

# 1. Introduction to Seismology

M. Ravasi

ERSE 210 Seismology

# Course Objectives

- Learn fundamentals of Seismology, both Global and Exploration
- Familiarize with theory of wave propagation (basis for ErSE 326 and 390N)
- Recent developments in the field (last 20 years)

# Lectures

- Monday 3:00pm 4:30pm
- Wednesday 3:00pm 4:30pm
- Bldg. 9, Room 4137 (Theory) / Bldg. 9, Room 2220 (Labs)

**! Be on time: participation is recorded !**

# Teaching Staff

## Instructors:

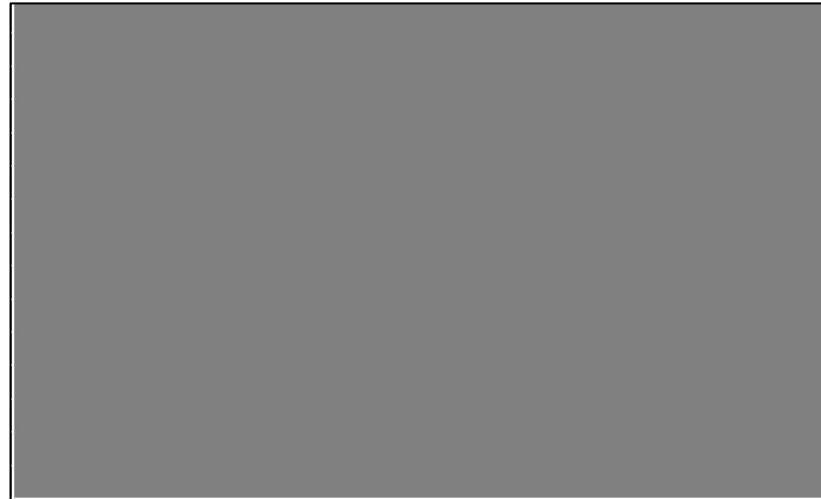
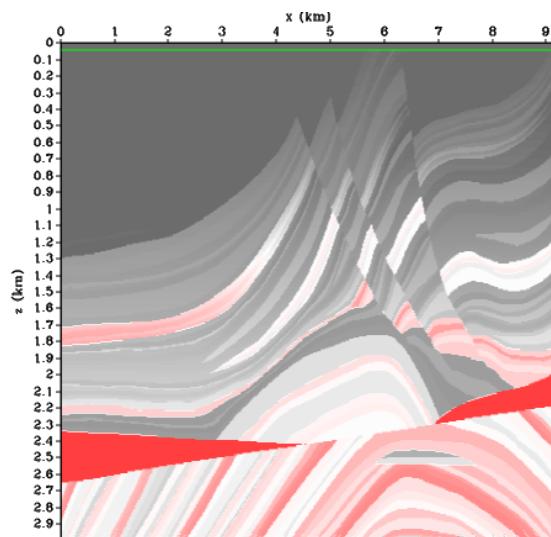
- [Matteo Ravasi](#) - Office Hours: Tuesday 4pm to 5pm  
(by Appointment: Zoom or Office - BI-1432)

# Textbook

- Shearer, P., Introduction to Seismology (**Main reference**)
- Aki, K., and Richards, P.G. ,Quantitative Seismology
- Avseth, P., Mukerji, T., and Mavko, G., Quantitative Seismic Interpretation
- Ikelle, L.T., and Amundsen, L., Introduction to Petroleum Seismology
- Yilmaz, O., Seismic Data Analysis

# What is Seismology?

“Field of study of **propagation of elastic waves**”



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“Field of study of **propagation of elastic waves**”

Earthquakes



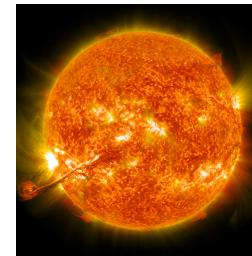
Volcanoes



Tsunamies

**GLOBAL**

Sun (helioseismology)



Stars (asteroseismology)

