1. Introduction to Seismology

M. Ravasi

ERSE 210 Seismology

Course Objectives

- Learn fundaments 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

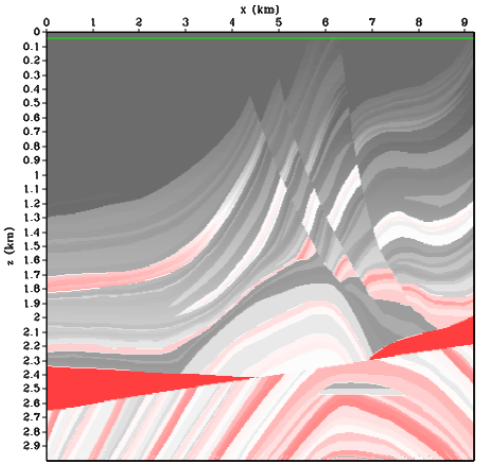
Course material

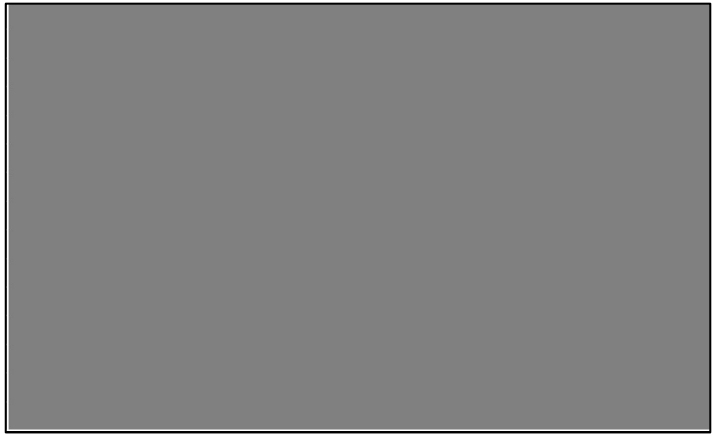
- Slides and Laboratory exercises can be accessed from:

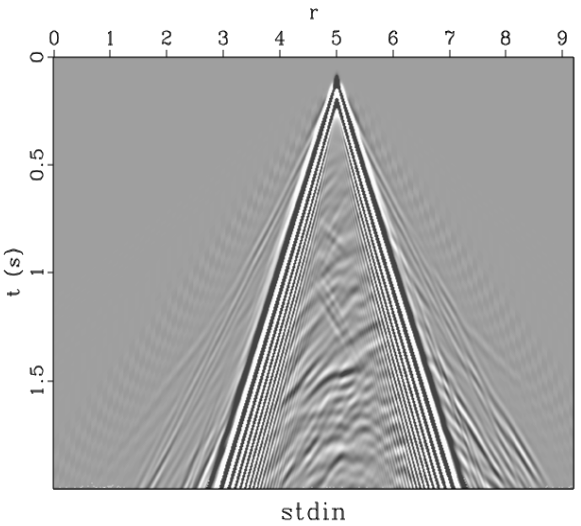
http://github.com/dig-kaust/seismology

What is Seismology?

"Field of study of **propagation of elastic waves**"







What is Seismology?

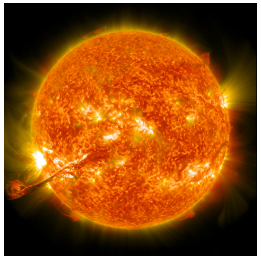
"Field of study of **propagation of elastic waves**"

Earthquakes

Volcanoes

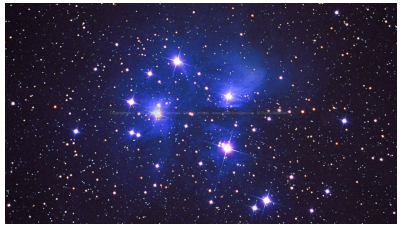
Tsunamies

Sun (helioseismology)



Planetary bodies
(planetary seismology)

Stars (asteroseismology)

