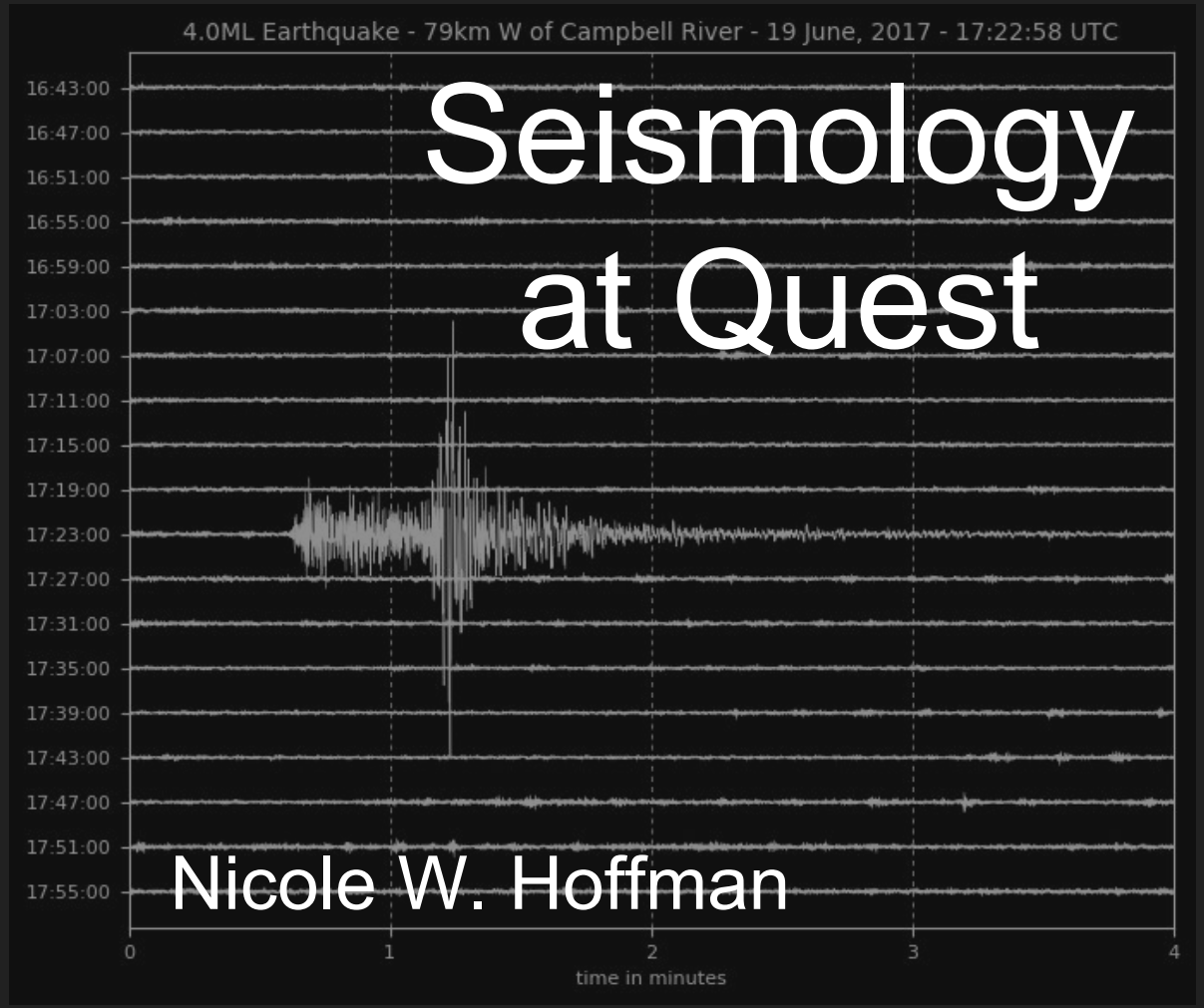
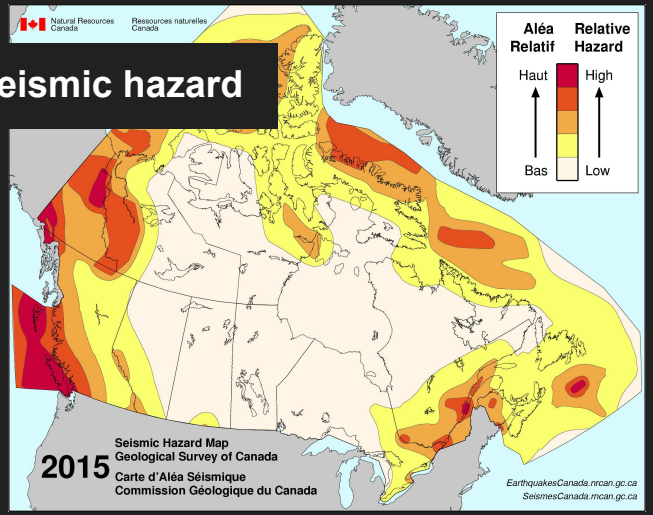
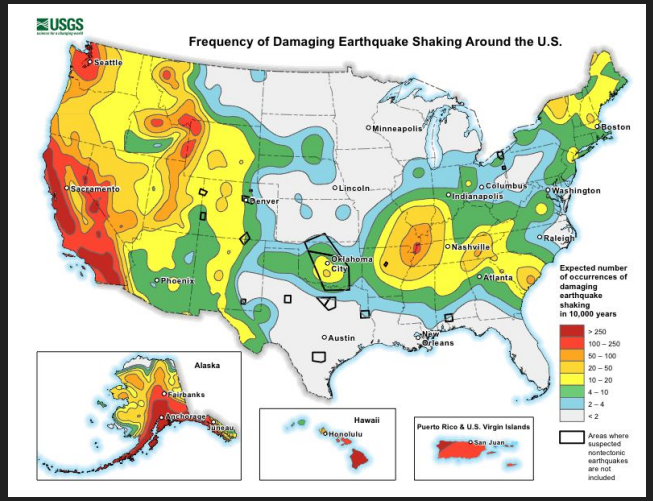


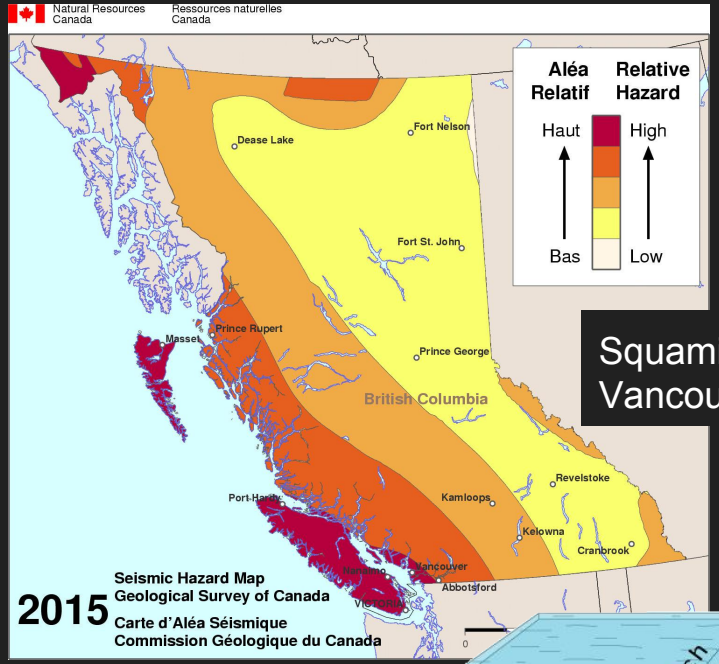
Seismology at Quest

Nicole W. Hoffman

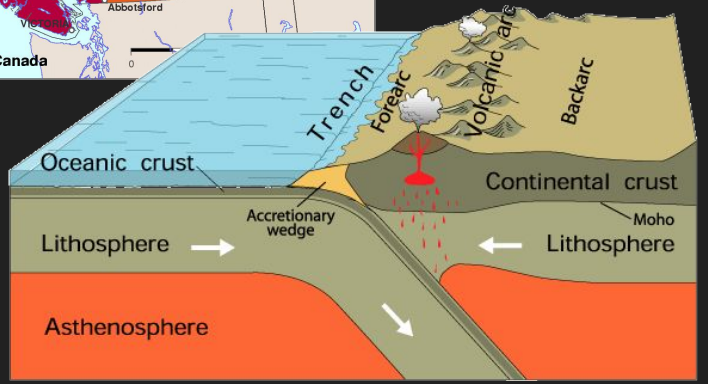
Seismic hazard







Squamish - orange (high)
Vancouver - red (highest)



A figure showing the oceanic plate sliding beneath the continental plate. Credit: USGS

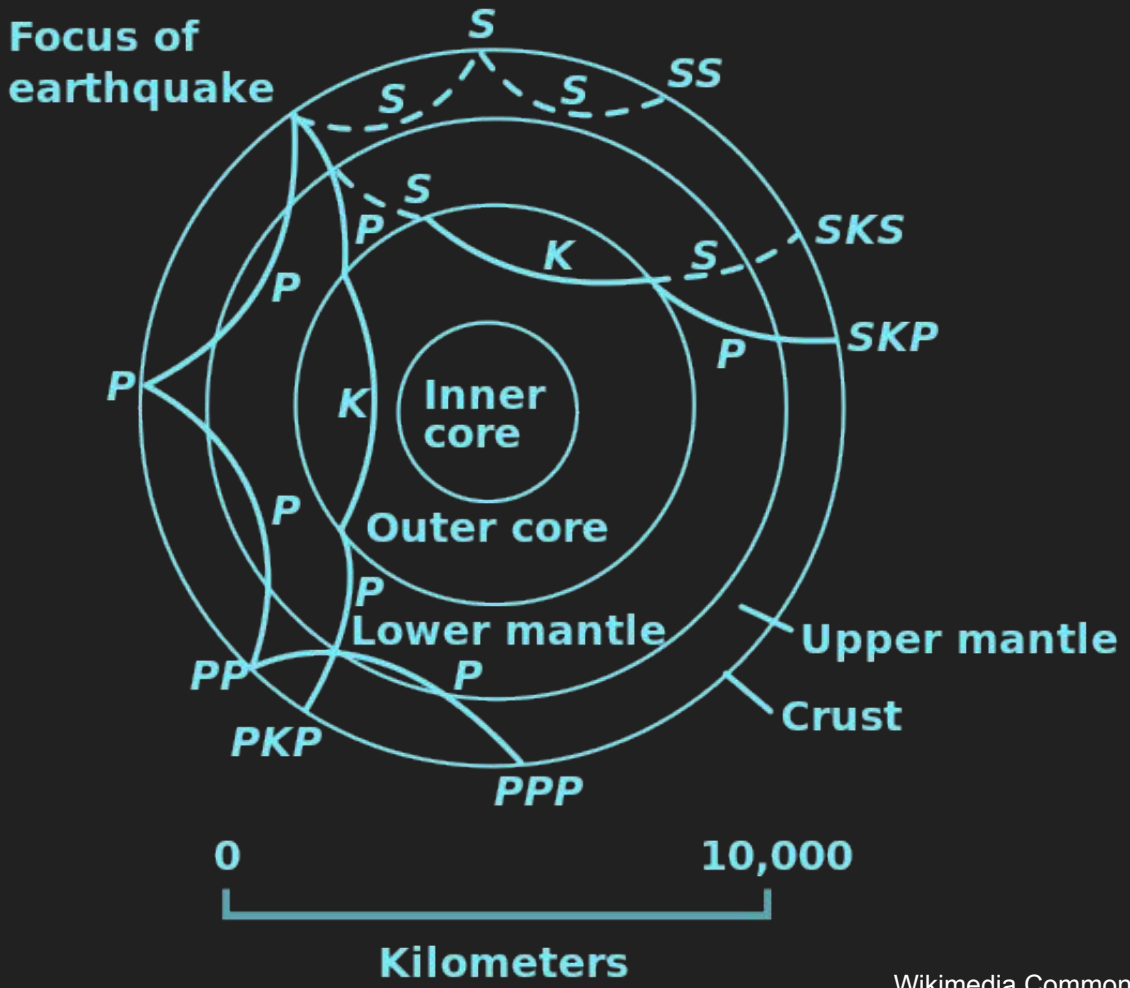
Seismology

seismos

Greek for shaking, shock, earthquake

Modern definition:

The study of how elastic waves move through the Earth (or other planets & moons)



Wikimedia Commons

Seismic sources

Earthquakes

Volcanoes

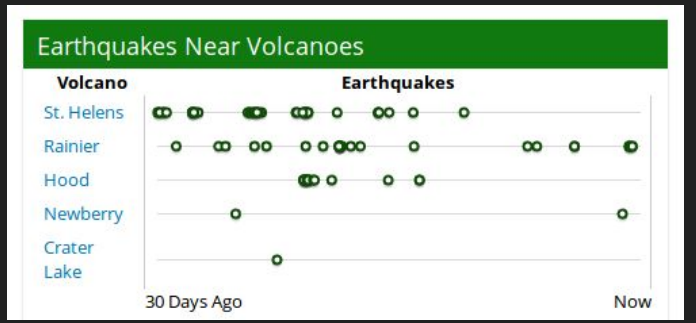
Landslides & rockfalls

Explosions

- nuclear tests
- mining
- excavation
- demolition


Nisqually earthquake damage


Mount Rainier



Credit: PNSN


Nevada Test Site

Photo courtesy of National Nuclear Security Administration / Nevada Site Office

A wave is a disturbance that carries energy through a medium.

Mechanical waves - require a medium (ground, water, air)

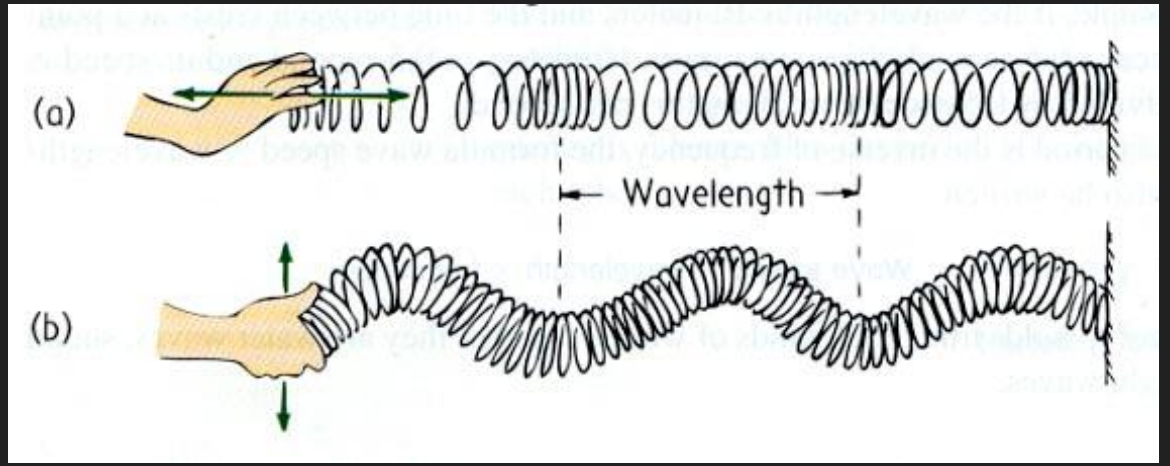
Electromagnetic waves - can travel through a vacuum

Longitudinal wave
(compressional wave)

- Particle motion in the same direction as wave motion

Transverse wave

- Particle motion orthogonal to direction of wave motion

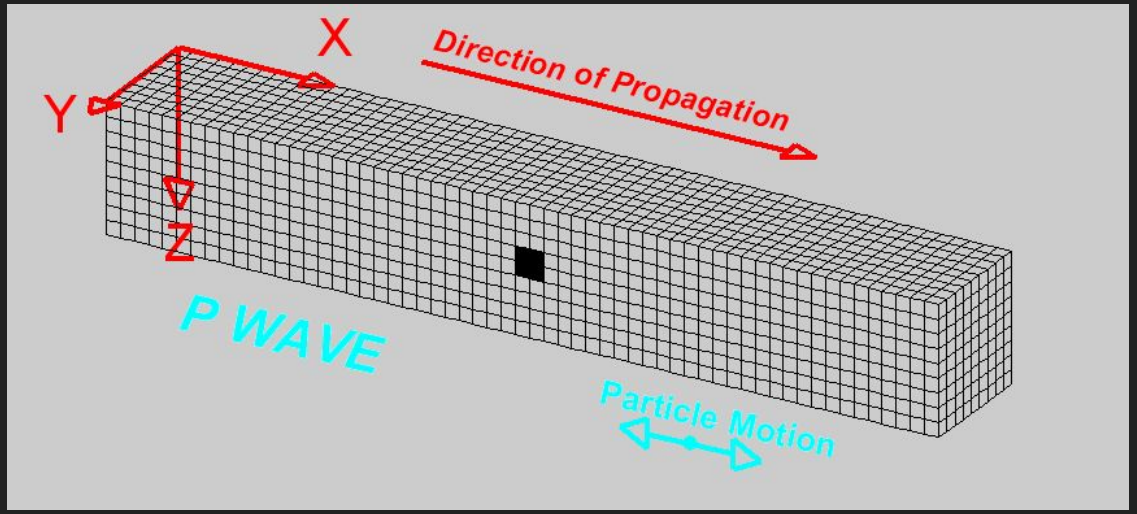


"Slinky waves". Via SEG Wiki - http://wiki.seg.org/wiki/File:Slinky_waves.jpg#/media/File:Slinky_waves.jpg

Body Waves

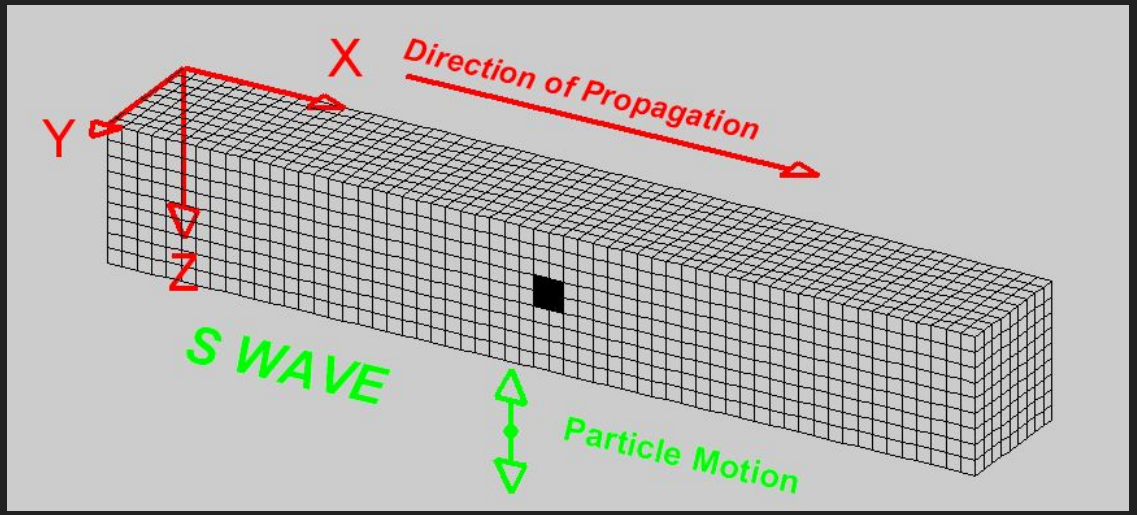
P waves

- primary waves
- greatest velocity
  →arrive first
- longitudinal wave
- “push - pull” motion