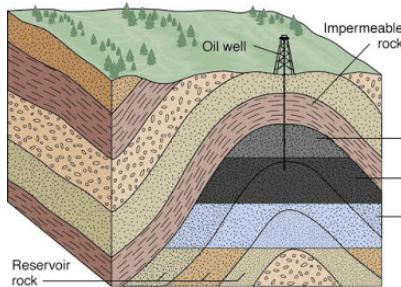


Planetary bodies  
(planetary seismology)

# What is Seismology?

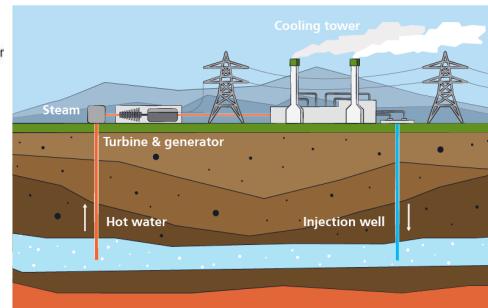
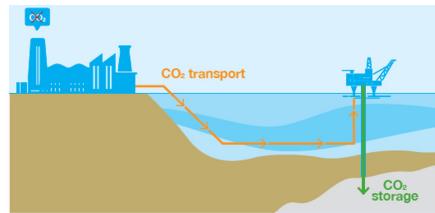
“Field of study of **propagation of elastic waves**”

Hydrocarbon prospection



**APPLIED**

CCS



Geothermal

Geotechnics

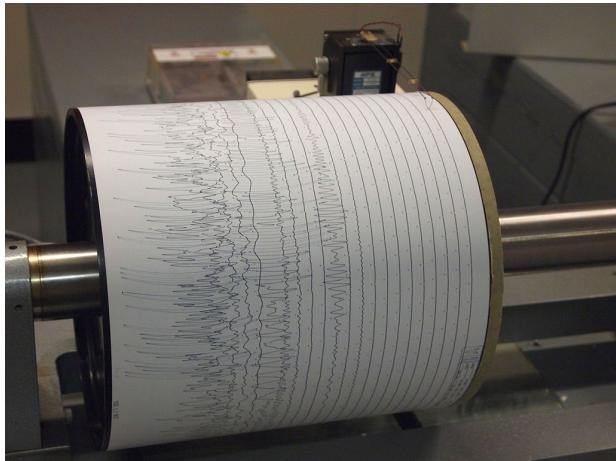


Nuclear Explosions

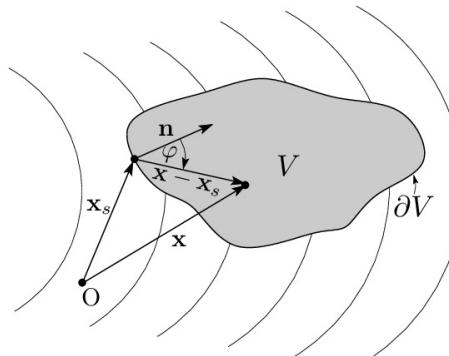
Transportation monitoring



# How do we learn about waves?



OBSERVATIONS



THEORY



EXPERIMENTS

# History of global seismology

Cauchy



Stokes

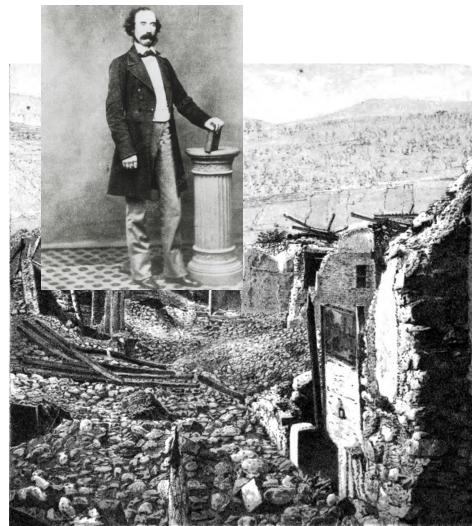


Rayleigh



1800s: early **theories** of elastic waves

Mallet



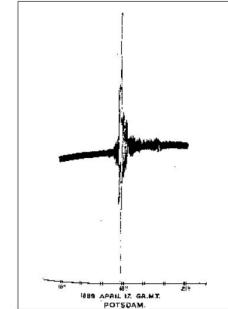
1857: Napoli earthquake – beginning of **observational seismology**

Cecchi



1875: First time-recording **seismograph**

This seismogram was recorded in Potsdam in 1889. The seismic waves were generated by an earthquake in Japan.