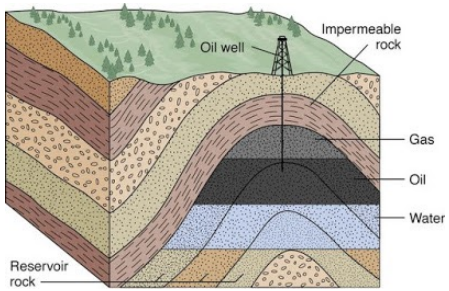


GLOBAL

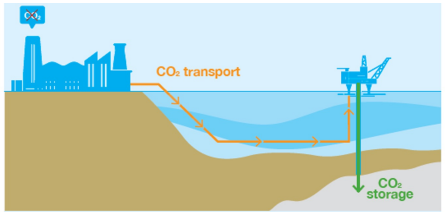
What is Seismology?

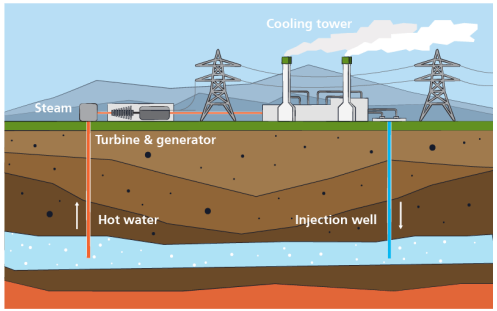
"Field of study of **propagation of elastic waves**"

Hydrocarbon prospection



CCS





Geothermal

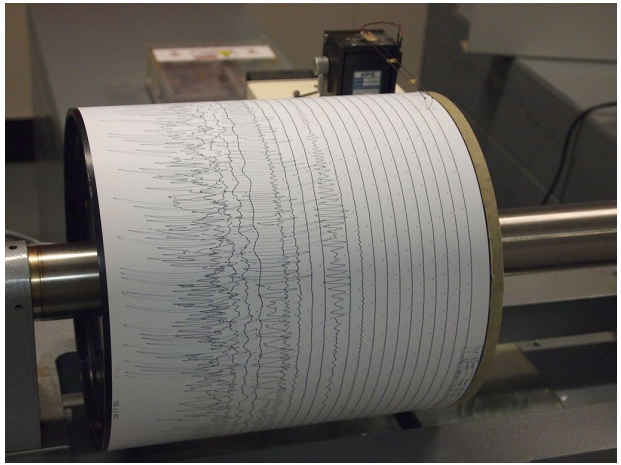
Geotechnics

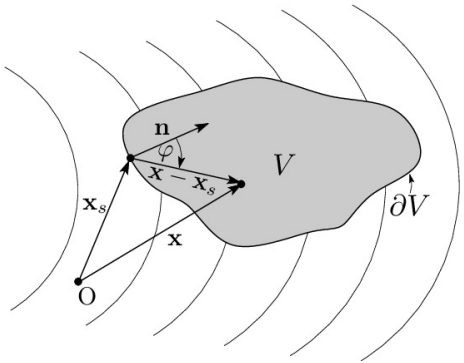
Nuclear Explosions

Transportation monitoring

APPLIED

How do we learn about waves?

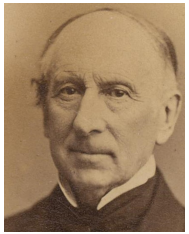




OBSERVATIONS **THEORY** **EXPERIMENTS**

History of global seismology

Cauchy

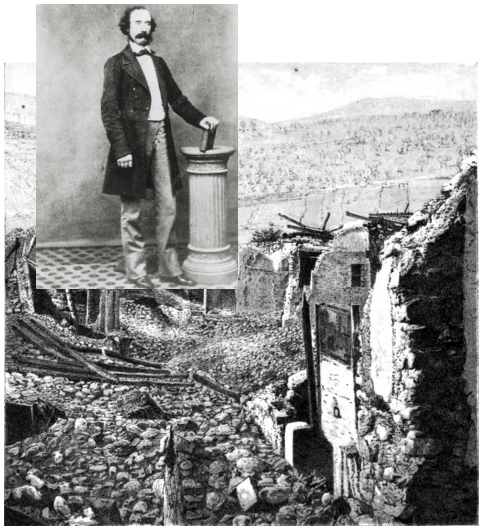


Stokes

Rayleigh

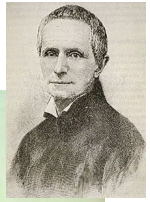
1800s: early **theories** of elastic waves