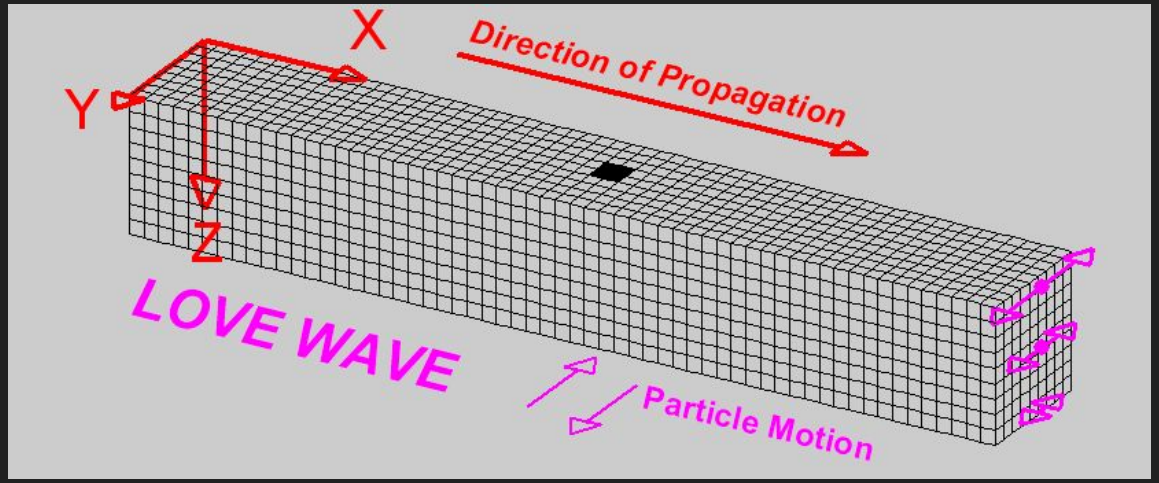


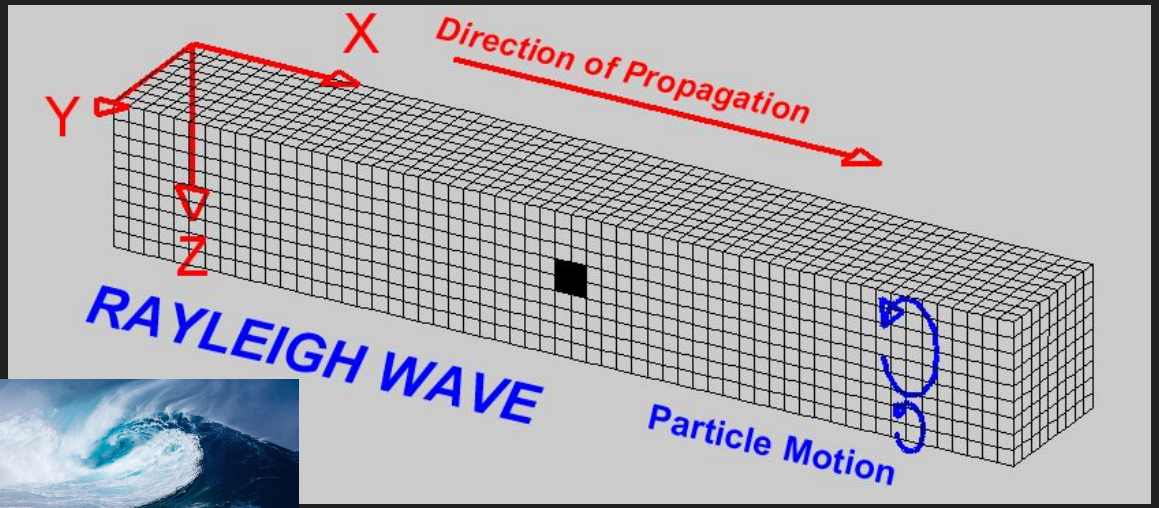
S waves

- secondary waves
- slower than P waves
  →arrive second
- transverse wave
- shearing motion



http://www.geo.mtu.edu/UPSeis/waves.html





http://www.geo.mtu.edu/UPSeis/waves.html

Love waves

- Fastest surface waves
- shaking motion

Surface waves

- Generally the strongest arrivals (amplitude of the trace)
- Travel more slowly than body waves
- Amplitude decay ~ $1/d^{1/2}$ (body waves decay ~ $1/d$)

Rayleigh waves

- Slower than Love waves
- Ground roll

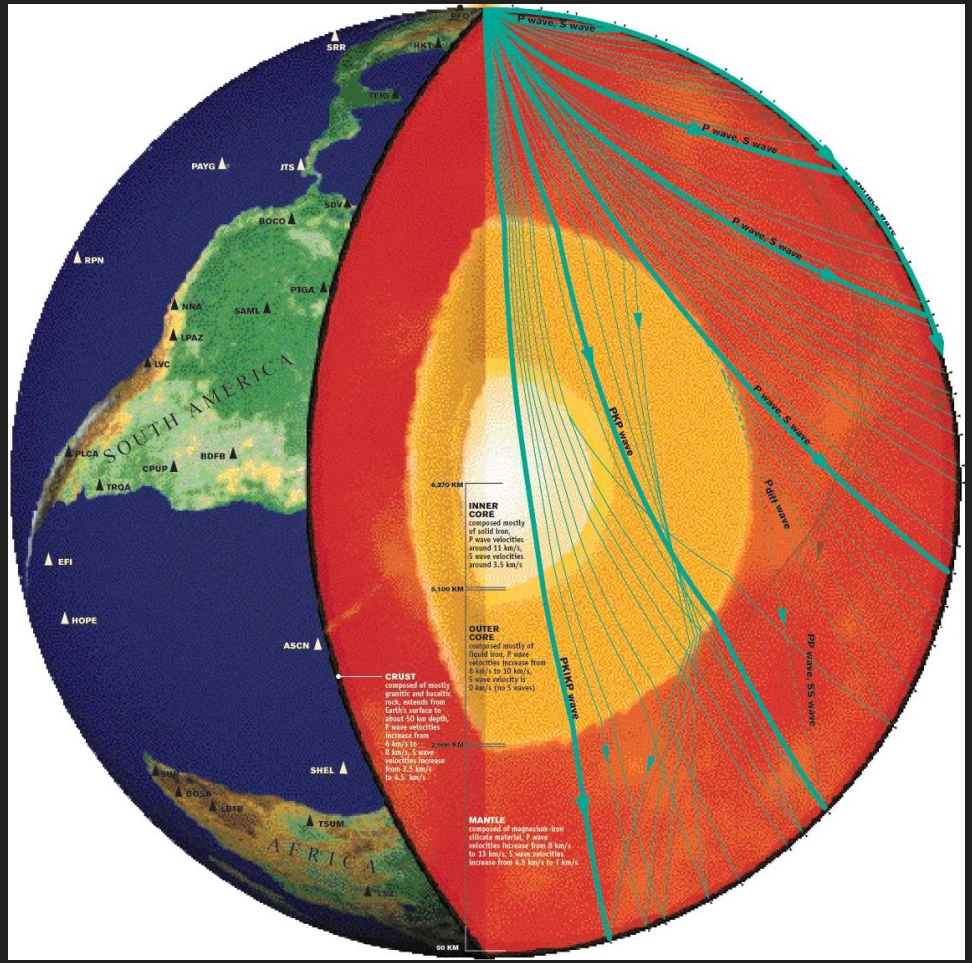
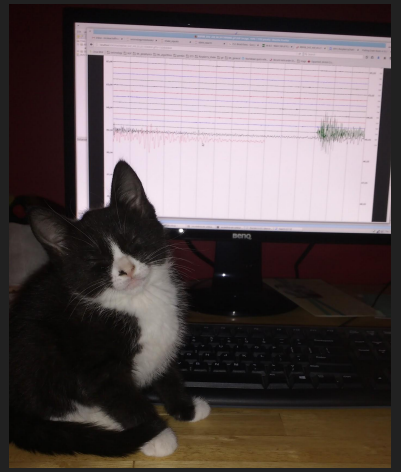


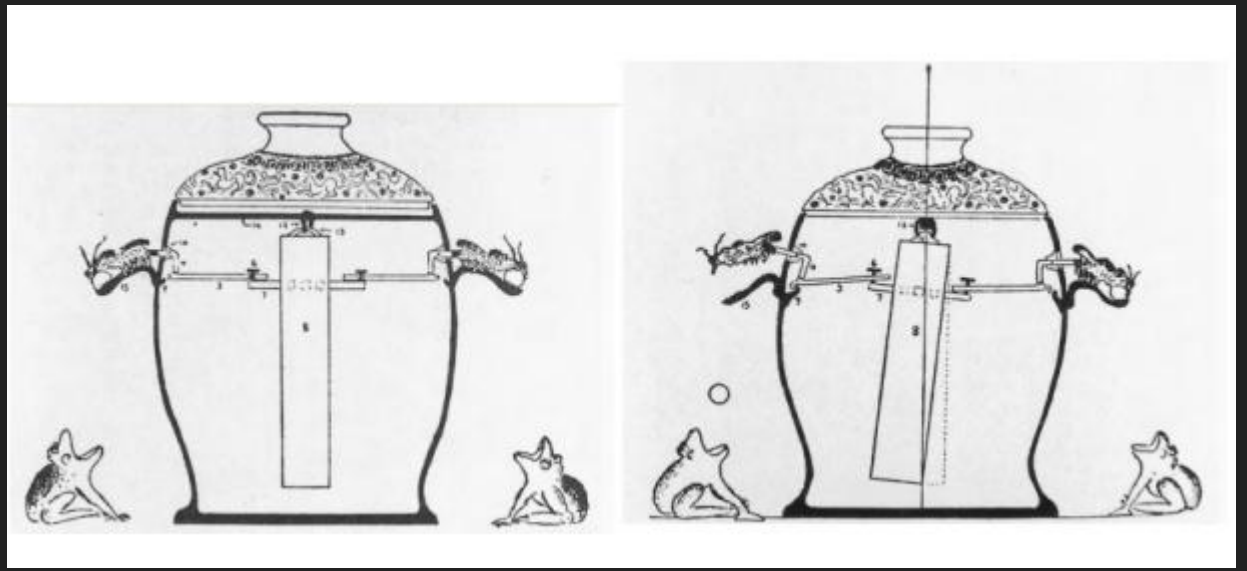
Image credit : IRIS

What do we learn about the Earth?

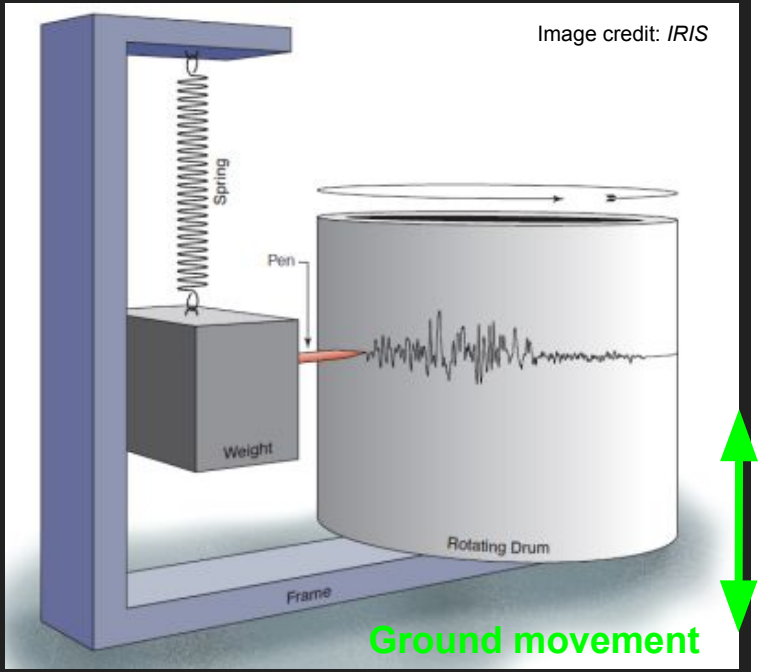
- Seismic velocities of the crust, mantle, and core
  - discovery of the inner core in 1936
- Earthquake locations delineate the boundaries of the plates
  - Depth profile
- Seismic tomography
  - CAT scan of the Earth
  - 3D model of the Earth showing the velocity “anomalies”



Detecting seismic waves….2000 years ago



Detecting seismic waves….how it works now



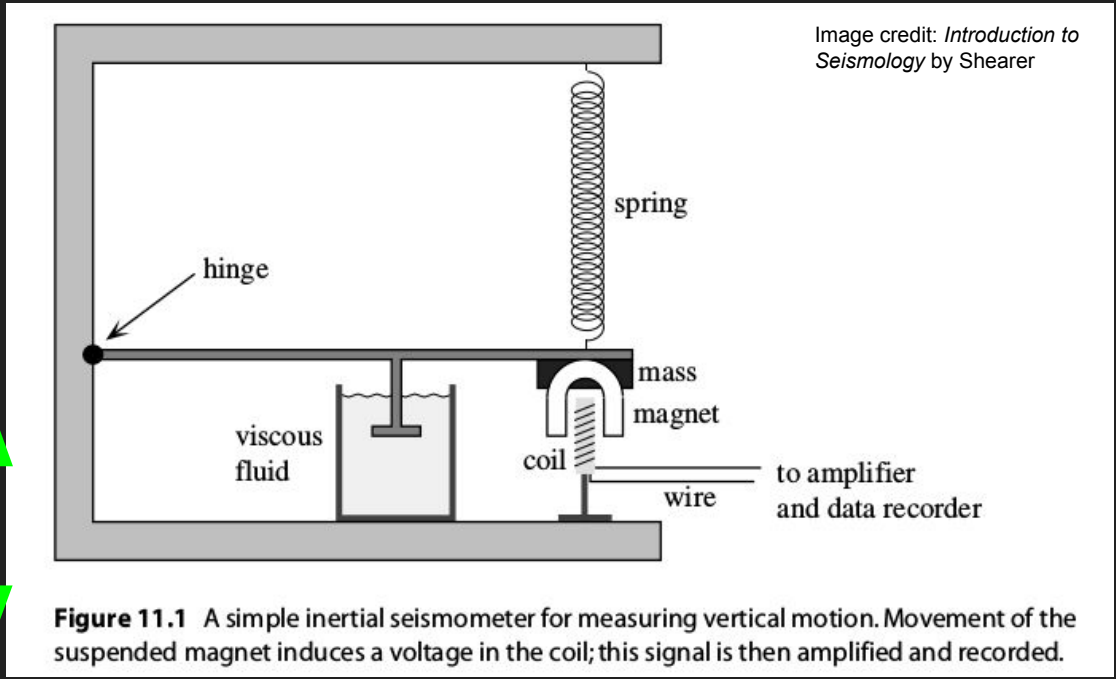


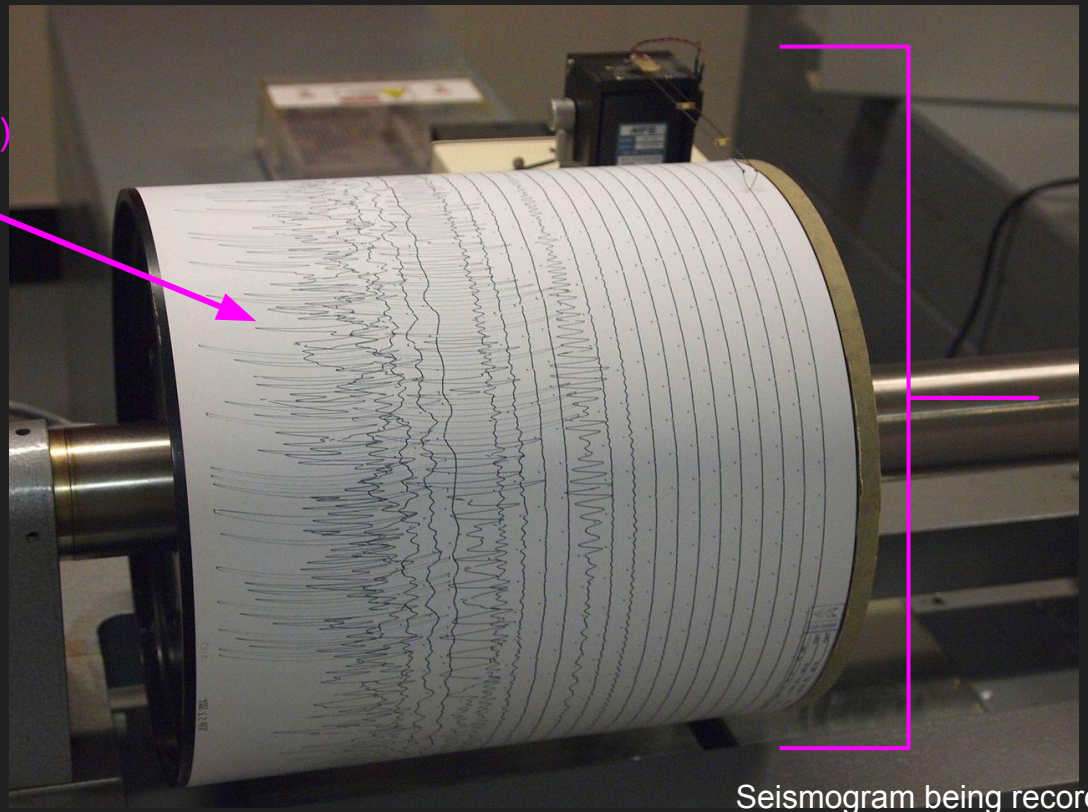
Figure 11.1 A simple inertial seismometer for measuring vertical motion. Movement of the suspended magnet induces a voltage in the coil; this signal is then amplified and recorded.

Very simplified
(no magnet/current)

Moving mass (magnet) induces a current in the coil; this current is amplified and recorded separately

Detecting seismic waves….analog seismograph

Seismogram
(paper with squiggles)



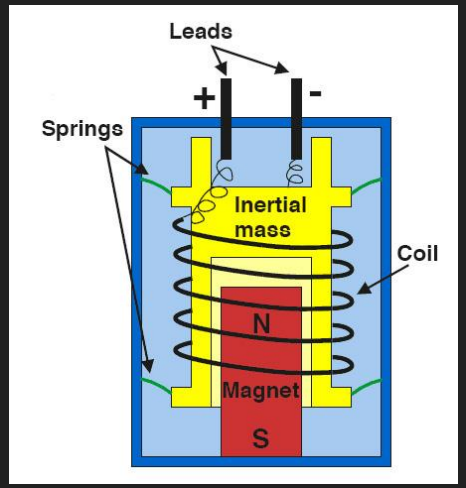
seismograph
(sensor, electronics, drum, pen, etc.)

Seismogram being recorded by a seismograph at the Weston Observatory in Massachusetts, USA.

