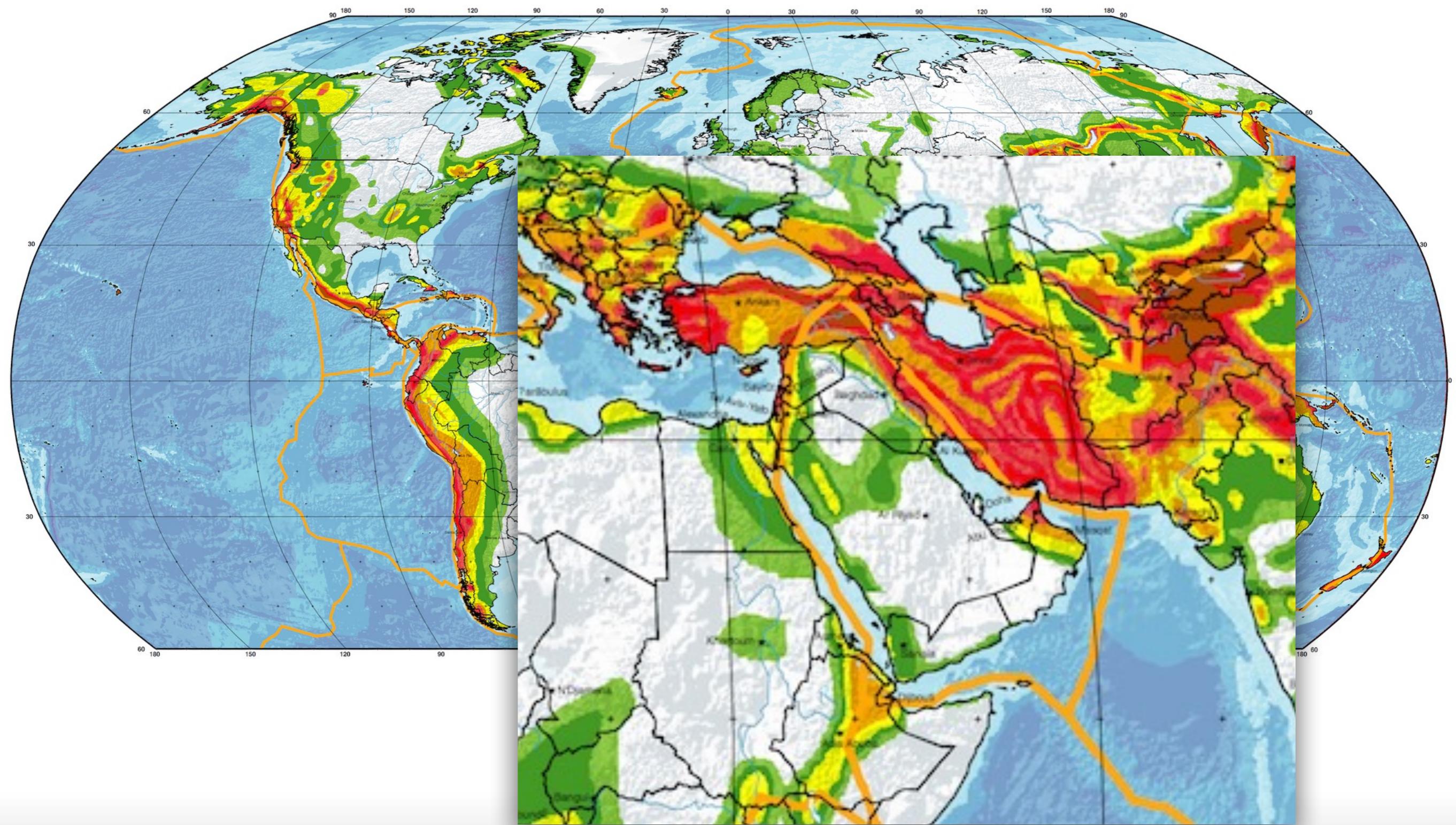
- 1. How did Earth and other planets form?**
2. What happened during Earth's "dark age" (the first 500 million years)?
3. How did life begin?
- 4. How does Earth's interior work, and how does it affect the surface?**
- 5. Why does Earth have plate tectonics and continents?**
- 6. How are Earth processes controlled by material properties?**
- 7. What causes climate to change -- and how much can it change?**
8. How has life shaped Earth -- and how has Earth shaped life?
- 9. Can earthquakes, volcanic eruptions, and their consequences be predicted?**
- 10. How do fluid flow and transport affect the human environment?**