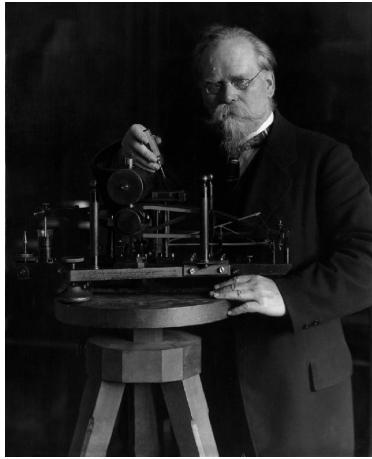
1889: First recorded **teleseism**

# History of global seismology

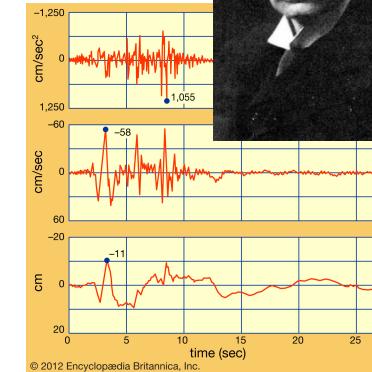


1897: First seismograph in US: will record S.Francisco earthquake in 1906

Wiechert

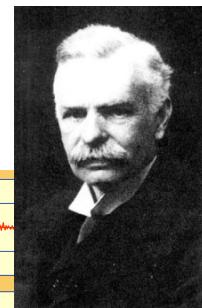


1898: First seismometer with viscous damping



1906: First P, S, and surface waves identified on seismogram

Oldham



Zoeppritz



Gutenberg



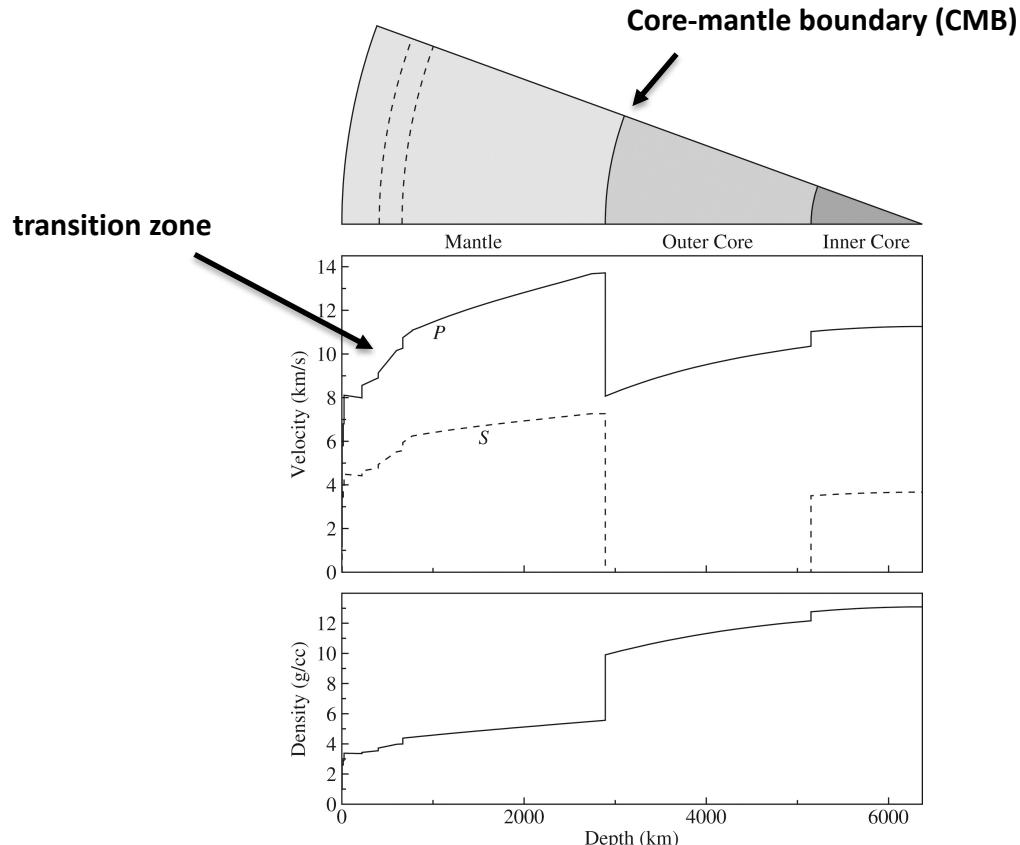
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TABLE 2  
CALCULATED TRAVEL TIMES