Detecting seismic waves…digital seismometer

https://www.guralp.com

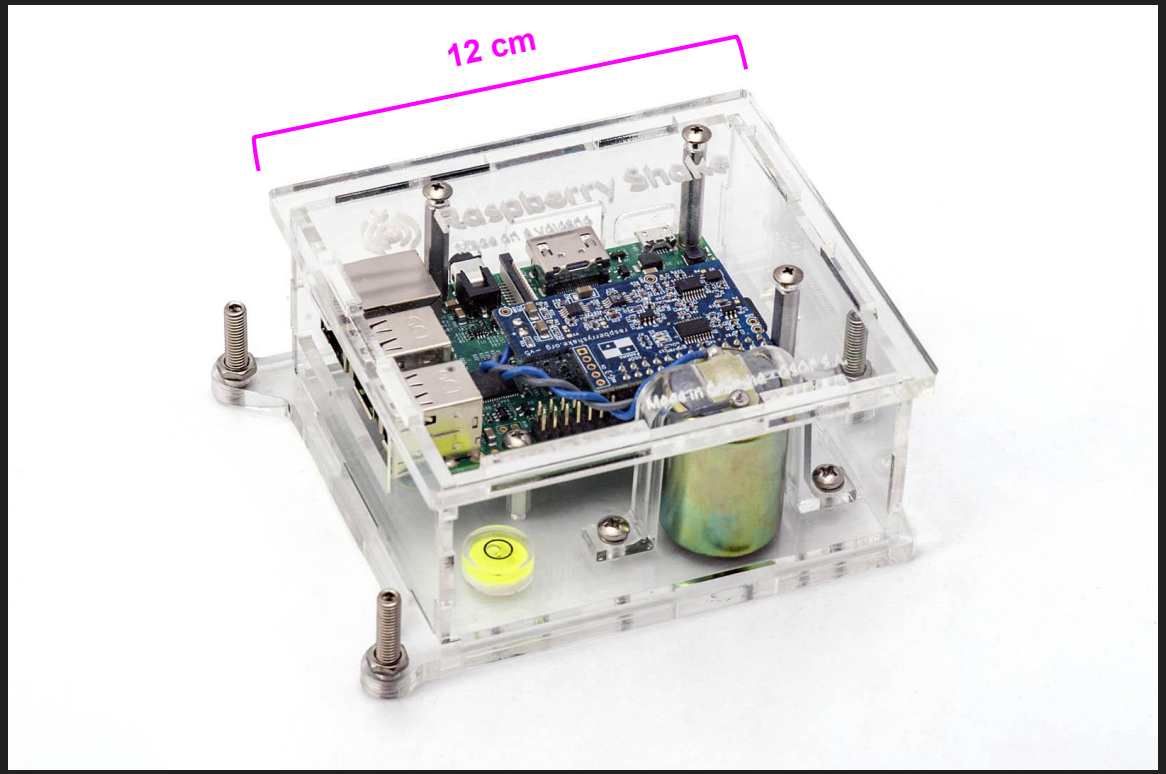
Three sensors: N-S, E-W, and vertical (Z)



http://newsline.linearcollider.org/images/2007/20070809_ftr1_3.jpg

Installation for a temporary seismic station, north Iceland highland, Güralp CMG-3ESP seismometer (Heidi Soosalu)

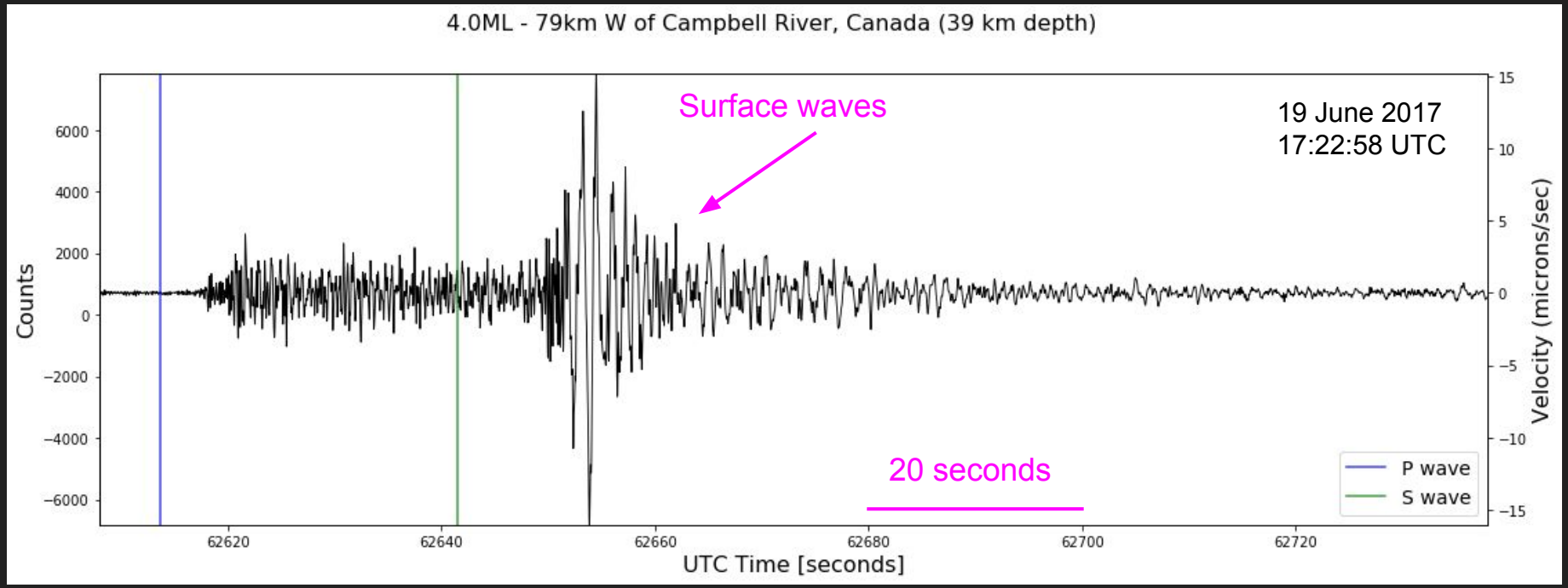
Detecting seismic waves….Raspberry Shake



Geophone

- Measures ground motion in one direction only (vertical)
- Output in volts
- Signal goes into an amplifier & A/D converter

Reading a seismogram

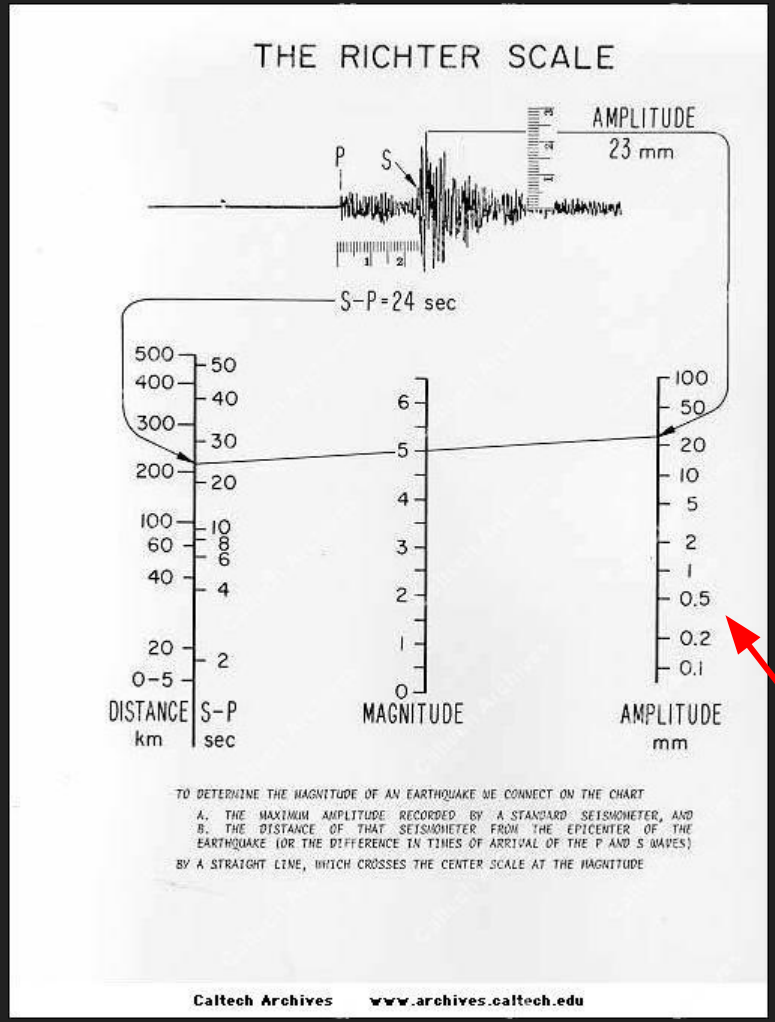


y-axis:

- Ground motion (displacement, velocity, acceleration)
- Instrument units (counts)

x-axis:

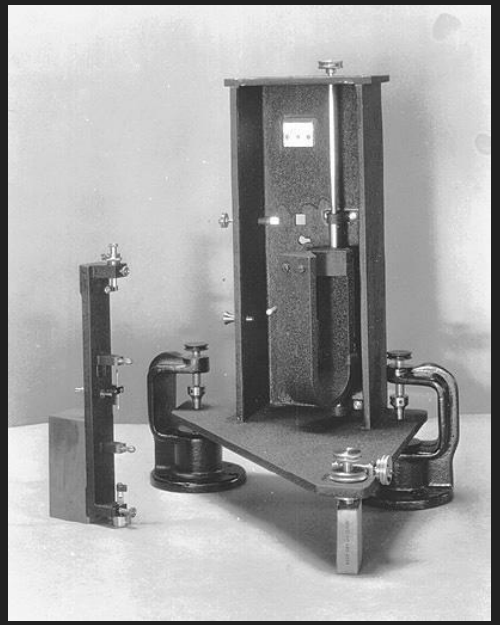
Time (usually in seconds)



The first earthquake magnitude scale!

- Developed in 1935 at Caltech
- Event located < 600 km
- Specific type of seismograph
- Maximum magnitude of ~7
- Now called the local scale (ML)

Log scale for amplitude

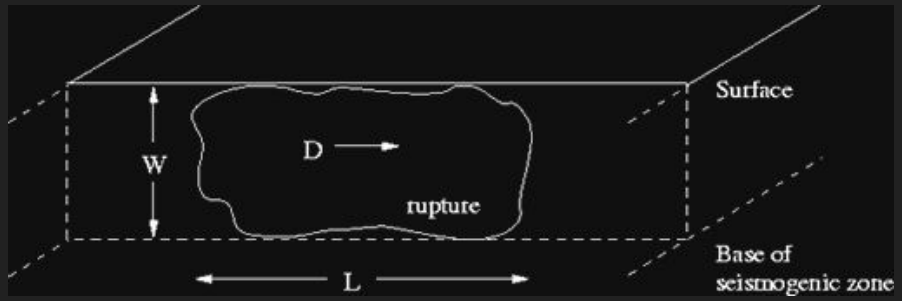


Wood Anderson Torsion beam seismometer.

http://www.bgs.ac.uk/discoveringGeology/hazards/earthquakes/History_of_instruments.

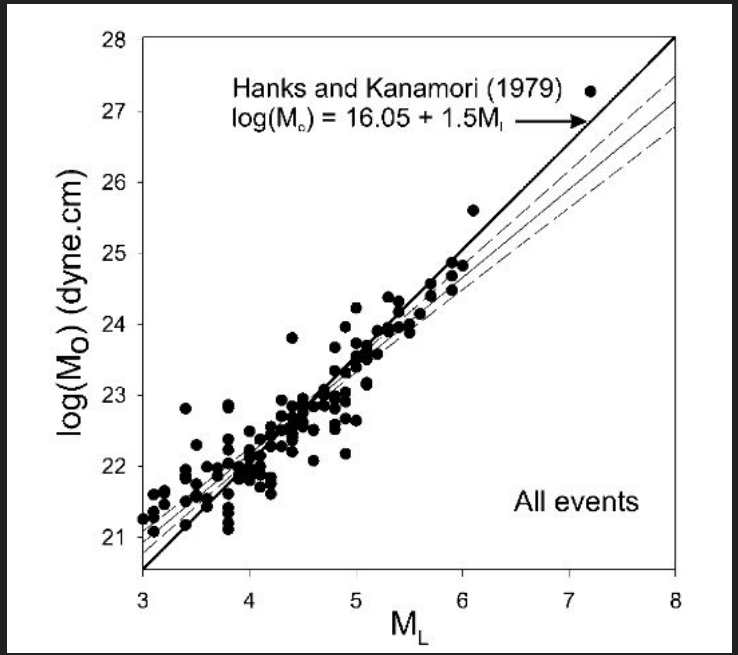
Moment Magnitude

$$M_w = \tfrac{2}{3} \log_{10}(M_0) - 10.7$$



Moment magnitude scale: Mw

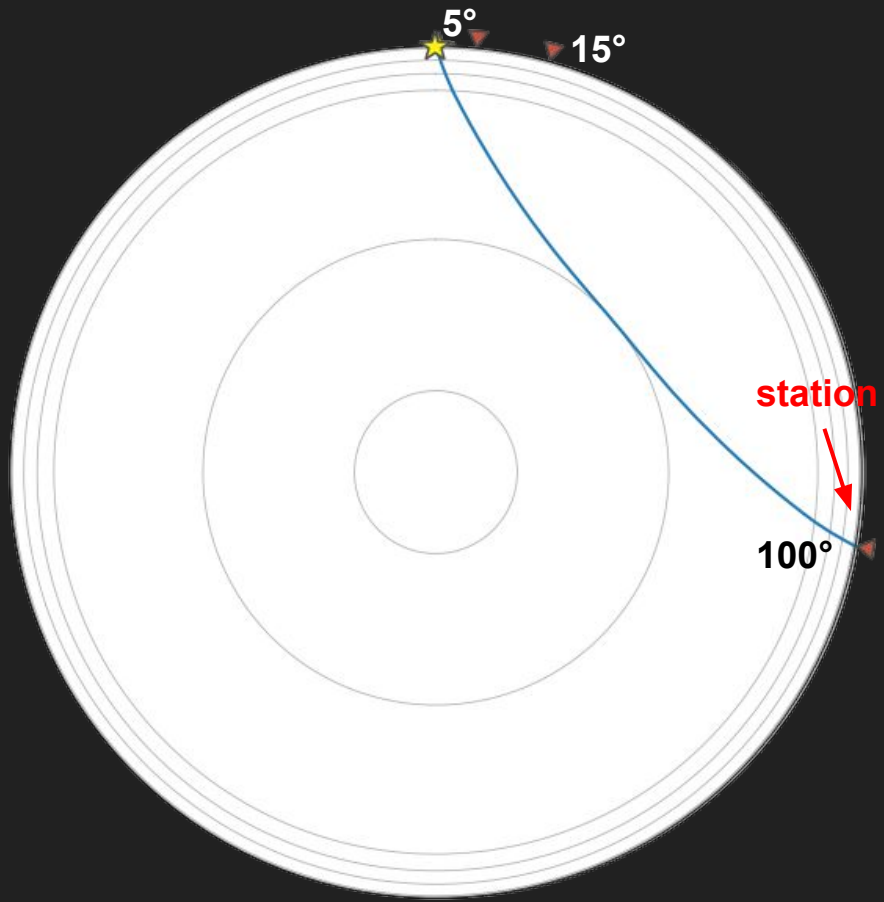
- Developed in the 1970s to replace/supplement the Richter scale
- Agrees with Richter scale for middle-magnitudes
- Based on the seismic moment $\mathbf{M_0}$
  - Proportional to energy released
  - shear modulus * fault area * displacement
- No upper magnitude limit
  → **earthquakes have a physical upper limit!**



Moment magnitude - local magnitude calibration for earthquakes in western Canada
Ristau, J; Rogers, G C; Cassidy, J F.
Bulletin of the Seismological Society of America vol. 95, no. 5, 2005; pages 1994-2000

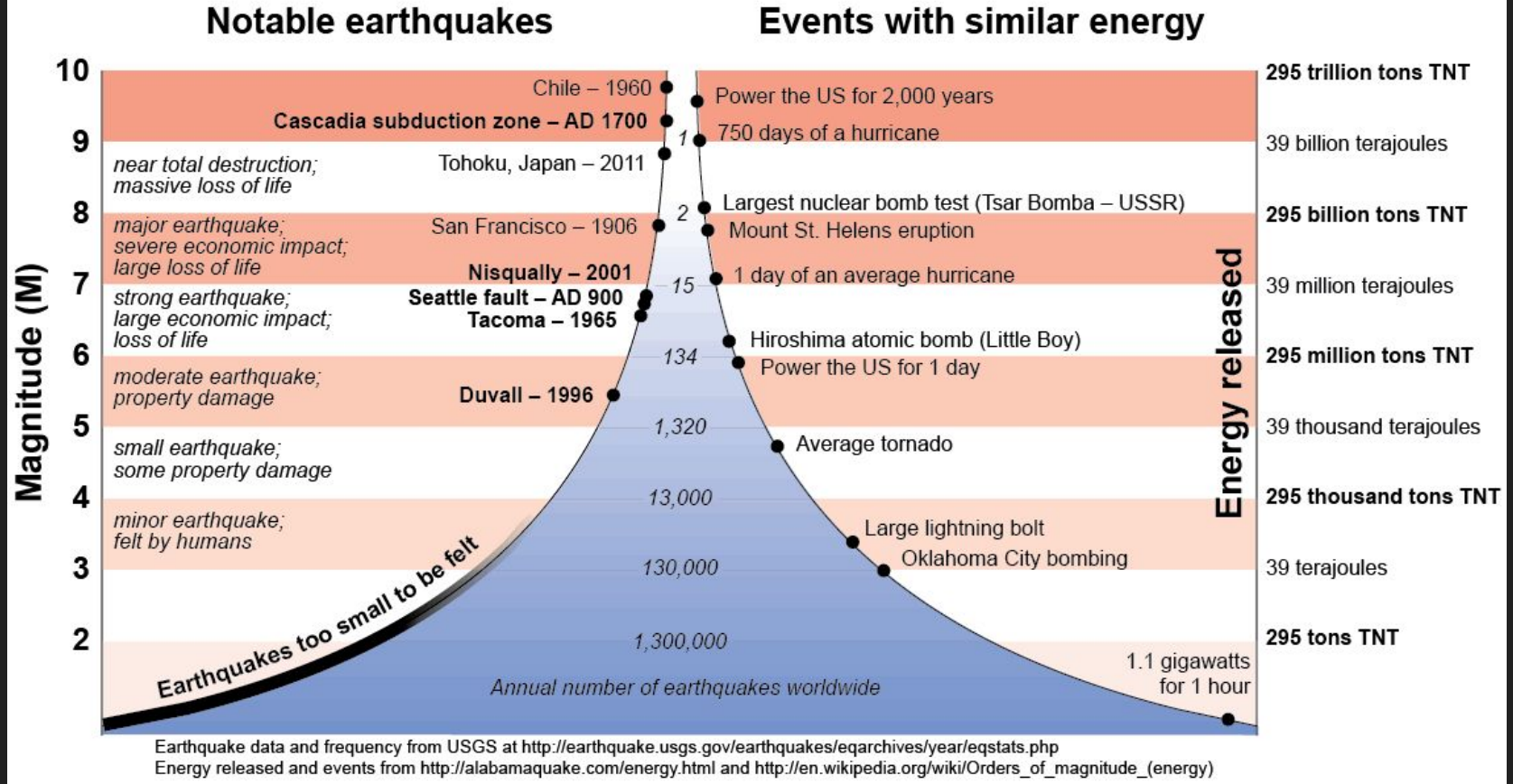
Magnitude scales and distance

Magnitude type	Range	Distance
Local (Ml)	< 7.5	0 - 600 km
Short-period body waves (Mb)	4 - 7	5 - 100 degrees (~600-11,000 km)
Moment (Mww)	> 3.5	any