Mallet



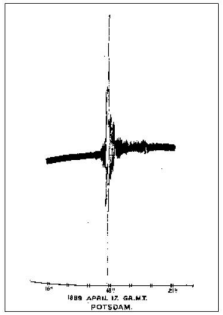
1857: Napoli earthquake – beginning of **observational seismology**

Cecchi



1875: First time-recording **seismograph**

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

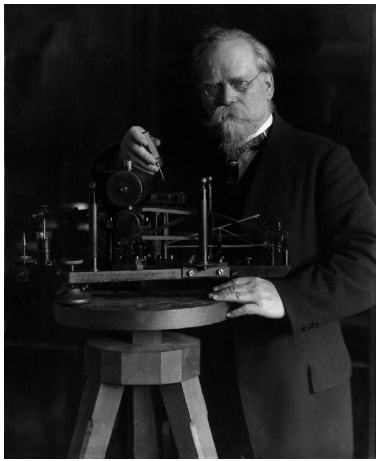


1889: First recorded **teleseism**

History of global seismology

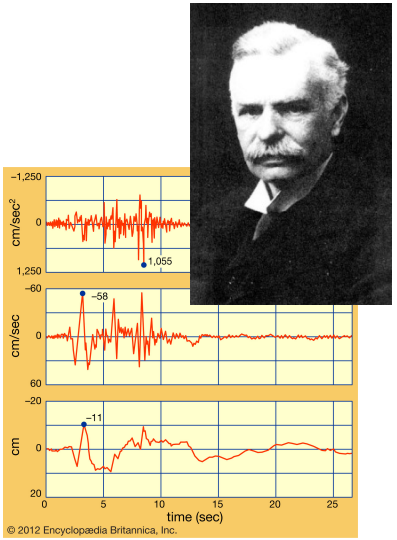
1897: First seismograph in **US**: will record S.Francisco earthquake in 1906

Wiechert



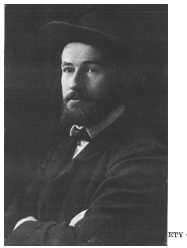
1898: Fist **seismometer** with viscous damping

Oldham



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

Zoeppritz



Gutenberg

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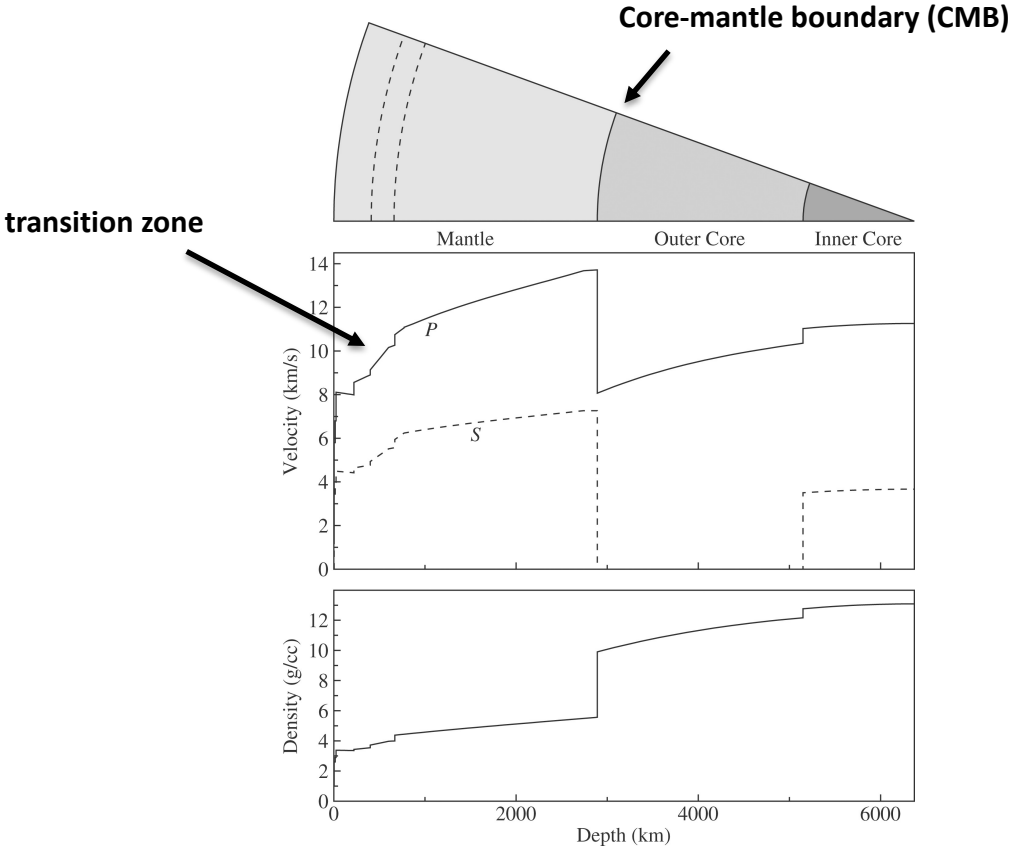
TABLE 2
CALCULATED TRAVEL TIMES