	1/P	PKP	PKP	S	PSS	PS	SSS	SSS
sec/deg.	deg.	sec.	deg.	sec.	deg.	sec.	deg.	sec.
0.000	180.000	1201.06	180.000	1116.09	180.000	1651.13		
2.310	146.345	1186.40	142.778	1393.77	1381.01	1600.94		
2.310	146.345	1186.40	142.778	1393.77	1381.01	1600.94		
2.383	146.688	1185.96	141.538	1391.56	1381.98	1598.96		
2.446	145.138	1185.73	141.031	1389.61	1383.98	1595.50		
2.510	147.610	1180.49	140.941	1387.05	1382.37	1592.20		
2.574	147.109	1181.14	139.470	1385.69	1381.83	1590.94		
2.638	146.657	1179.92	138.719	1383.74	1380.80	1587.55		
2.701	146.198	1178.74	137.987	1381.78	1379.70	1584.83		
2.765	145.761	1177.00	137.276	1379.83	1375.71	1582.07		
2.828	145.400	1176.54	136.568	1377.01	1372.77	1579.38		
2.892	145.063	1175.56	135.978	1374.50	1369.54	1578.45		
2.955	144.740	1174.08	135.274	1374.11	1368.80	1573.90		
3.018	144.466	1173.82	134.654	1372.27	1364.81	1570.72		
3.082	144.231	1173.10	134.059	1370.45	1368.86	1567.90		
3.145	144.040	1172.30	133.491	1368.68	132.942	1564.86		
3.208	143.894	1172.05	132.305	1366.97	132.009	1561.00		
3.271	143.765	1171.98	132.142	1366.77	131.870	1560.80		
3.334	143.757	1171.98	131.996	1363.74	131.176	1555.90		
3.397	143.765	1171.08	131.820	1362.25	131.275	1562.87		
3.460	143.841	1171.89	131.113	1369.85	118.365	1549.82		
3.523	143.985	1172.38	130.746	1359.56	117.807	1546.74		
3.586	144.205	1173.17	130.422	1358.41	116.638	1543.66		
3.649	144.456	1173.96	130.148	1357.25	115.566	1541.66		
3.711	144.913	1175.78	129.924	1356.59	114.994	1537.42		

1900-1950: Traveltime tables of earthquake arrivals

# Earth interior



**Crust:** ~6km to 30-50 km thickness

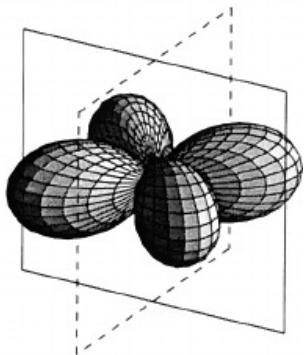
## Interior:

- Mantle: solid outer shell (84% volume) with rapid velocity increase at the start (transition zone) and then gradually up until CMB
- Inner core: drastic drop in velocities at CMB due to solid-to-fluid transition ( $VS \rightarrow 0$ )
- Outer core: slow velocity increase
- Inner core: solid, small increase in P-wave velocities and non-zero S-wave velocities