Epicentral distance: 5° = 555 km, 15° = 1670 km, 45° = 5000 km

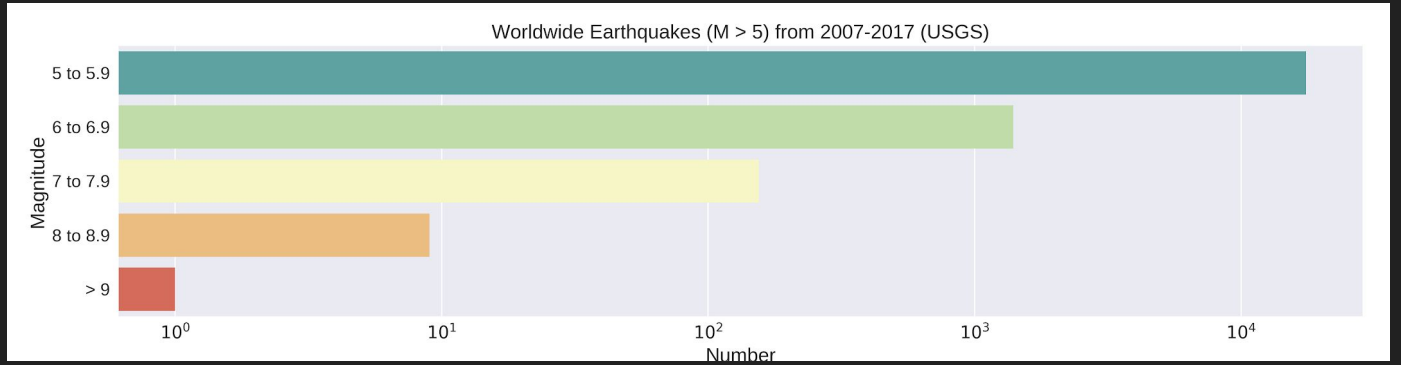
Earthquake energy and frequency



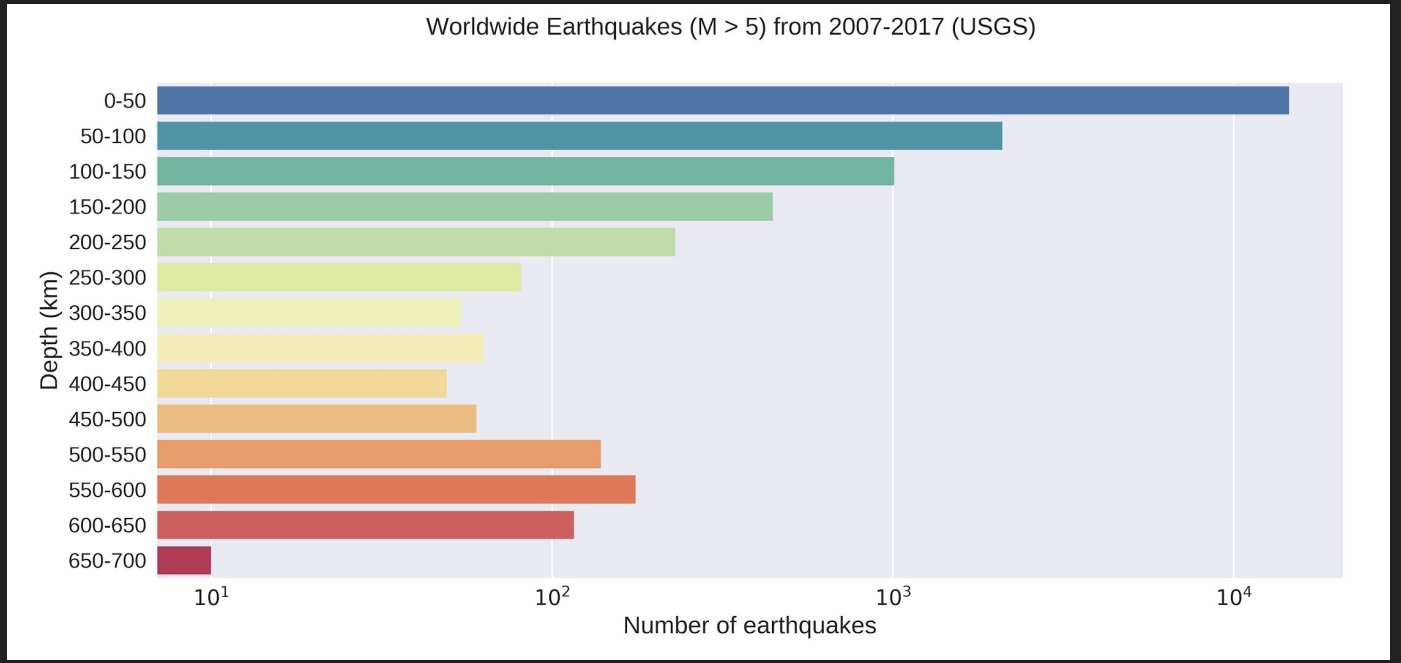
Earthquake data and frequency from USGS at http://earthquake.usgs.gov/earthquakes/eqarchives/year/eqstats.php
Energy released and events from http://alabamaquake.com/energy.html and http://en.wikipedia.org/wiki/Orders_of_magnitude_(energy)

https://www.dnr.wa.gov/pictures/ger/ger_hazards_eq_mag_freq_1140.pn

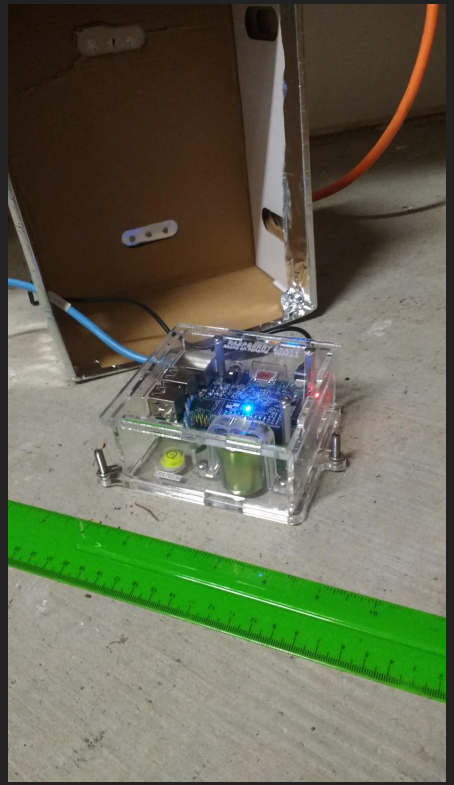
Earthquake occurrence by magnitude



Earthquake occurrence by depth

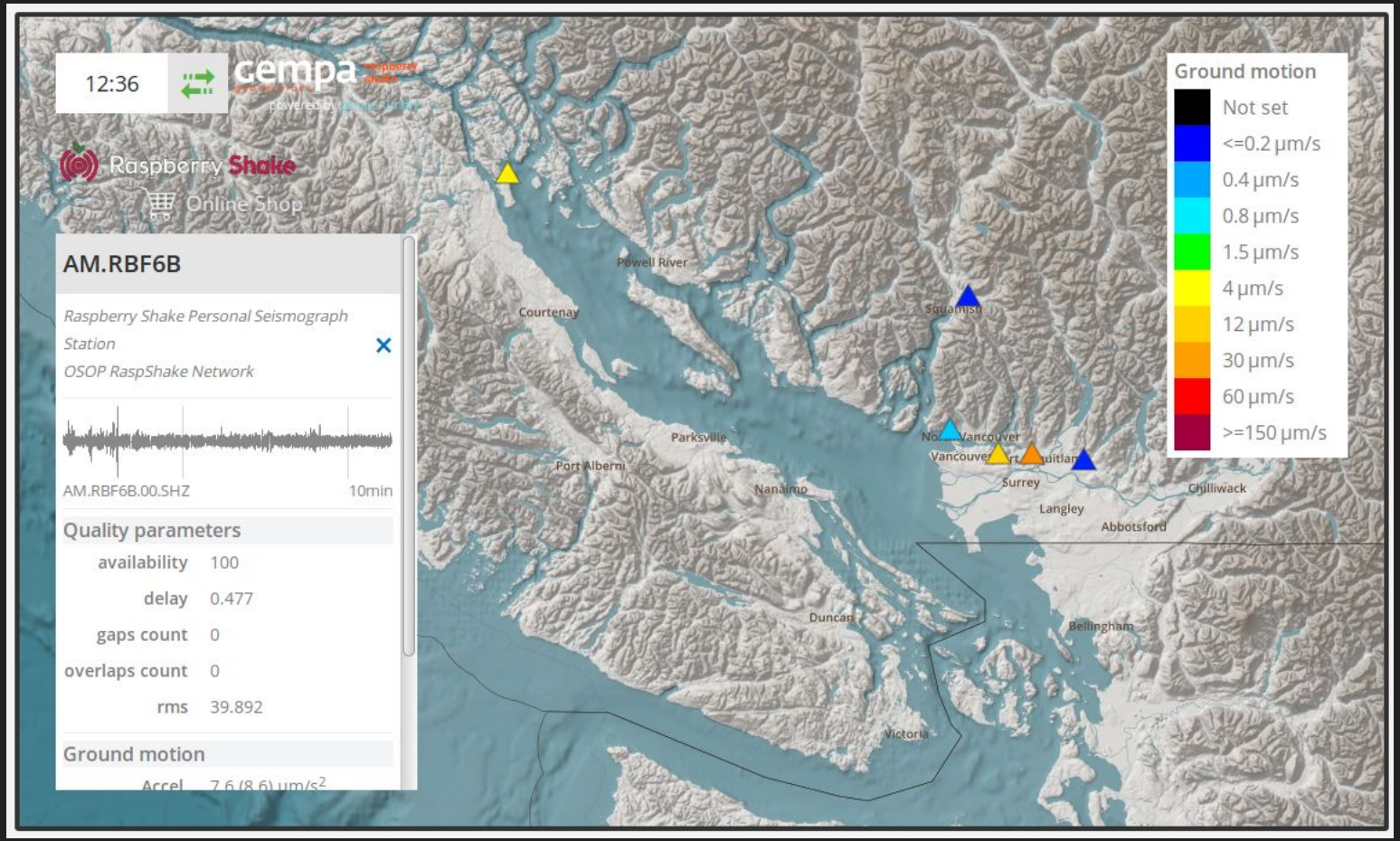


Quest Raspberry Shake - Location



Why Four Winds Condo?

- Quiet building - no mechanical noise
- Sits on a concrete slab, poured on bedrock(?)
- Quest network access
- Secure

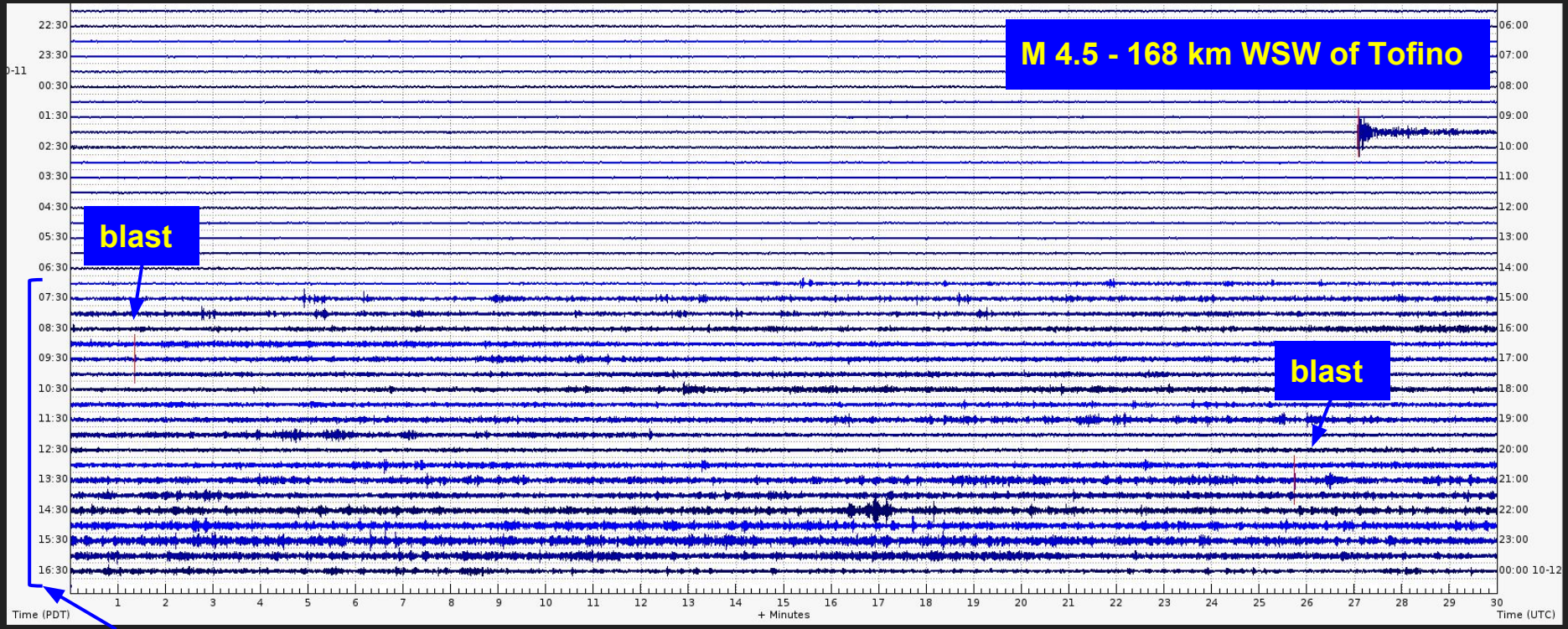


http://www.raspberryshake.org/stationview

October 10th - 10:30 pm to October 11th - 5 pm PDT

y-axis: Time (hours PDT)

y-axis: Time (hours UTC)



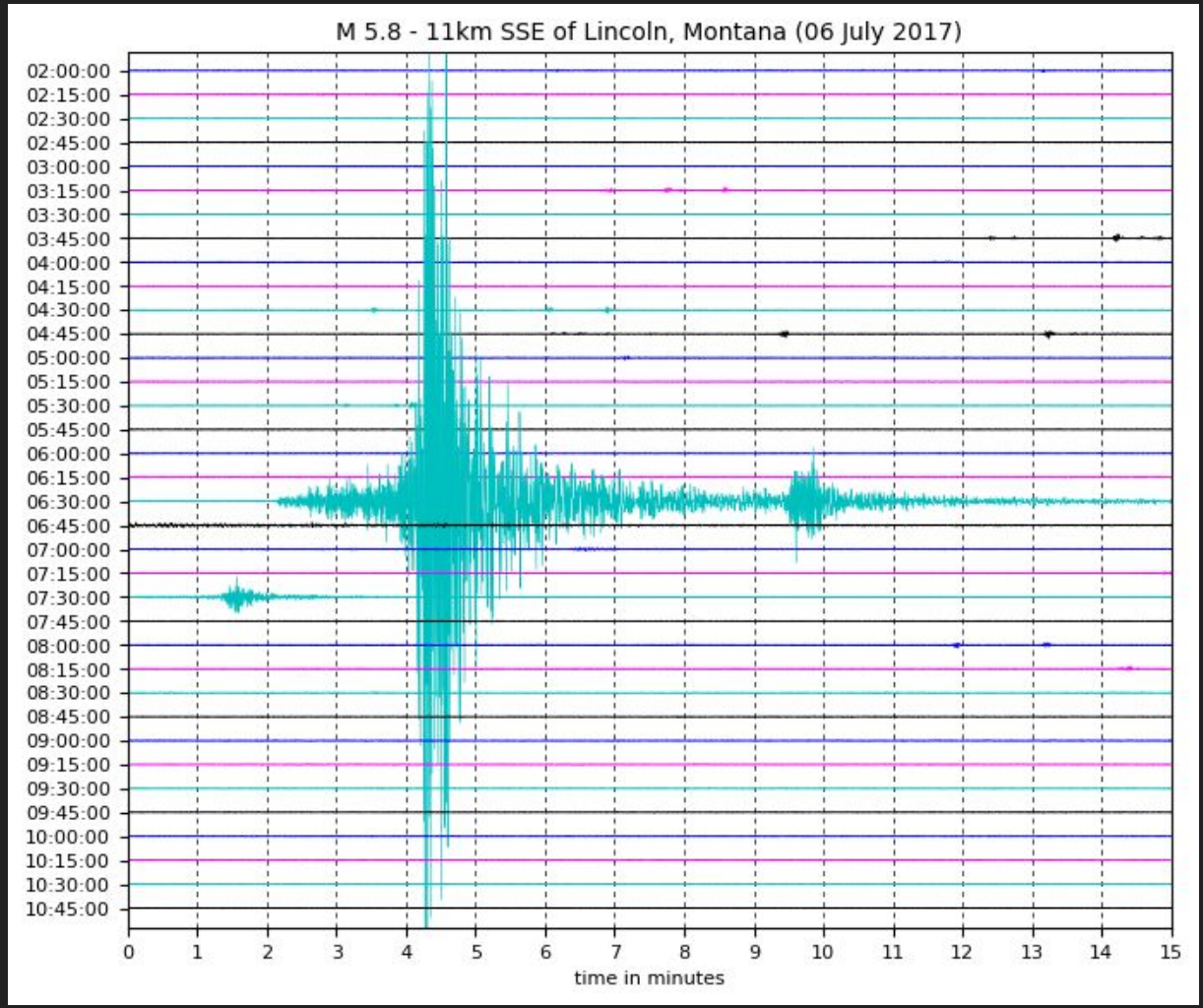
Daytime noise (e.g. traffic) and construction (next door)

x-axis: Time (30 minutes)

Largest ground movement:

M 5.8, 12.2 km depth
6 July, 2017
06:30:17 UTC (23:30:17 PDT)