1/V	Δ PKP	t PKP	Δ PKS	t PKS	Δ SKS	t SKS
sec/deg.	deg.	sec.	deg.	sec.	deg.	sec.
0.000	180.000	1201.06	180.000	1416.09	180.000	1631.13
2.310	149.345	1186.60	142.776	1393.77	136.207	1600.94
2.319	149.264	1186.61	142.663	1393.50	136.061	1600.58
2.383	148.688	1185.06	141.838	1391.56	134.988	1598.06
2.446	148.136	1183.73	141.031	1389.61	133.926	1595.50
2.510	147.610	1182.42	140.241	1387.66	132.873	1592.89
2.574	147.109	1181.14	139.470	1385.69	131.831	1590.24
2.638	146.637	1179.92	138.719	1383.74	130.801	1587.55
2.701	146.193	1178.74	137.987	1381.78	129.780	1584.83
2.765	145.781	1177.60	137.276	1379.83	128.771	1582.07
2.828	145.400	1176.54	136.586	1377.91	127.772	1579.28
2.892	145.052	1175.55	135.918	1376.00	126.784	1576.45
2.955	144.740	1174.63	135.274	1374.11	125.808	1573.60
3.018	144.466	1173.82	134.654	1372.27	124.841	1570.72
3.082	144.231	1173.10	134.059	1370.45	123.886	1567.80
3.145	144.040	1172.50	133.491	1368.68	122.942	1564.86
3.208	143.894	1172.05	132.951	1366.97	122.009	1561.90
3.271	143.797	1171.72	132.442	1365.31	121.087	1558.90
3.334	143.757	1171.58	131.966	1363.74	120.176	1555.90
3.397	143.765	1171.63	131.520	1362.25	119.275	1552.87
3.460	143.841	1171.89	131.113	1360.85	118.385	1549.82
3.523	143.985	1172.38	130.746	1359.56	117.507	1546.74
3.586	144.205	1173.17	130.422	1358.41	116.638	1543.66
3.649	144.510	1174.38	130.146	1357.42	115.781	1540.56
3.711	144.913	1175.76	129.924	1356.59	114.934	1537.42

1900-1950: **Traveltime tables** of earthquake arrivals

Earth interior



Crust: ~6km to 30-50 km thickness

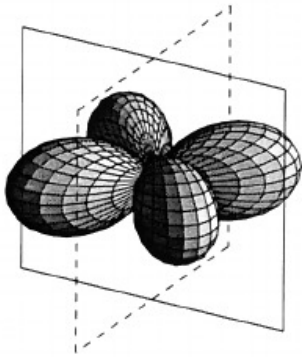
Interior:

- Mantle: solid outer shell (84% volume) with rapid velocity increase at the start (transition zone) and then gradually up until CMB
- Outer core: drastic drop in velocities at CMB due to solid-to-fluid transition (VS→0), followed by 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.