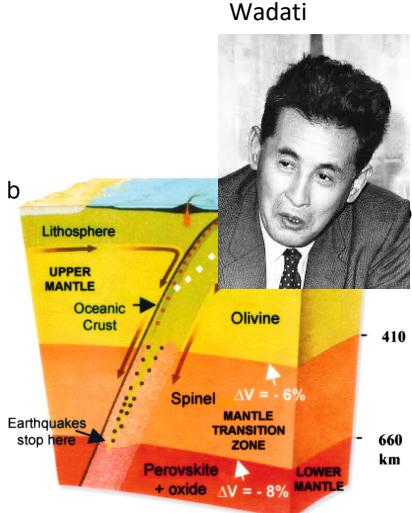
Density is less understood as traveltimes do not provide direct constraints.

# History of global seismology

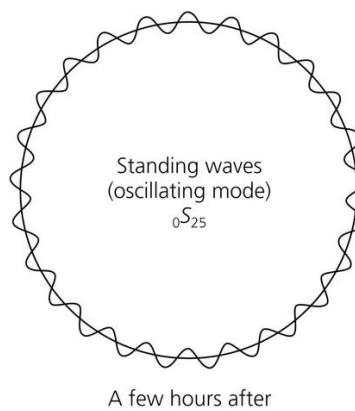
Nakano



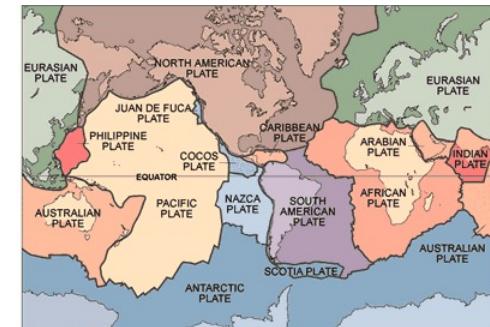
1923: Theory of **double couple source** (i.e., how earthquake originates)



1928+: Evidence of **deep earthquakes** (>100km)