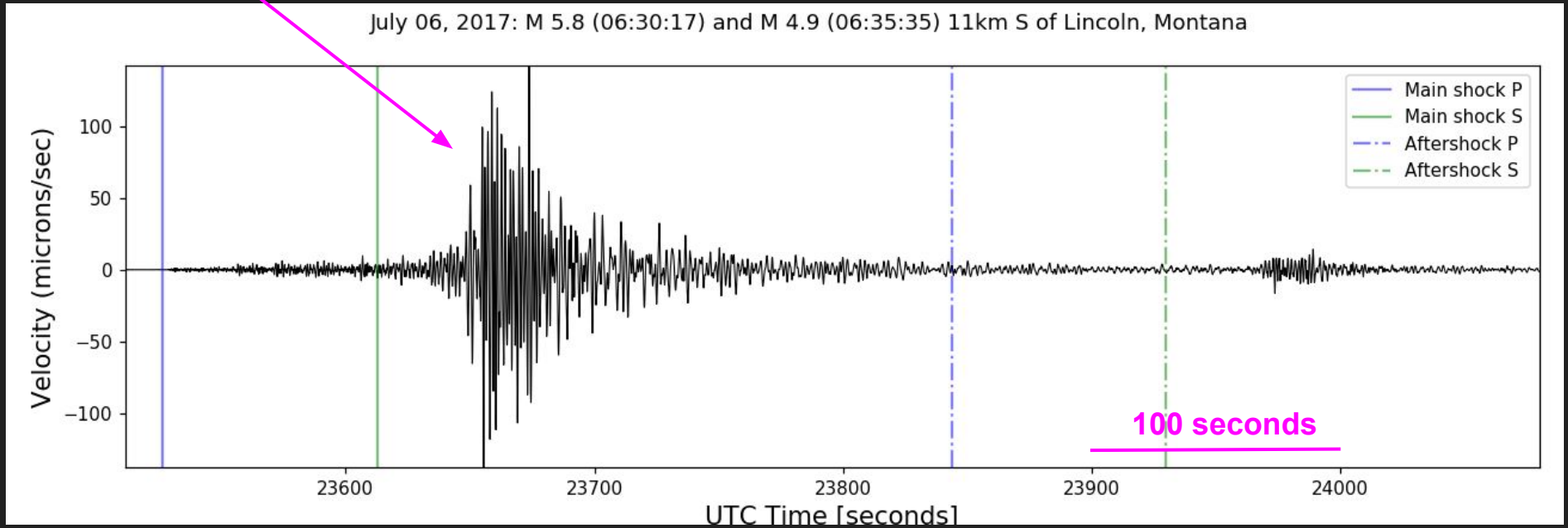
11 km SE of Lincoln, Montana
(52.2 km NW of Helena, MT)



Maximum recorded velocity = 150 microns/sec

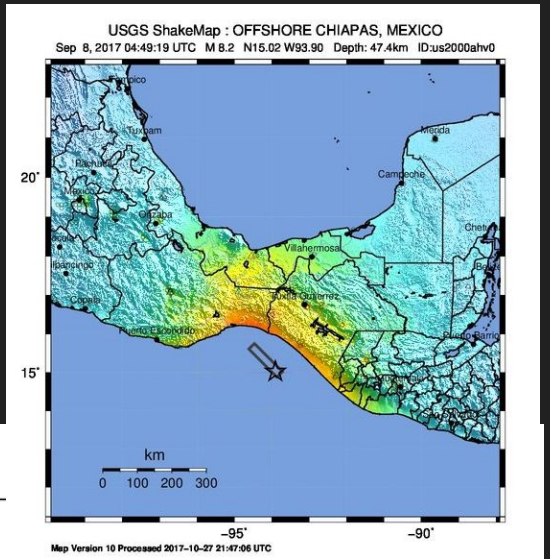
Thickness of paper = 0.1mm = 100 microns

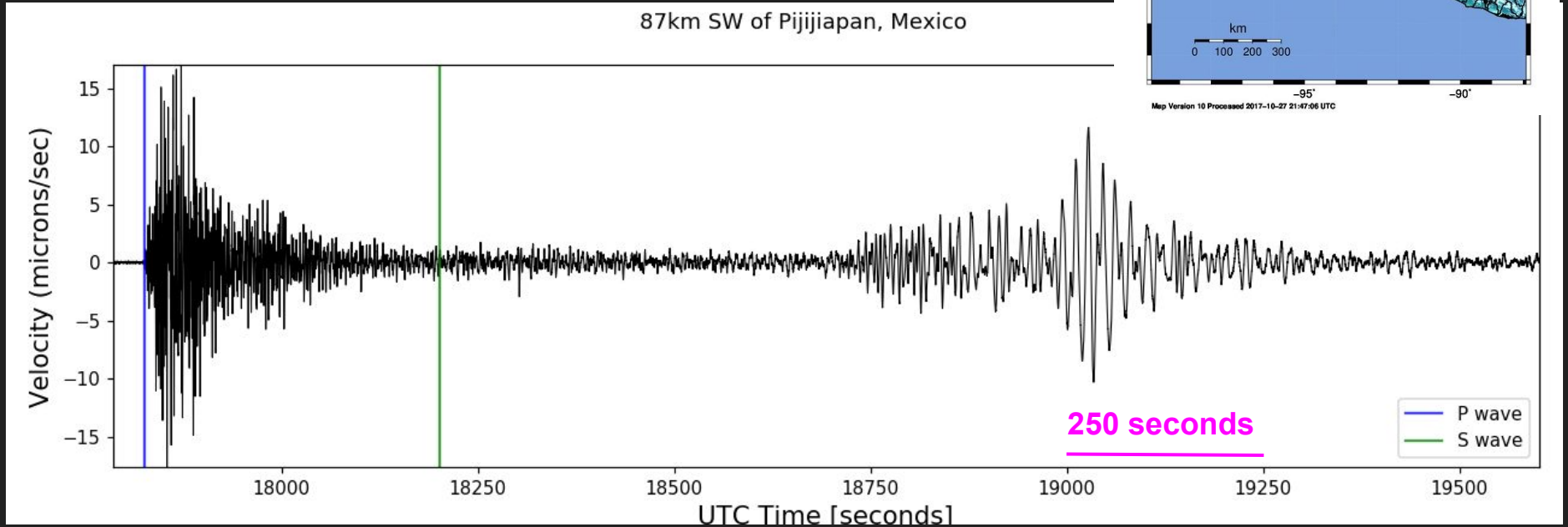
The ground moved through the thickness of a piece of paper every second! (for ~50 seconds)

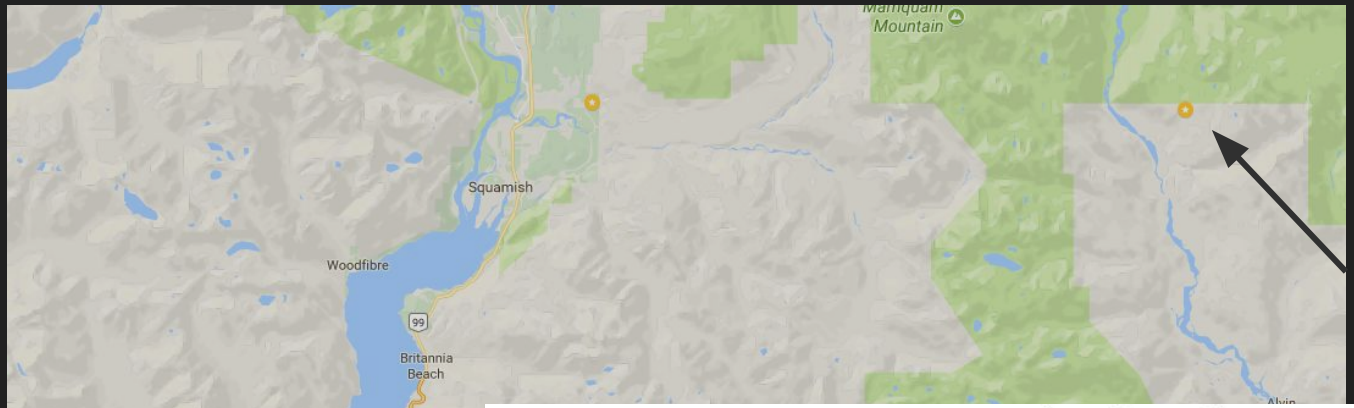


Largest earthquake magnitude:

Mexico **- M 8.2**
8 Sept, 2017 04:49:19 UTC
47.4 km depth

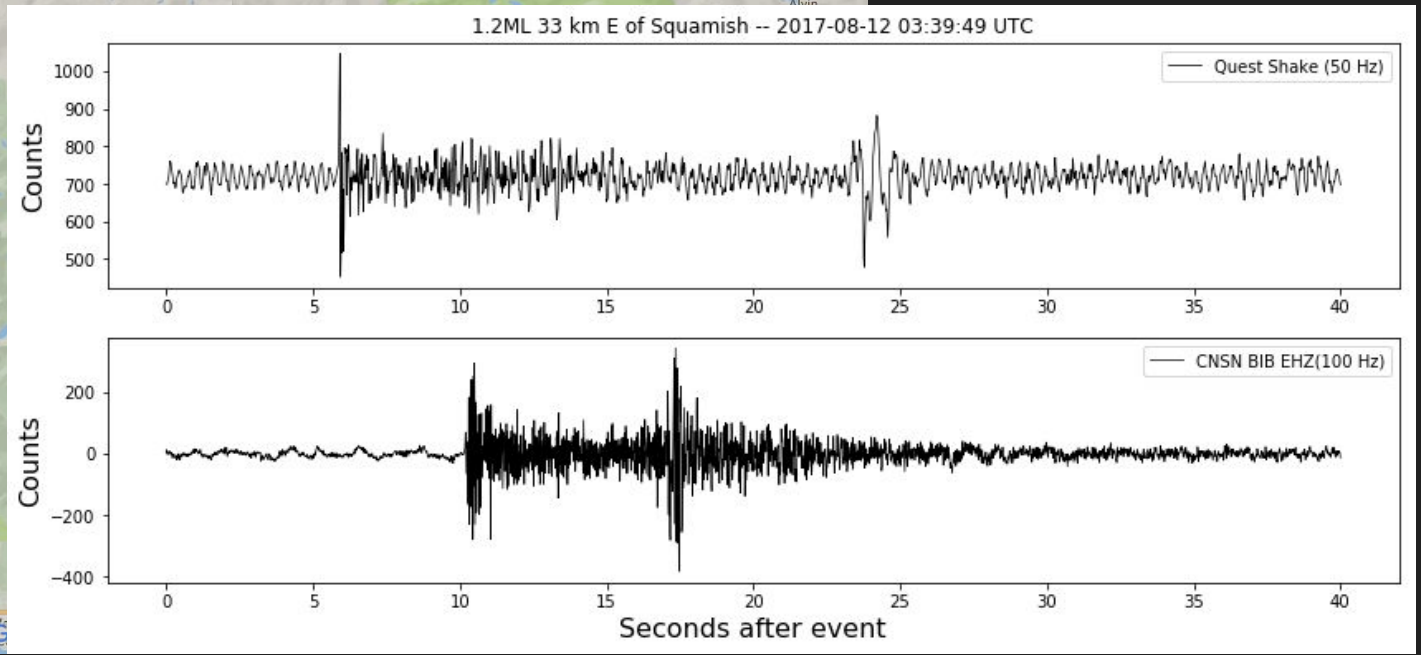


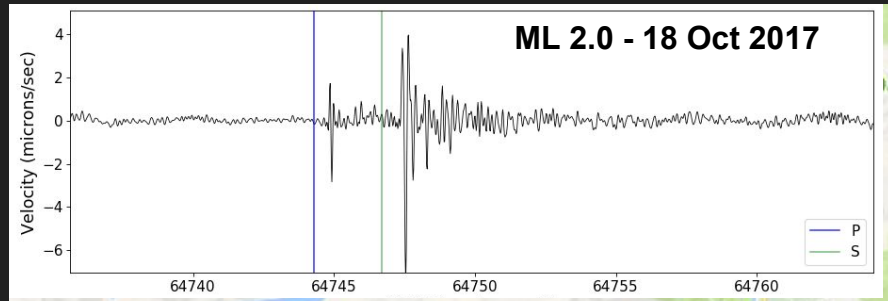




Nearby earthquake:

33 km E of Squamish
ML 1.2
12 Aug, 2017
< 1 km depth




ML 2.0 - 18 Oct 2017
Velocity (microns/sec)
4
2
0
−2
−4
−6
64740
64745
64750
64755
64760
P
S

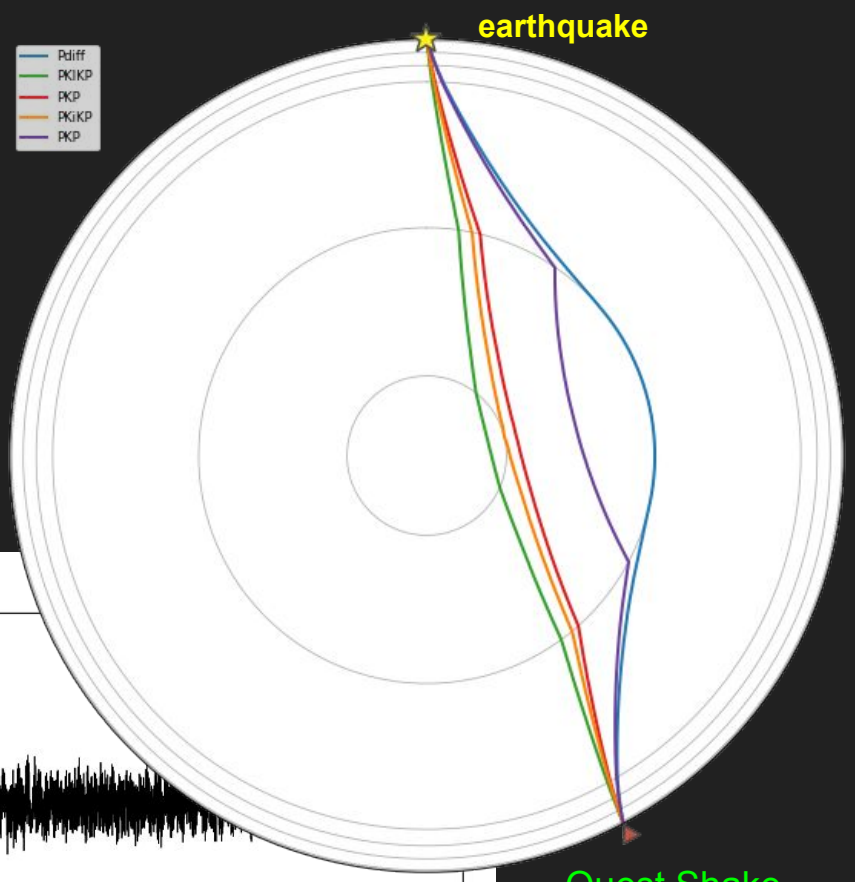
Mamquam Mountain
Squamish
Woodfibre
Britannia Beach
Tetrahedron Provincial Park
Furry Creek
McNab Creek
Porteau
Port Mellon
Gambier Island
Anvil Island
Lions Bay
Iron Bay
Hopkins Landing
Golden Ears Provincial Park
Mt Robie Reid
99

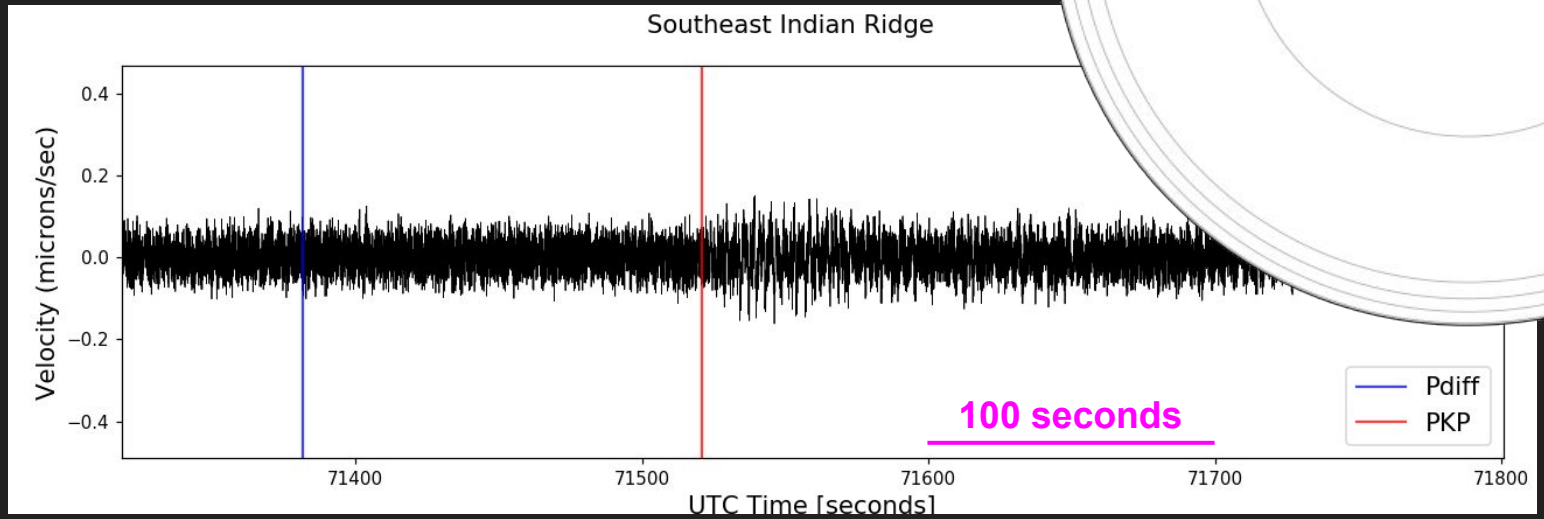
ML 1.2 - 12 Aug 2017
Velocity (microns/sec)
0.75
0.50
0.25
0.00
−0.25
−0.50
−0.75
13190
13195
13200
13205
13210
13215
13220
P
S

Most distant earthquake:

M5.8
6 August 2017 19:32:06 UTC
depth 10 km
distance 152 degrees

Pdiff (diffracted around the outer core)
PKP (refracted through outer core)
PKP (refracted through outer core)
PKiKP (diffracted around inner core)
PKIKP (refracted through inner core)

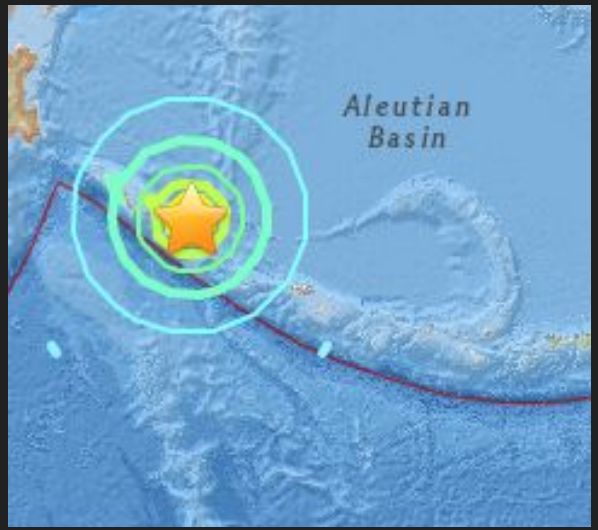




Most interesting earthquake:

M 7.7
10.0 km depth

202km ESE of Nikol'skoye, Russia
17 July, 23:34:13 UTC



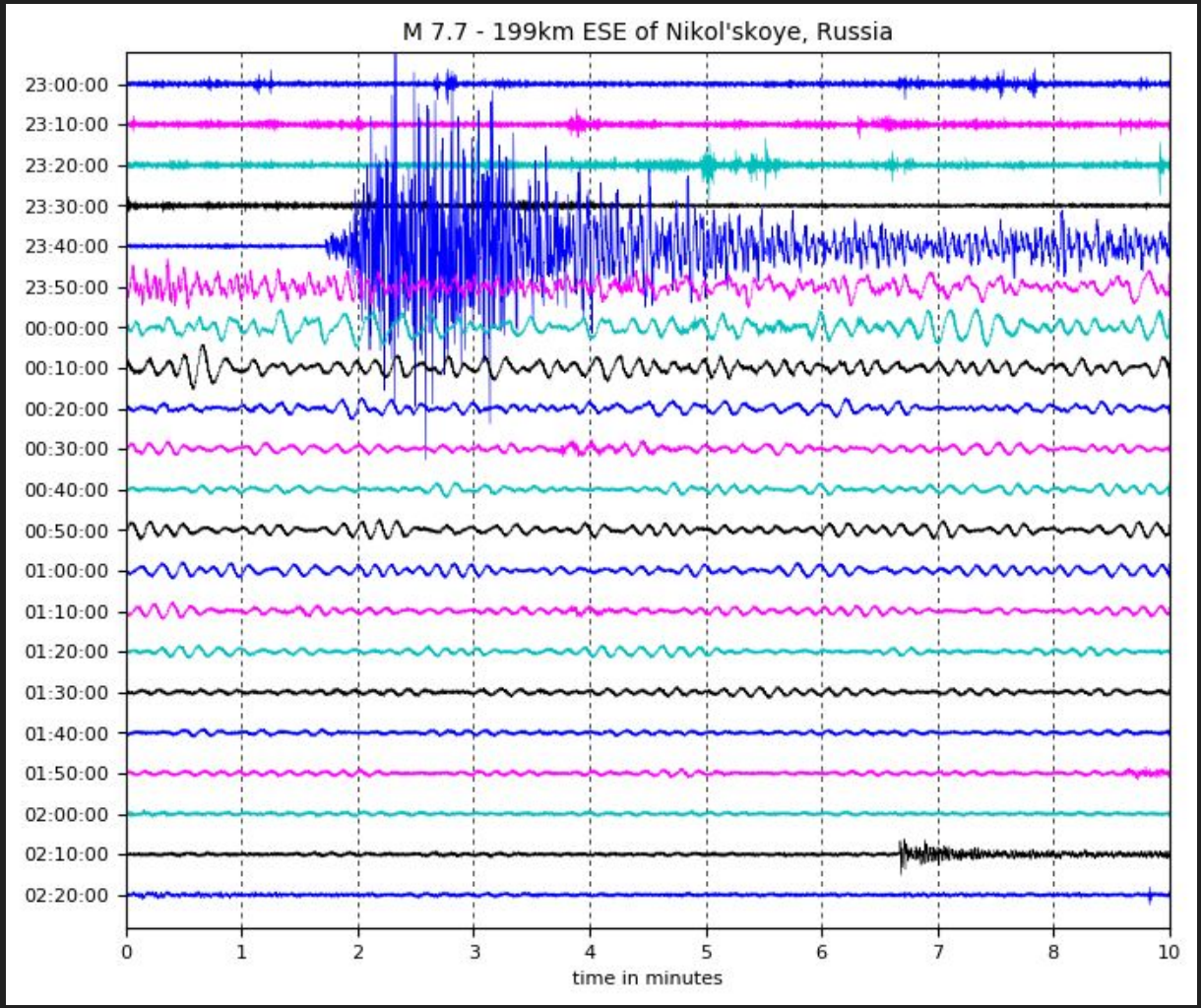


Figure: *Introduction to Seismology* by Shearer

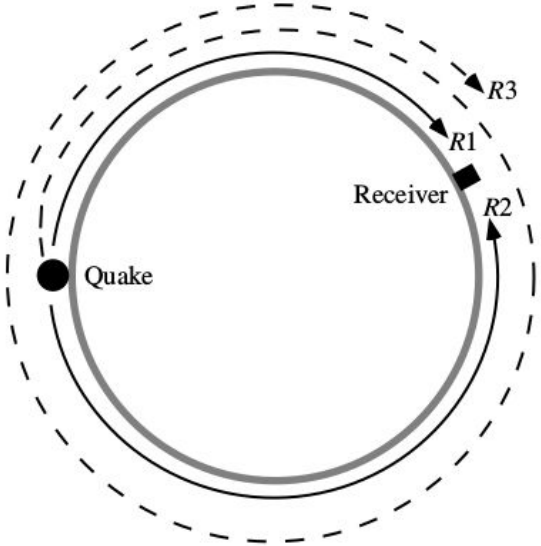
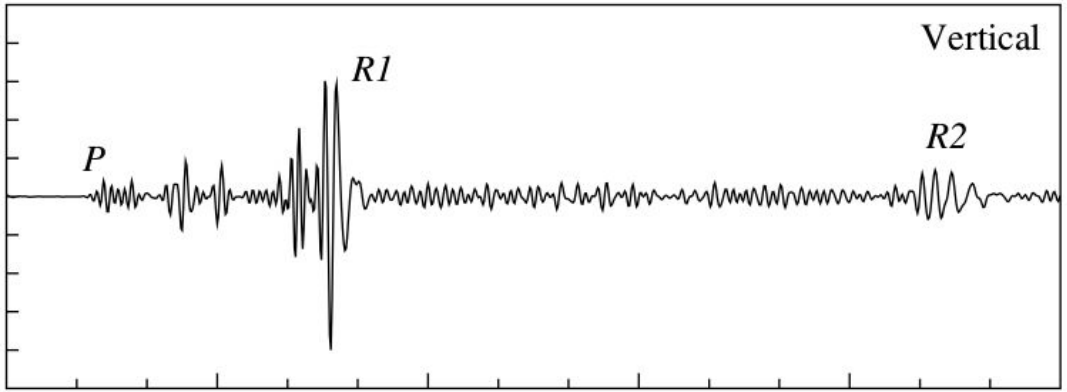
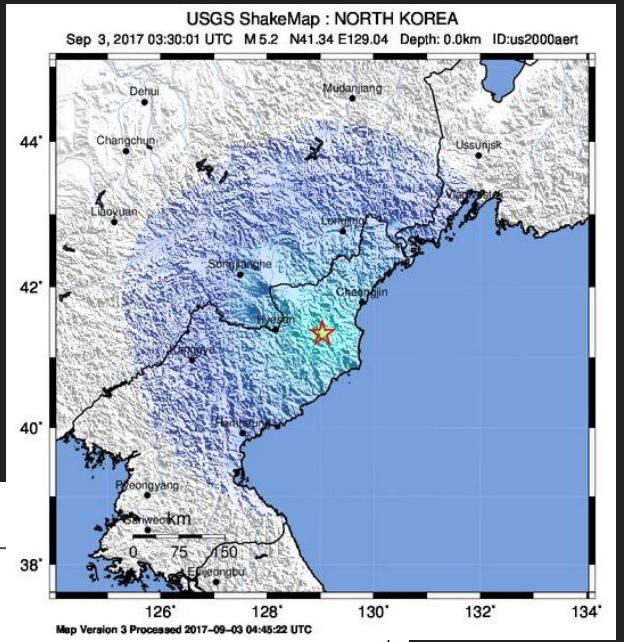


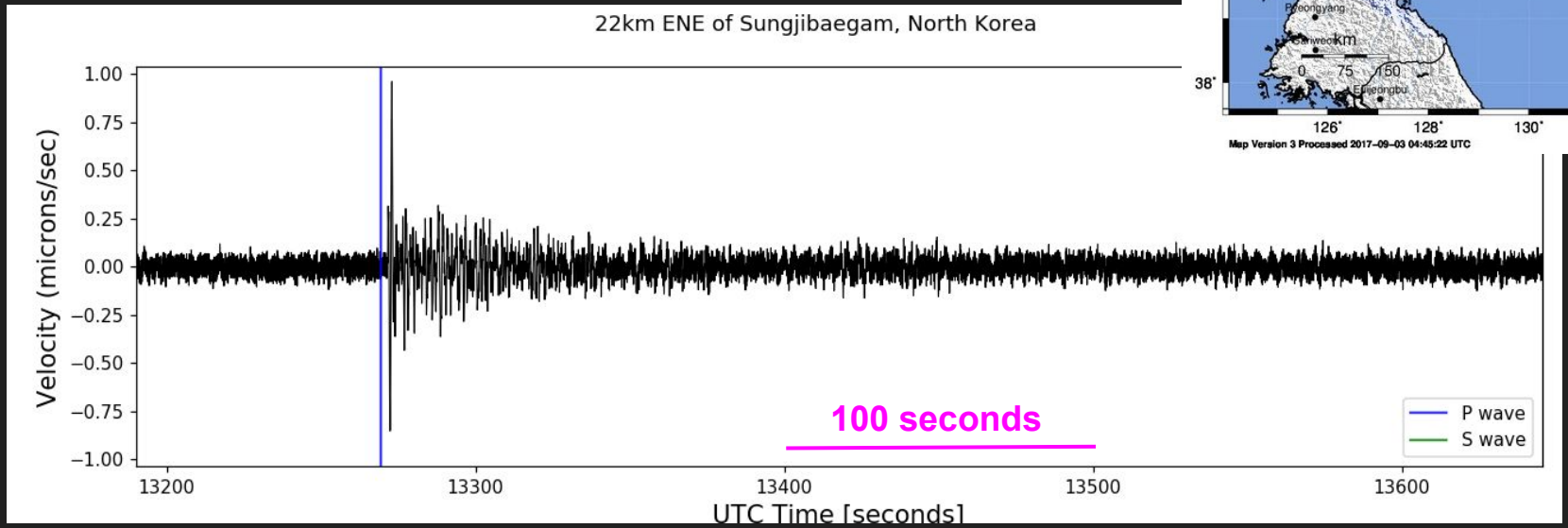
Figure 8.7 Ray paths for the first three Rayleigh wave arrivals.



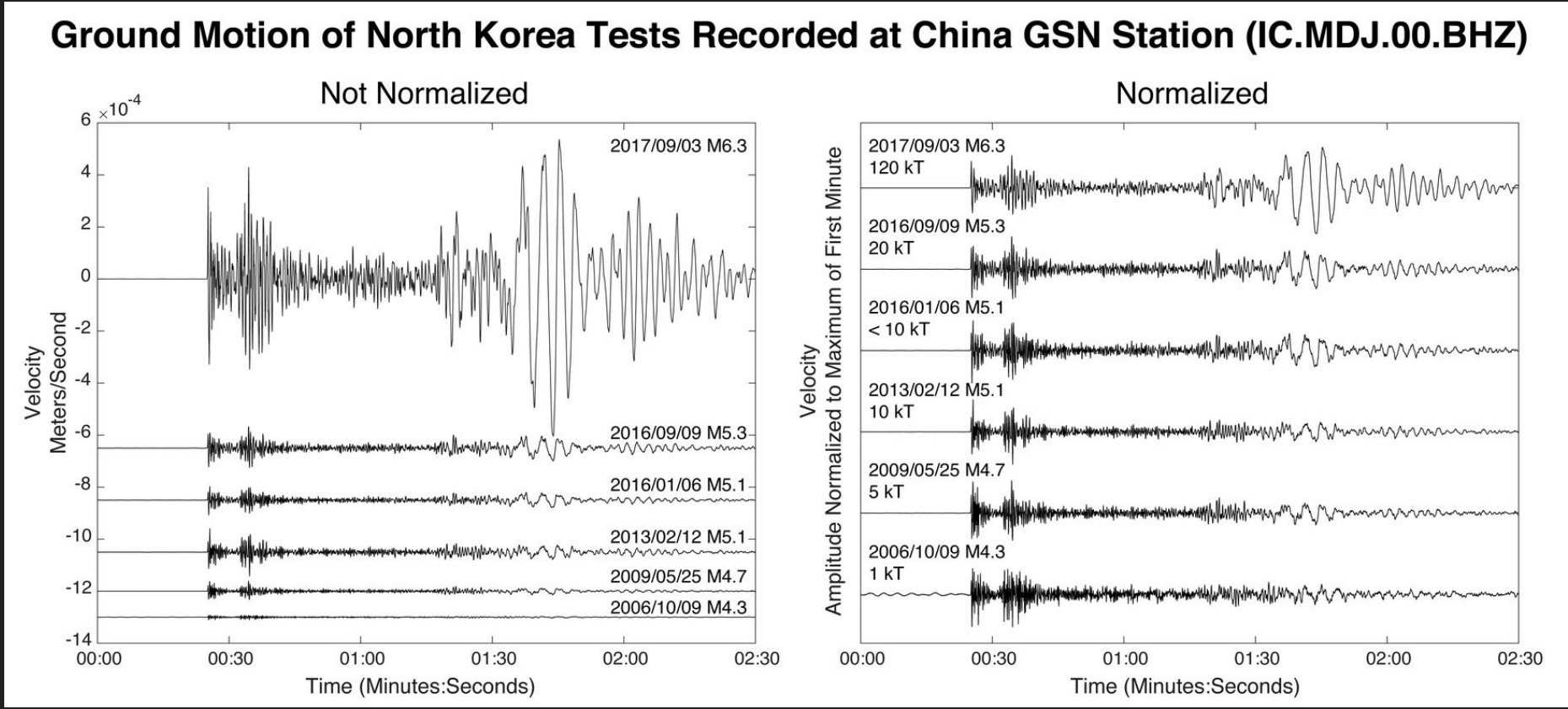
Nuclear test:

M 6.3 Explosion - 21km ENE of Sungjibaegam, North Korea
0.0 km depth! (shallow for a large earthquake)
3 Sept, 2017 03:30:01 UTC

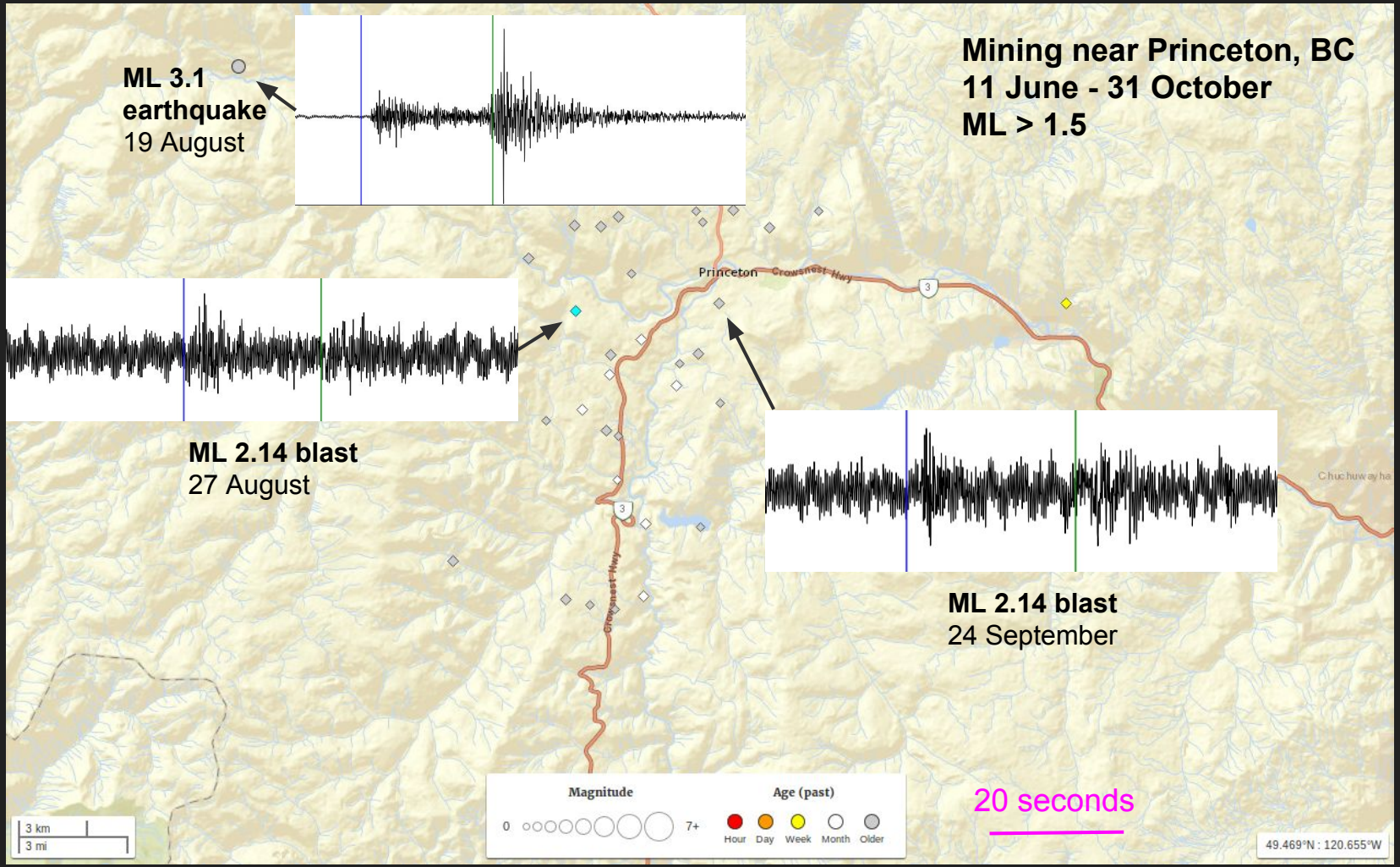




Comparison of all North Korea nuclear tests: Oct 2006 - Sept 2017



Kasey Aderhold, IRIS

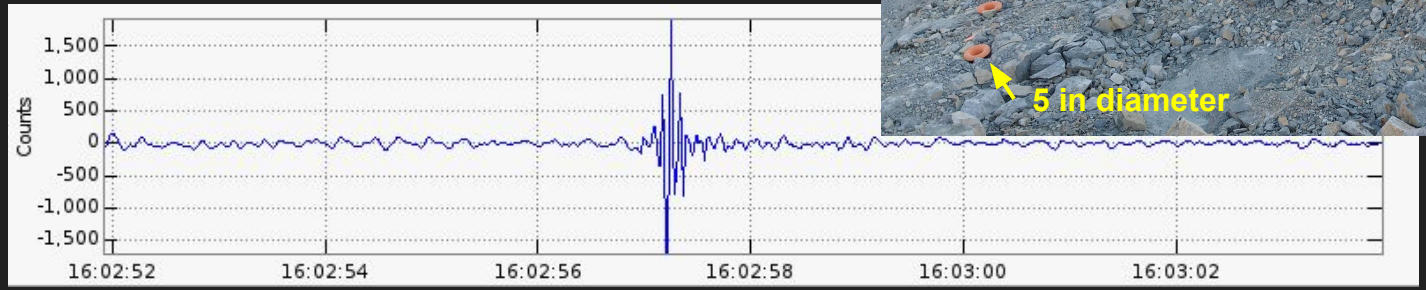

Mining near Princeton, BC
11 June - 31 October
ML > 1.5
ML 3.1
earthquake
19 August
ML 2.14 blast
27 August
ML 2.14 blast
24 September
Princeton
Crowsnest Hwy
3
Chuchuwayha
Magnitude
0
7+
Age (past)
Hour
Day
Week
Month
Older
3 km
3 mi
20 seconds
49.469°N : 120.655°W