[National Academies Report, 2008]

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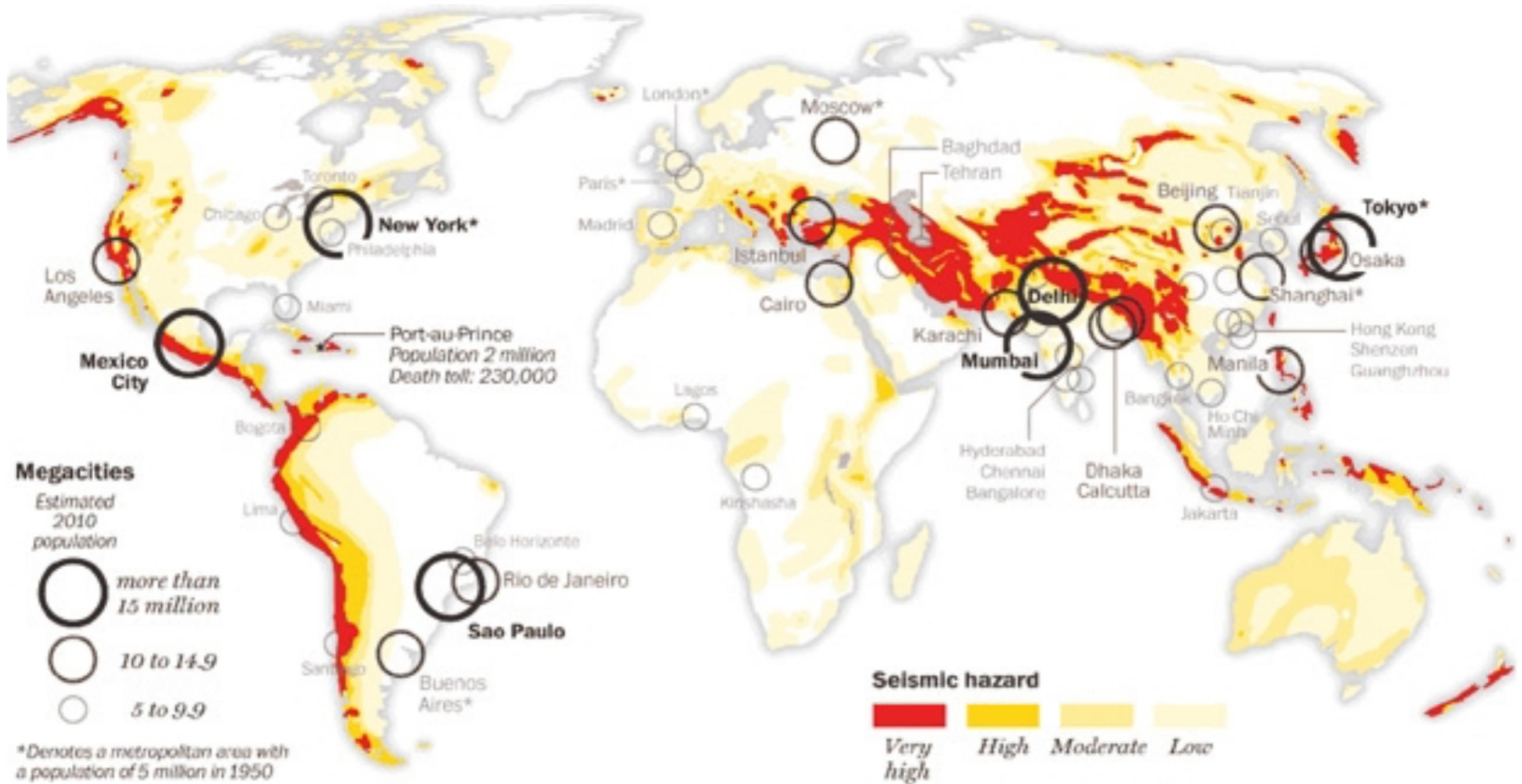
# *Global seismic hazard map*