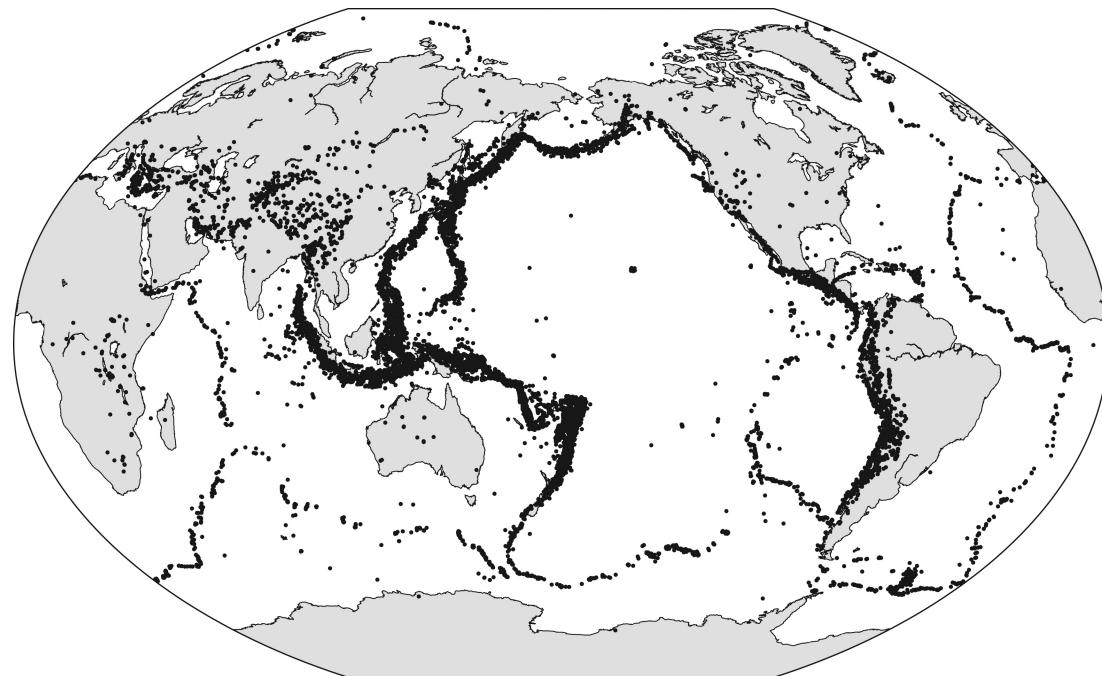


1960: Discovery of **Normal modes** from Chile earthquake

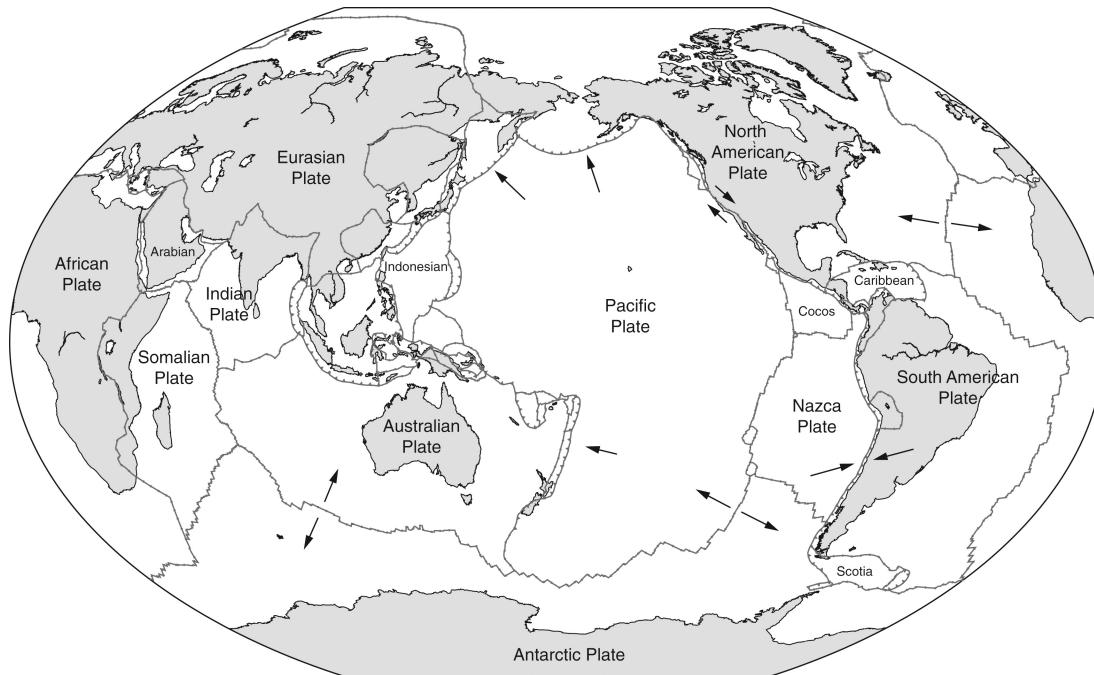


1960: Theory of **plate tectonics**

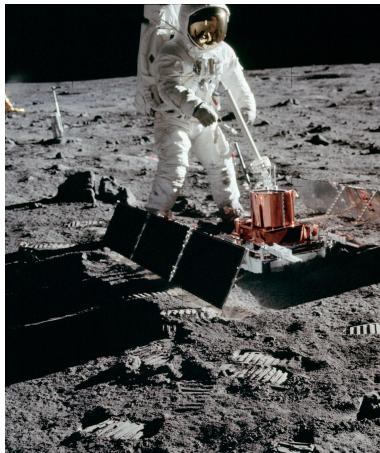
# Seismology role in plate tectonics theories



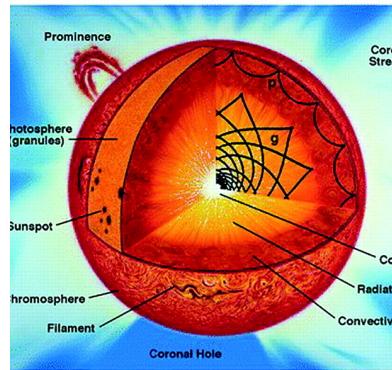
# Seismology role in plate tectonics theories