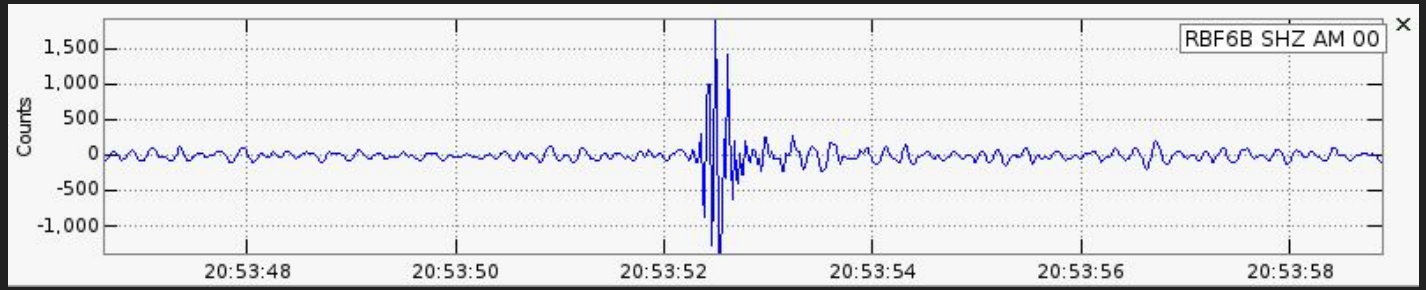
Construction blasting

Legacy Ridge (east of Aristotle Drive)

Construction blasting

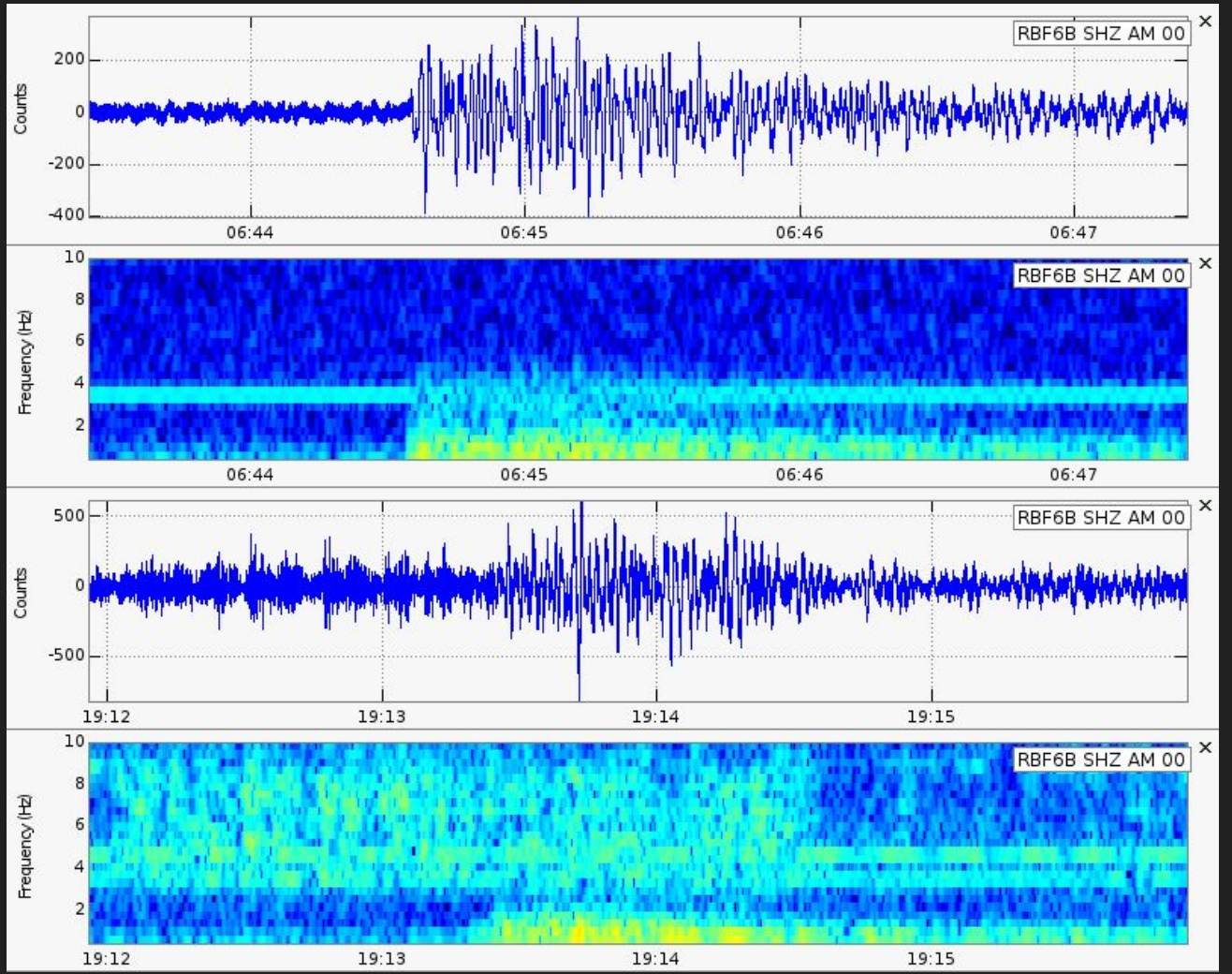
Legacy Ridge (east of Aristotle Drive)





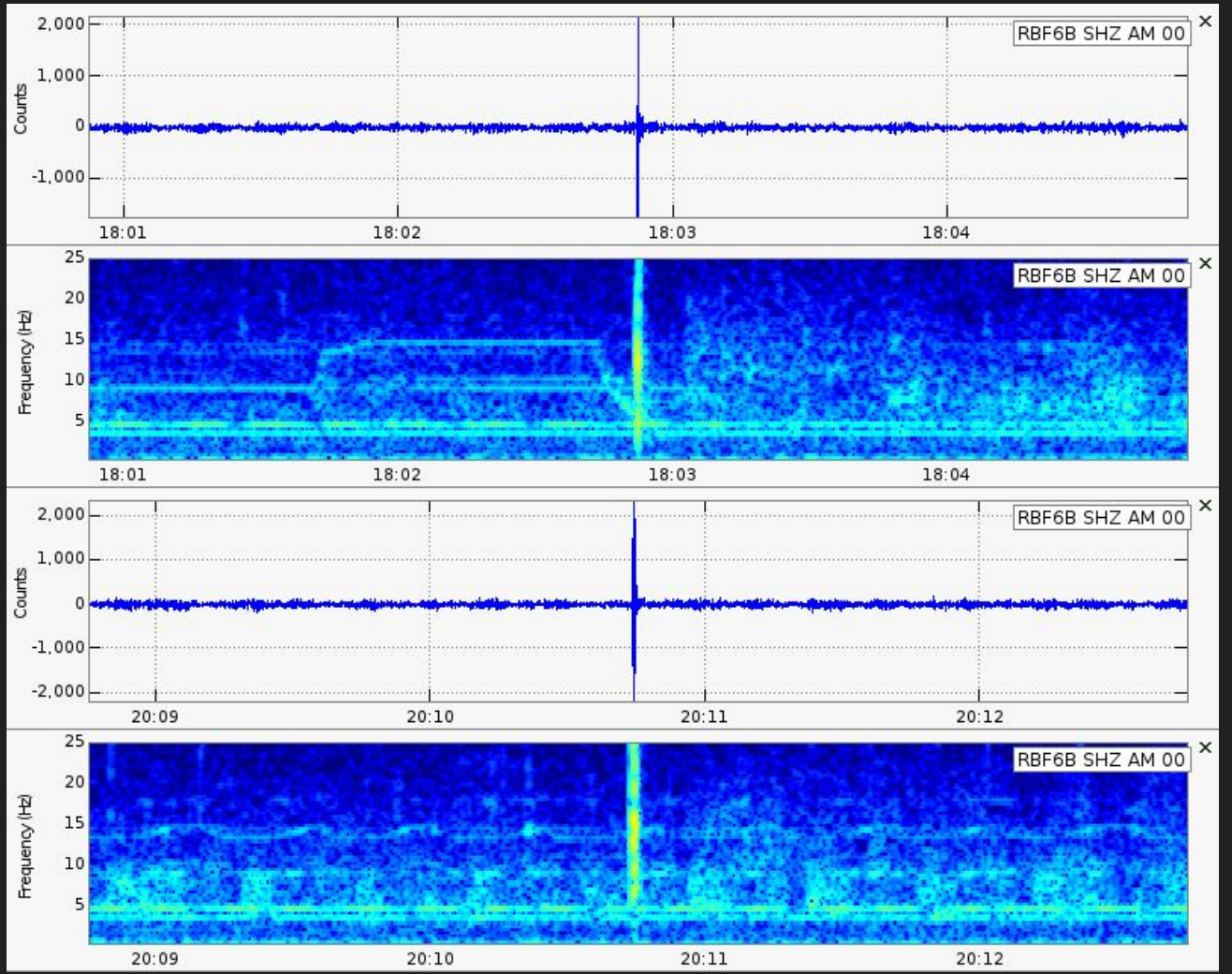
Drilled site, ready for explosives and blasting

Spectrograms:
Earthquakes



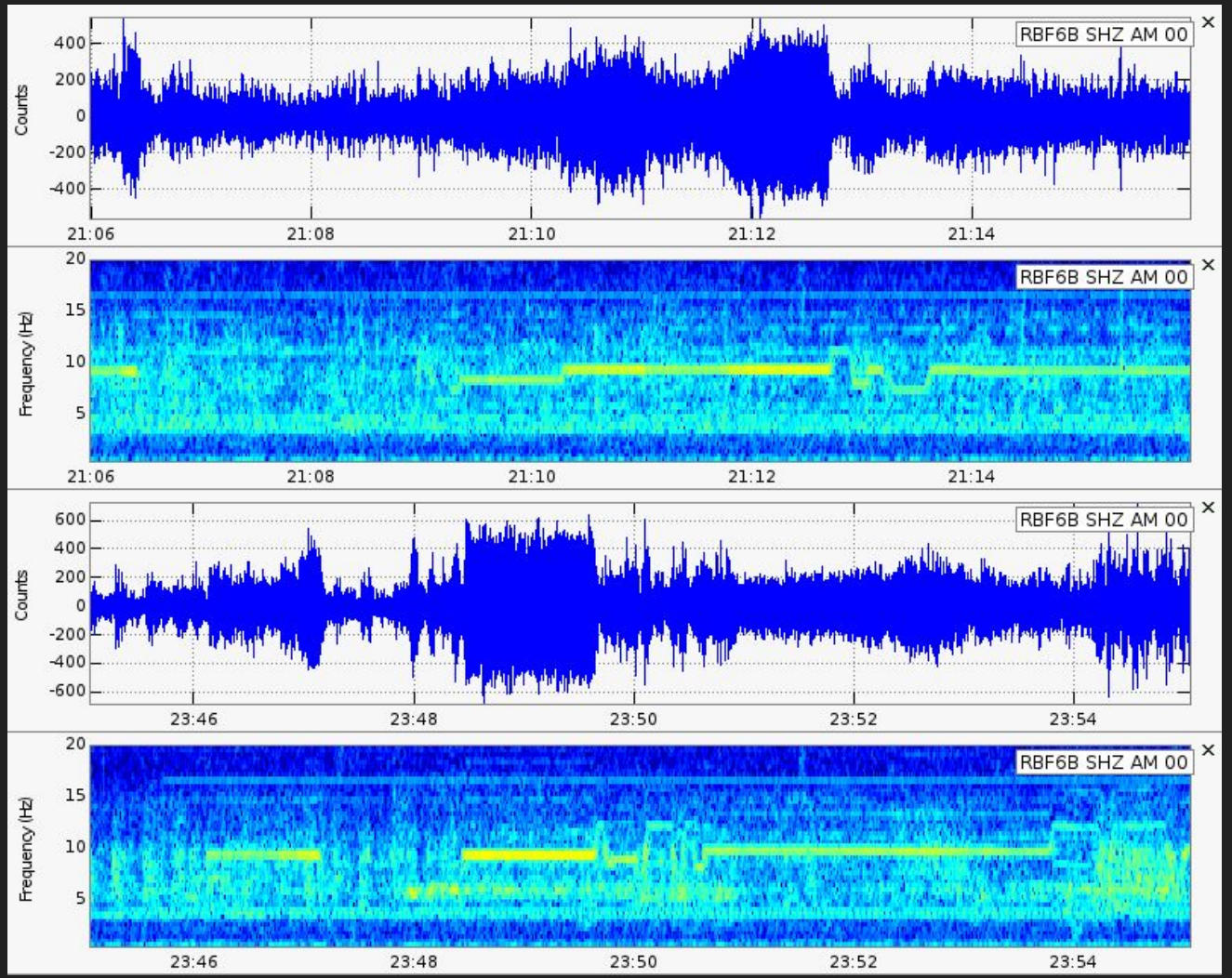
Spectrograms:

Construction blasts

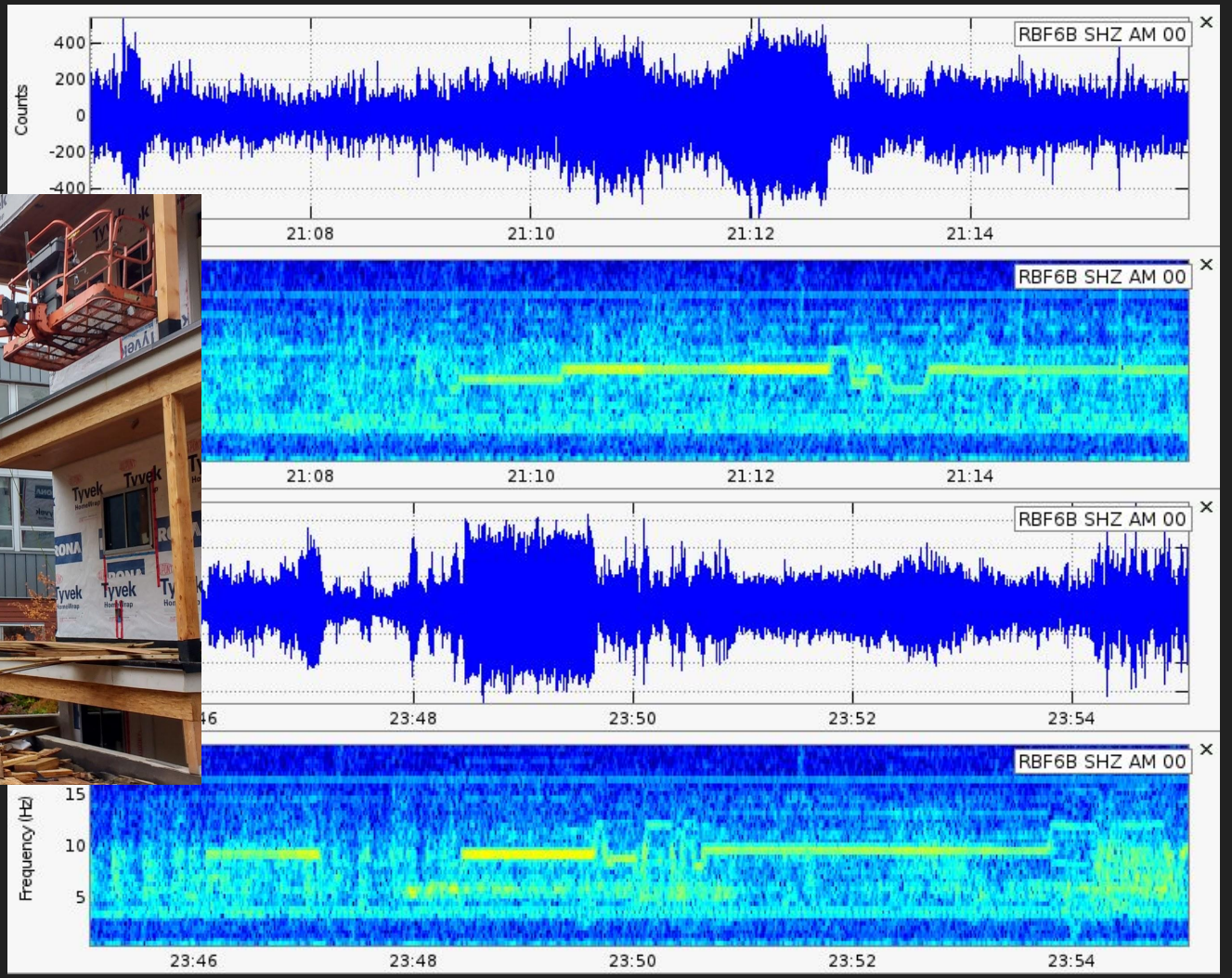


Spectrograms:

Noise



Spectrograms:
Noise



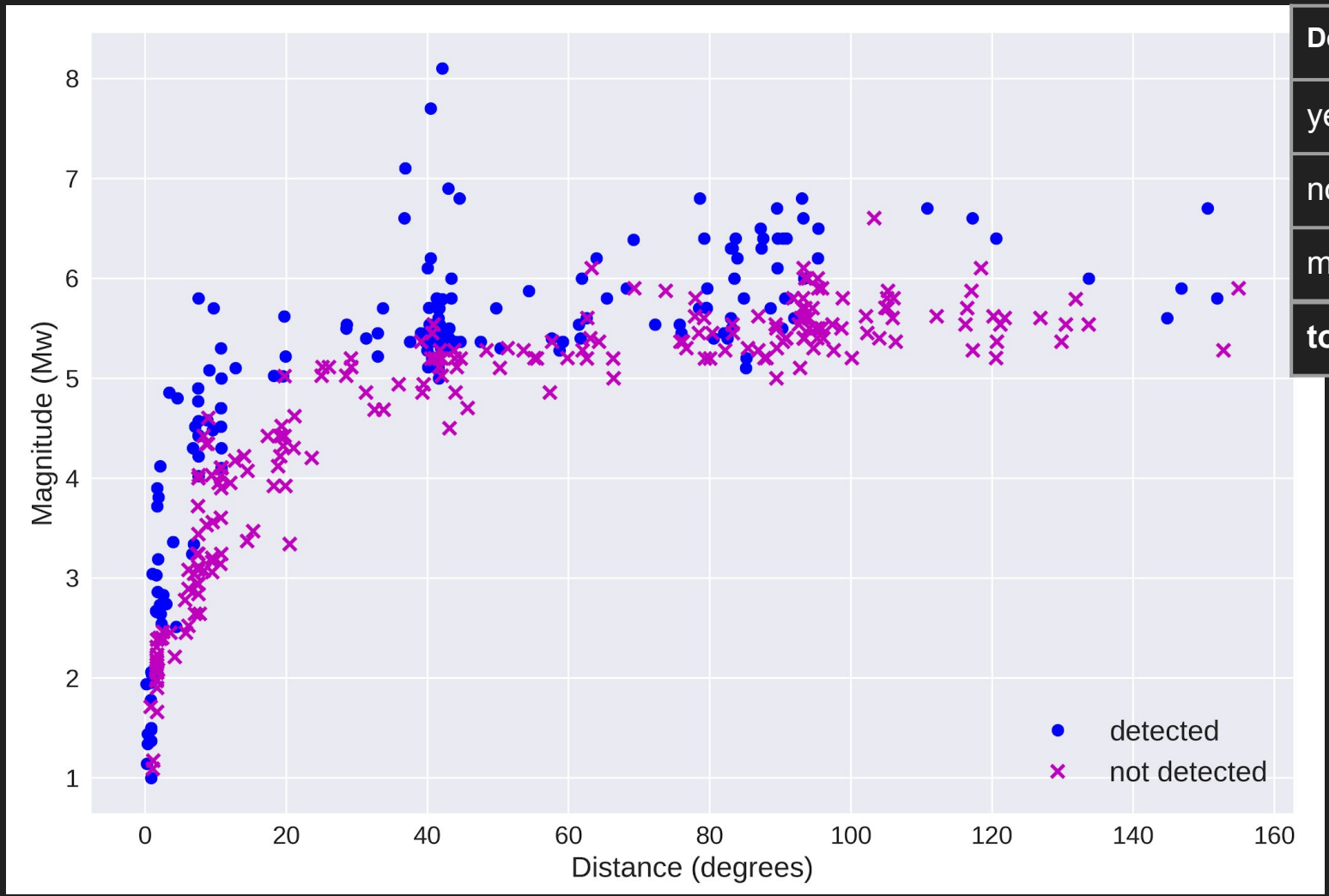
Summary

Data science time!