Seismic waves



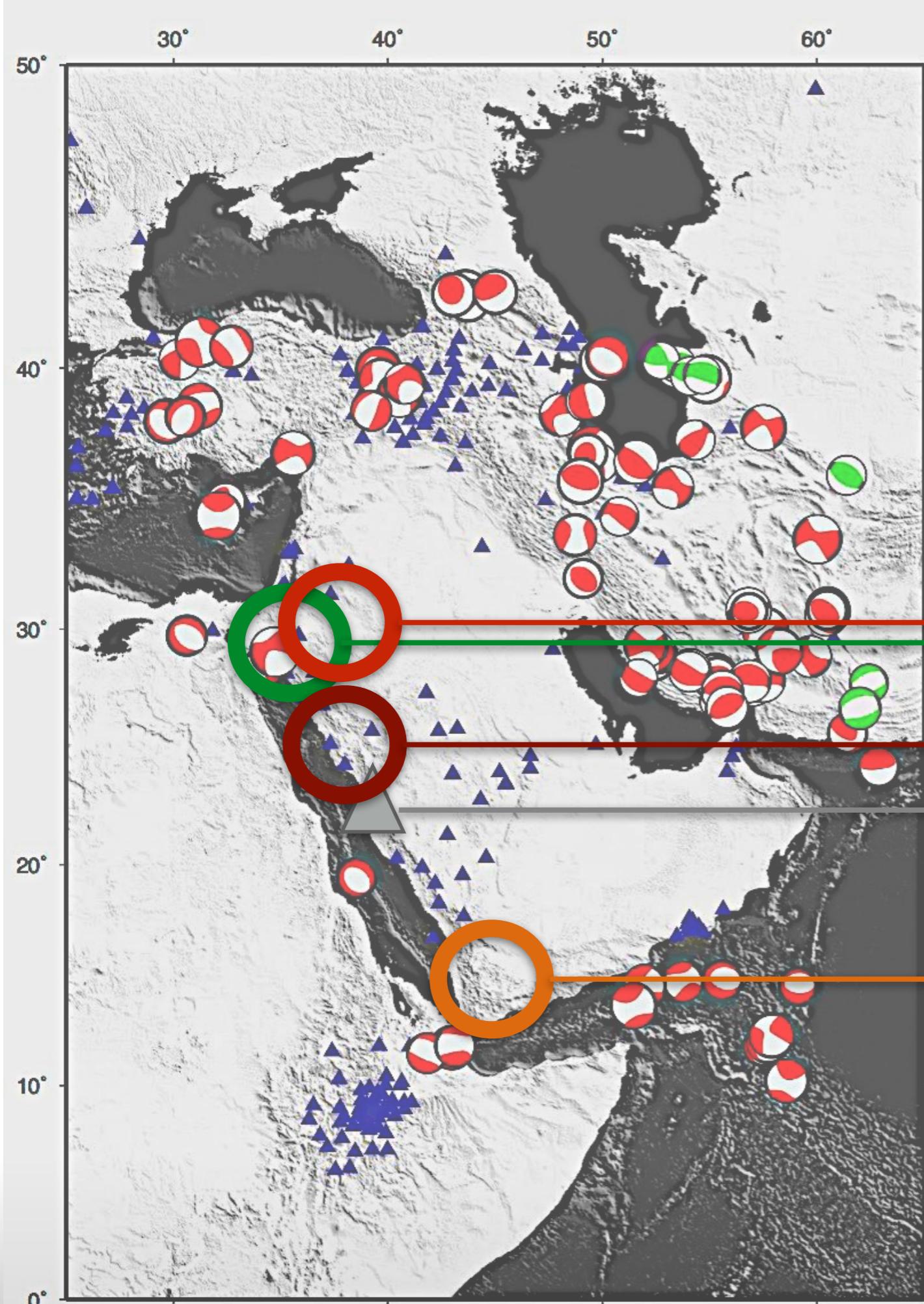
# *Seismic hazard on populations*



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# Arabian Peninsula earthquakes



- 1068, 1212, 1293, 1458,  
Dead Sea Transform Mw ~6.5-7.0
- 1995, Gulf of Aqaba Mw 7.3
- 2009, Harrat Lunayyir Mw 5.4
- KAUST
- 1982, North Yemen Mw ~6.2

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**... to be continued**

Seismic waves