# History of global seismology



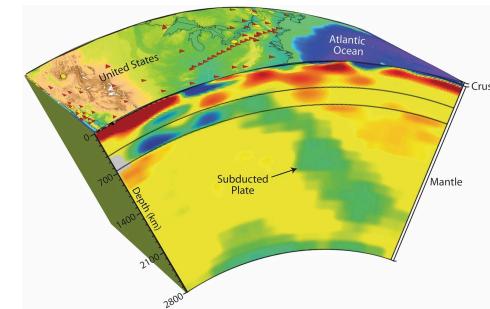
1961: Seismometers  
on **Moon**



1960/70: **Helioseismology**  
(Doppler shift similar to  
normal mode theories)

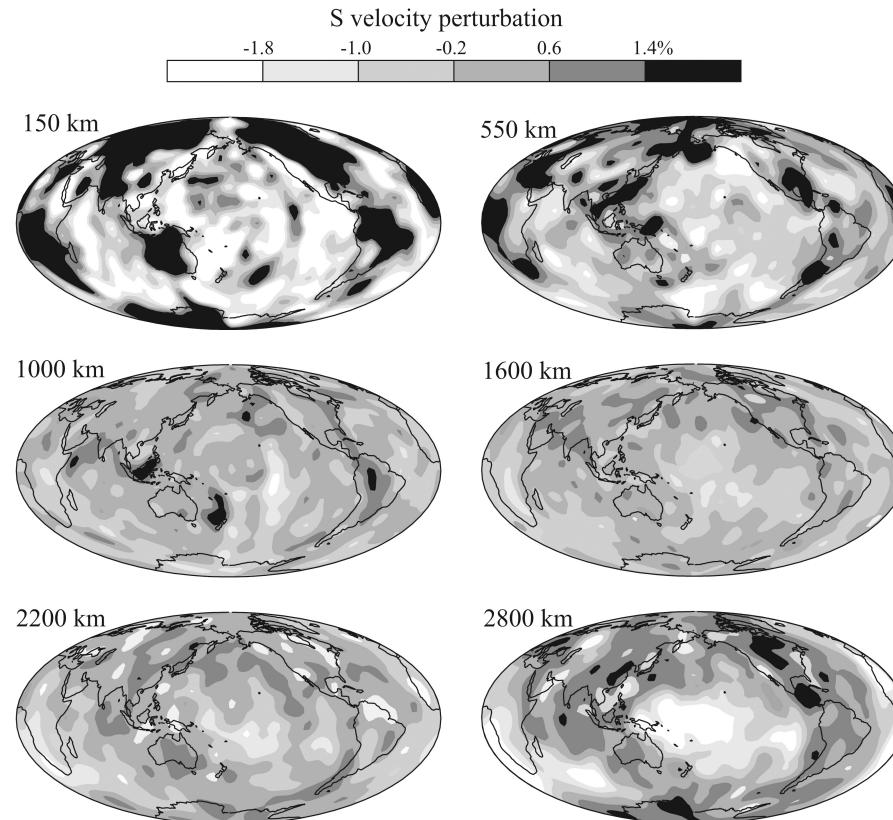


1970: Advent of  
**computers**, better  
modelling and storage  
solution

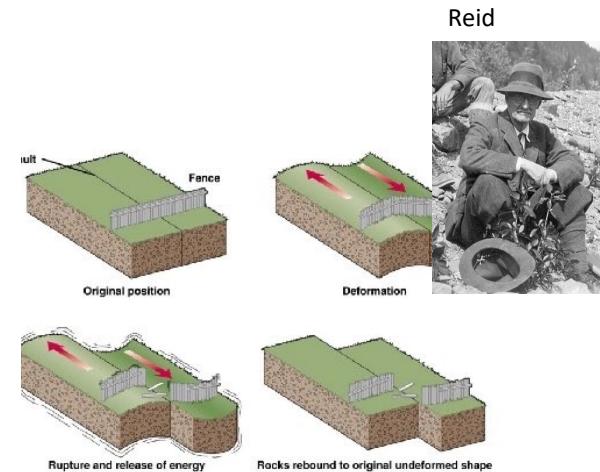


1970/80: Early  
successes in **seismic  
tomography**

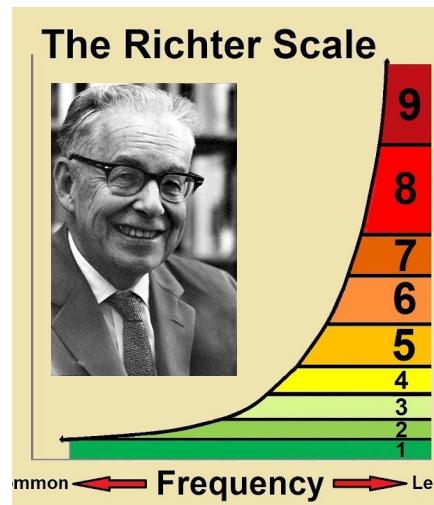
# Tomographic images of the Earth



# History of earthquake physics



1906: Elastic  
rebound theory



1935: Richter scale



$$M_0 = \frac{1}{\sqrt{2}} (M_{ij}^2)^{1/2}$$

1966: Seismic moment  
and moment magnitude

# History of applied seismology

Mintrop



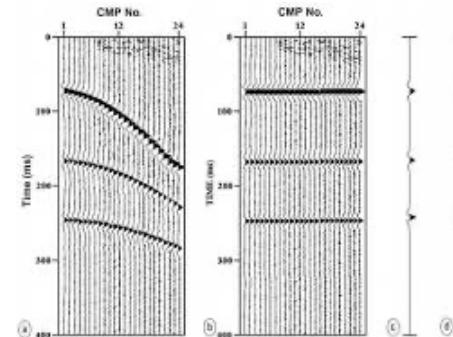