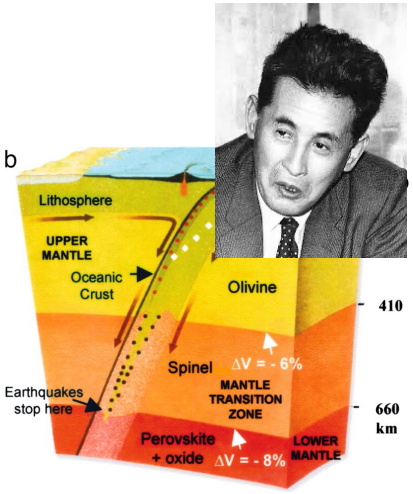
History of global seismology

Nakano

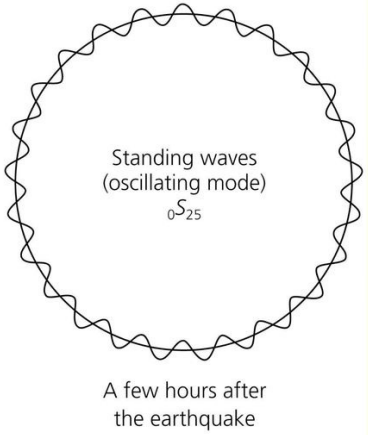


1923: Theory of **double couple source** (i.e., how earthquake originates)

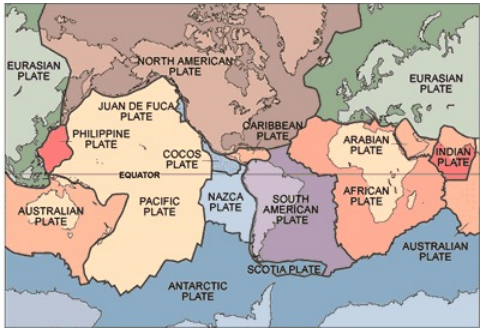
Wadati



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

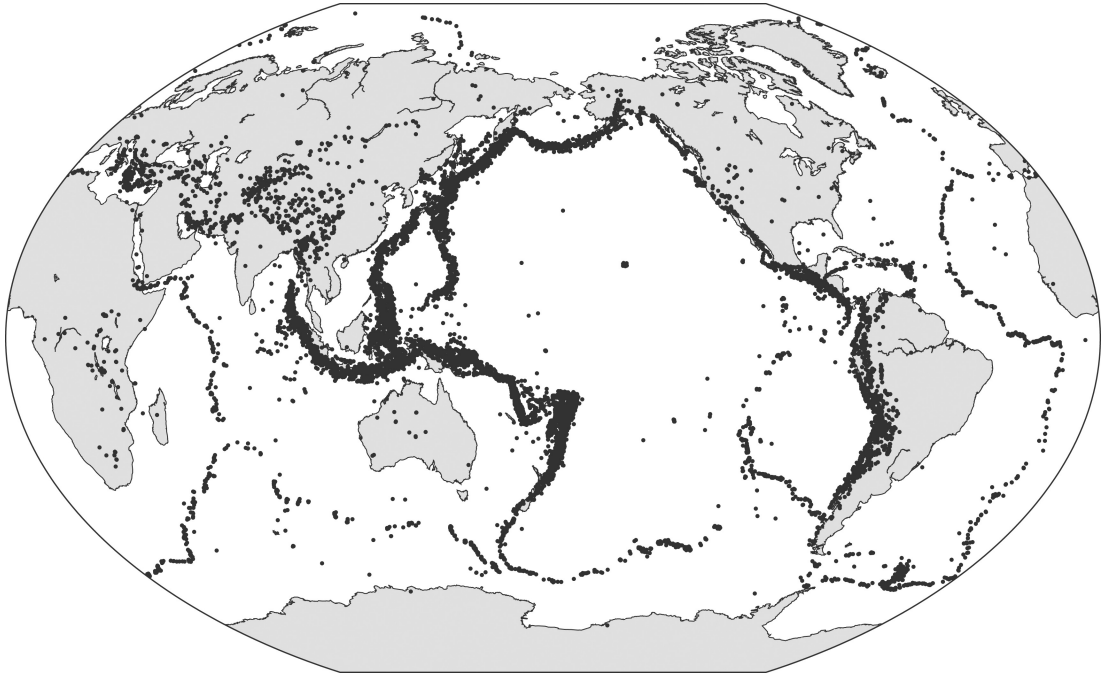


1960: Discovery of **Normal modes** from Chile earthquake

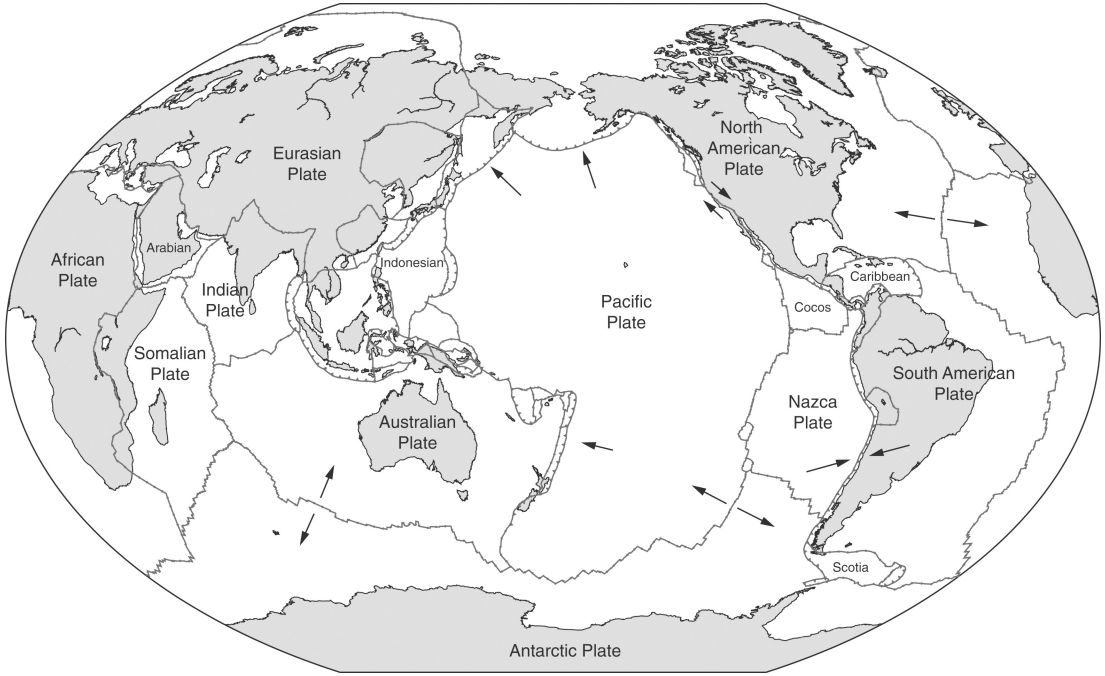


1960: Theory of **plate tectonics**

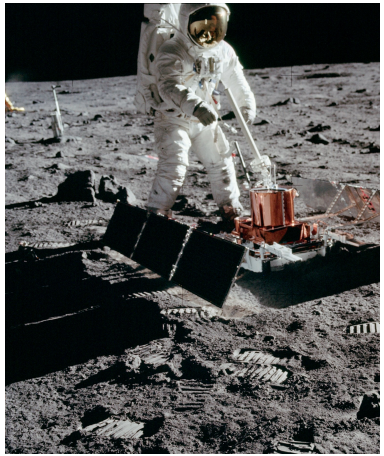
Seismology role in plate tectonics theories