Fessender



1914 and 1917:  
**Refraction and reflection seismology**  
was first conceived  
(and patented)



1920/30: First oil discoveries in US and Mexico using seismic methods

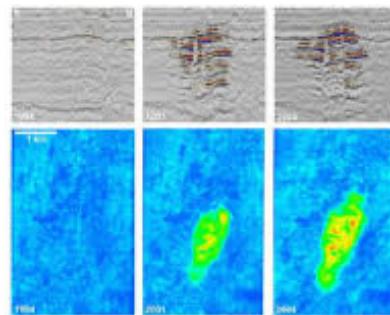
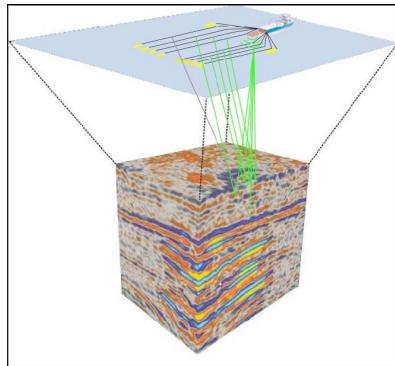


1956: **CMP stacking** was invented and patented



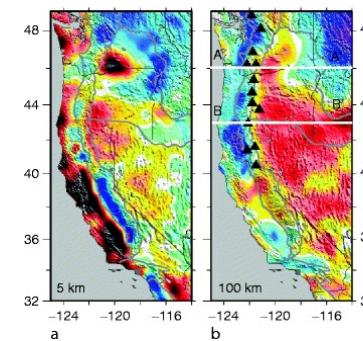
1950s: **Vibroseis** were introduced to replace explosive sources

# History of applied seismology

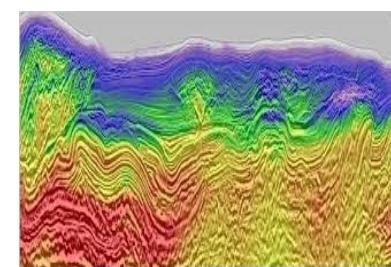


1970s: **3D** seismic was first introduced

1980: **4D** seismic was first introduced



2000': **Ambient noise** is first shown to carry information about subsurface properties



2000'2010': **Full-waveform-inversion (FWI)** takes off