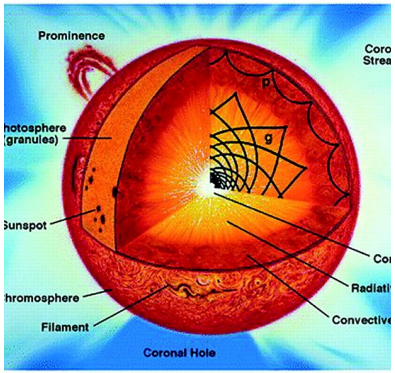
Seismology role in plate tectonics theories



History of global seismology

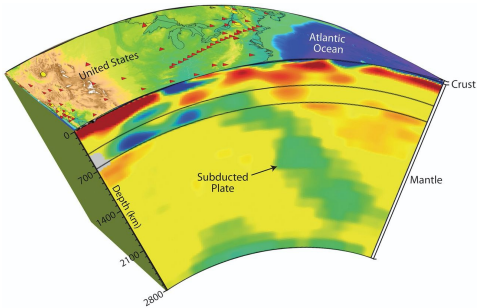


1961: Seismometers on **Moon**



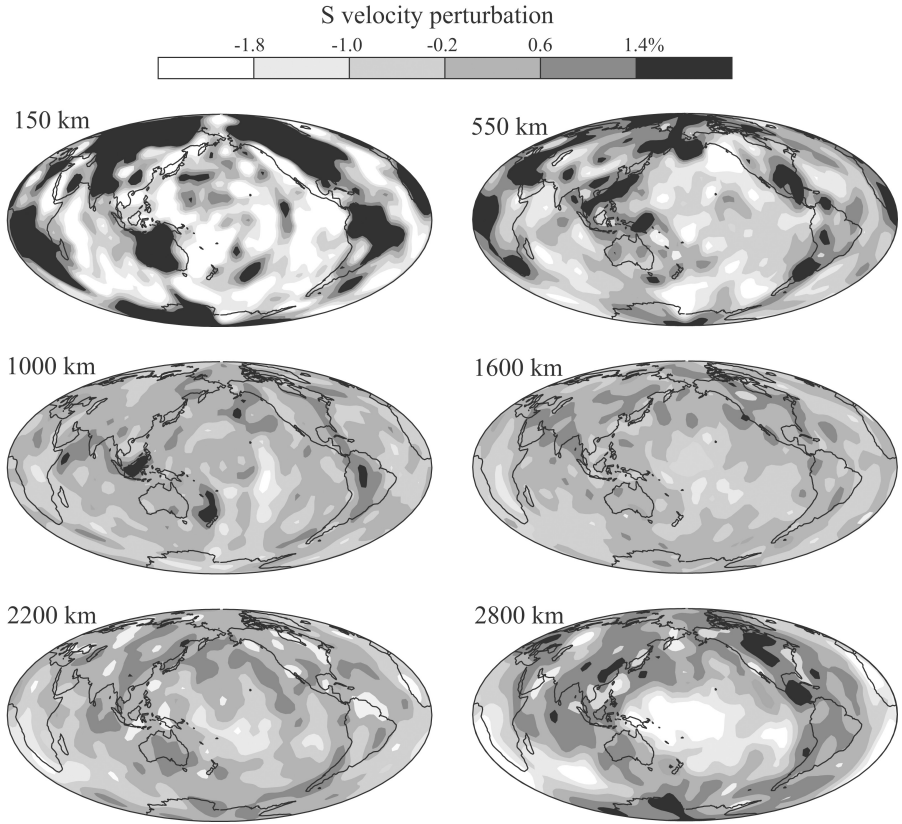
1960/70: **Helioseismology** (Doppler shift similar to normal mode theories)

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



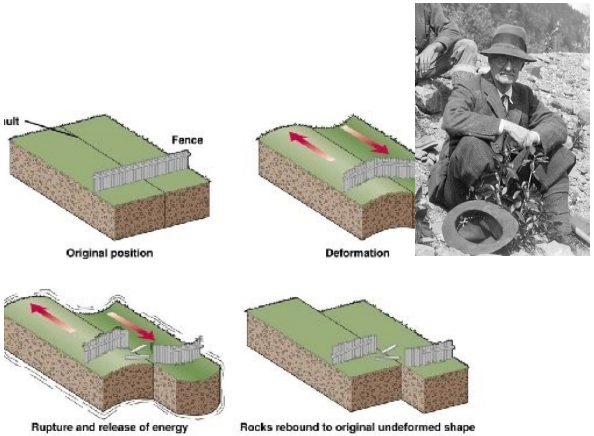
1970/80: Early successes in **seismic tomography**

Tomographic images of the Earth

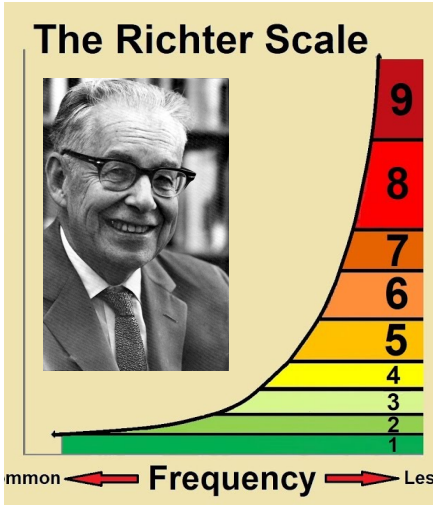


History of earthquake physics

Reid



1906: **Elastic rebound theory**



1935: **Richter scale**

Aki

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

1966: **Seismic moment** and moment magnitude

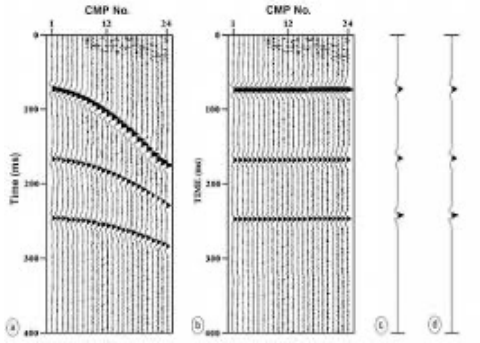
History of applied seismology

Mintrop

Fessender

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

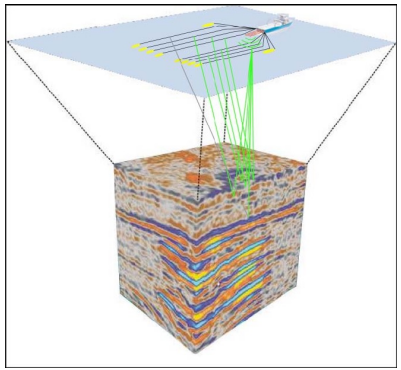
1920/30: First **oil discoveries** in US and Mexico using seismic methods



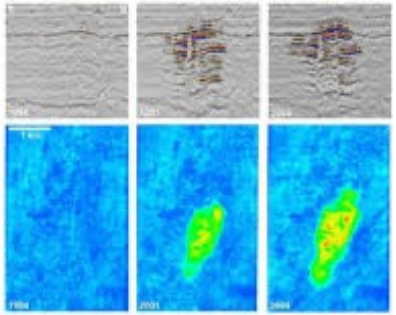
1956: **CMP stacking** was invented and patented

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

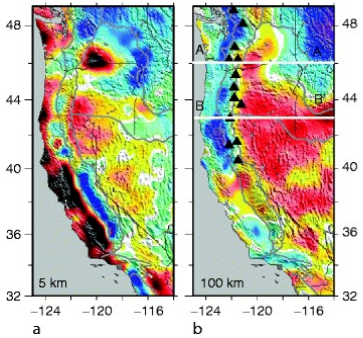
History of applied seismology



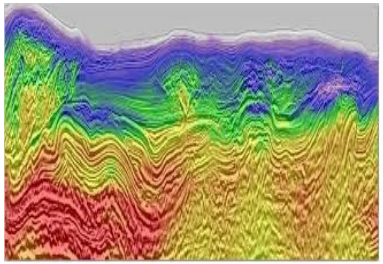
1970s: **3D** seismic was first introduced



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



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



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