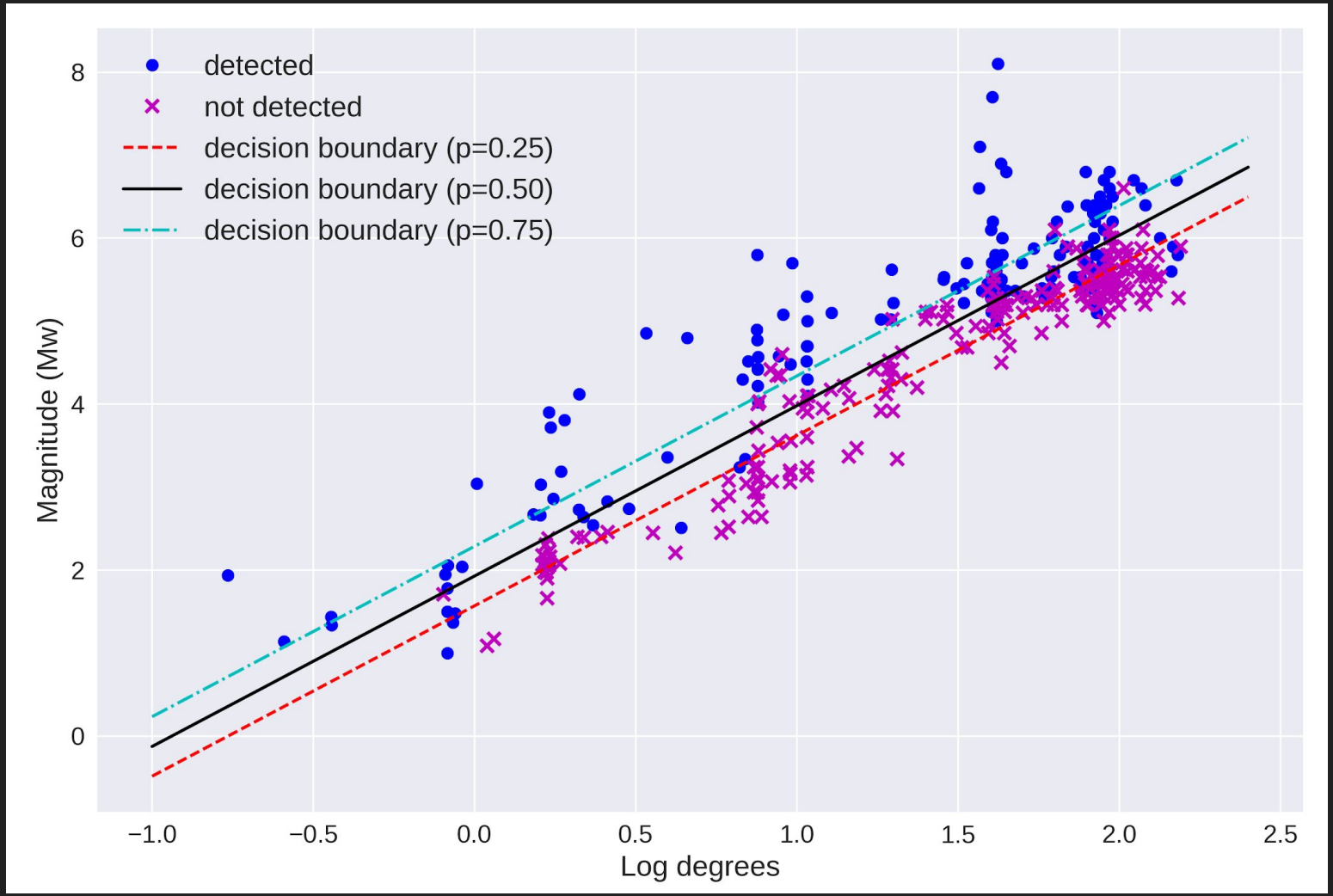
How many events did the Quest Shake detect?

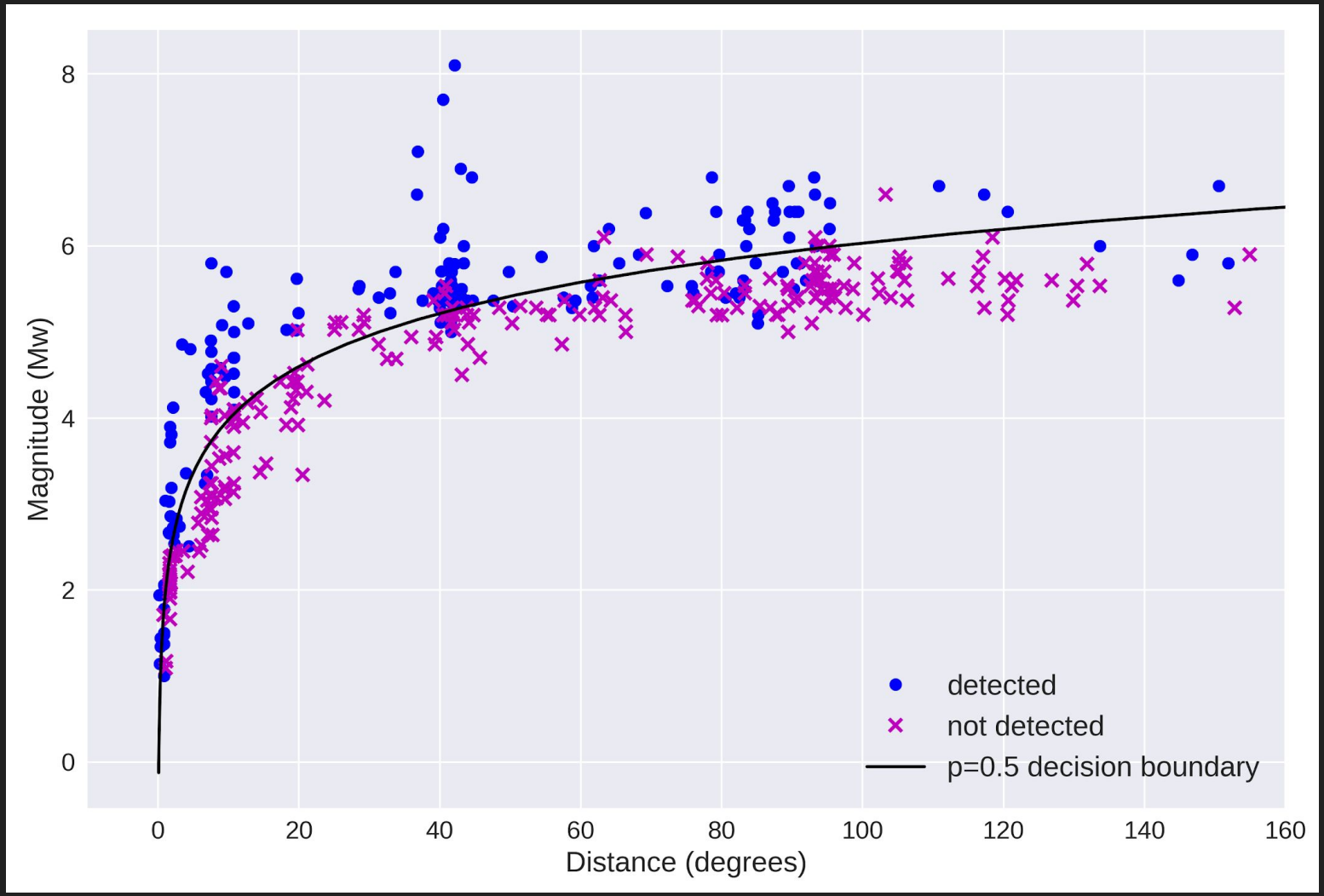
How does the sensitivity compare to the listed specifications?

Should we buy more Shakes?

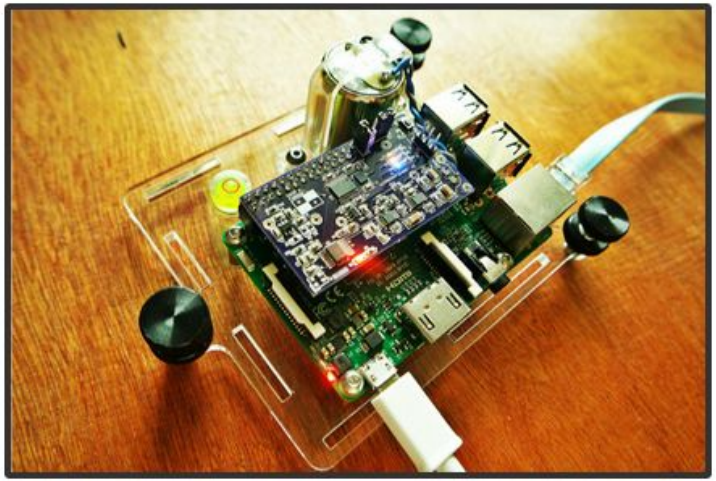


Decision	number
yes	173
no	222
maybe	61
total	**456**


detected
not detected
decision boundary (p=0.25)
decision boundary (p=0.50)
decision boundary (p=0.75)
Magnitude (Mw)
Log degrees
8
6
4
2
0
−1.0
−0.5
0.0
0.5
1.0
1.5
2.0
2.5


Magnitude (Mw)
Distance (degrees)
0
2
4
6
8
0
20
40
60
80
100
120
140
160
detected
not detected
p=0.5 decision boundary

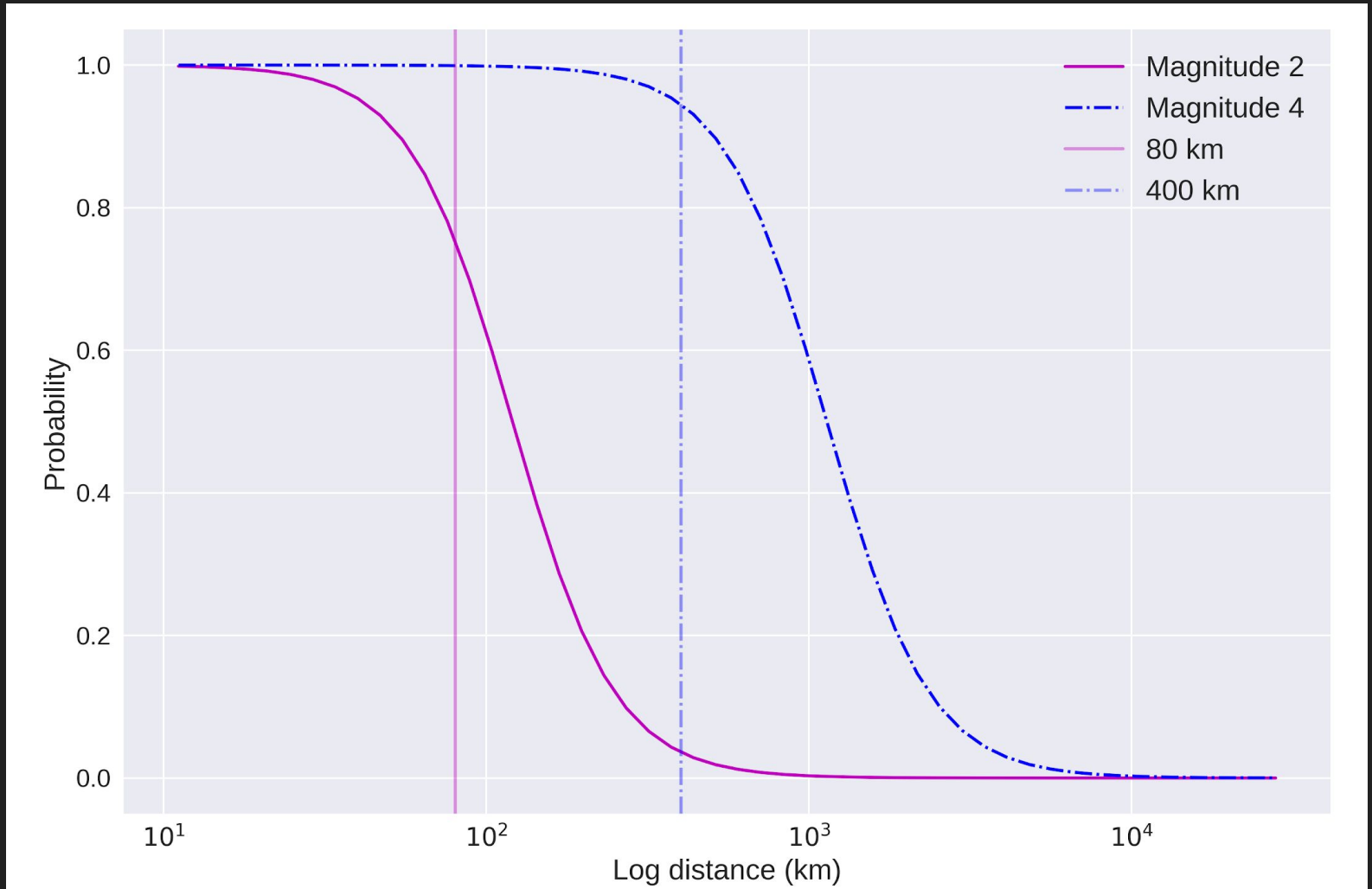
From the Raspberry Shake webpage:



- Earthquakes happen all the time! The Earth is always in motion. Now you can see it!
- Each Raspberry Shake is carefully put together by our experts and built with industrial quality hardware
- Watch the Earth's vibrations right from your home or office in real time!
- Monitor earthquakes and other Earth movements happening right beneath your feet
- Easily record local earthquakes that **you** actually felt

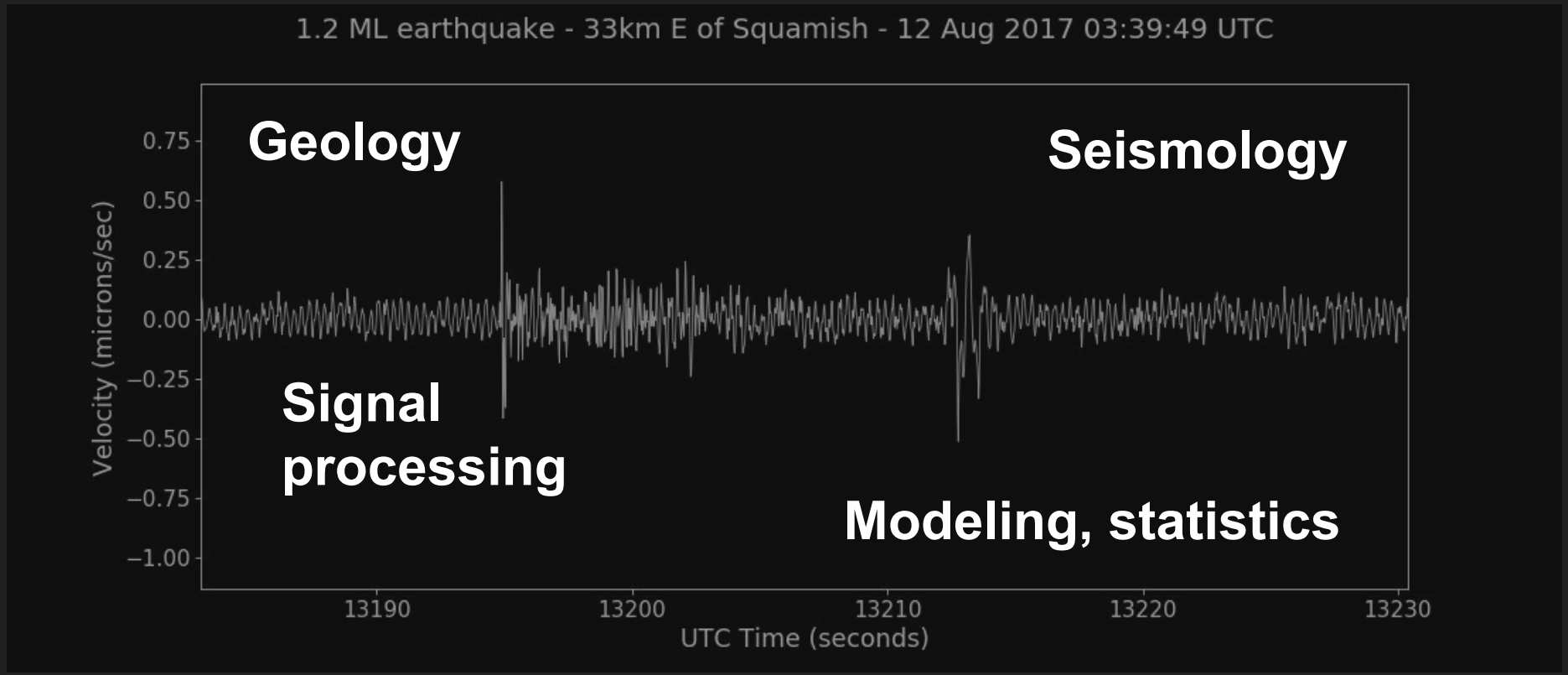
- Record earthquakes magnitude 2 and up within a radius of around 50 miles (80 km)
- Record earthquakes magnitude 4 and up within a radius of around 250 miles (400 km)

How good is our shake?	Mw 2 earthquake 41 km (for p=0.95)	Mw 4 earthquake 387 km (for p=0.95)


Magnitude 2
Magnitude 4
80 km
400 km
Probability
1.0
0.8
0.6
0.4
0.2
0.0
10^1
10^2
10^3
10^4
Log distance (km)

What's next?

Lots of possible projects!



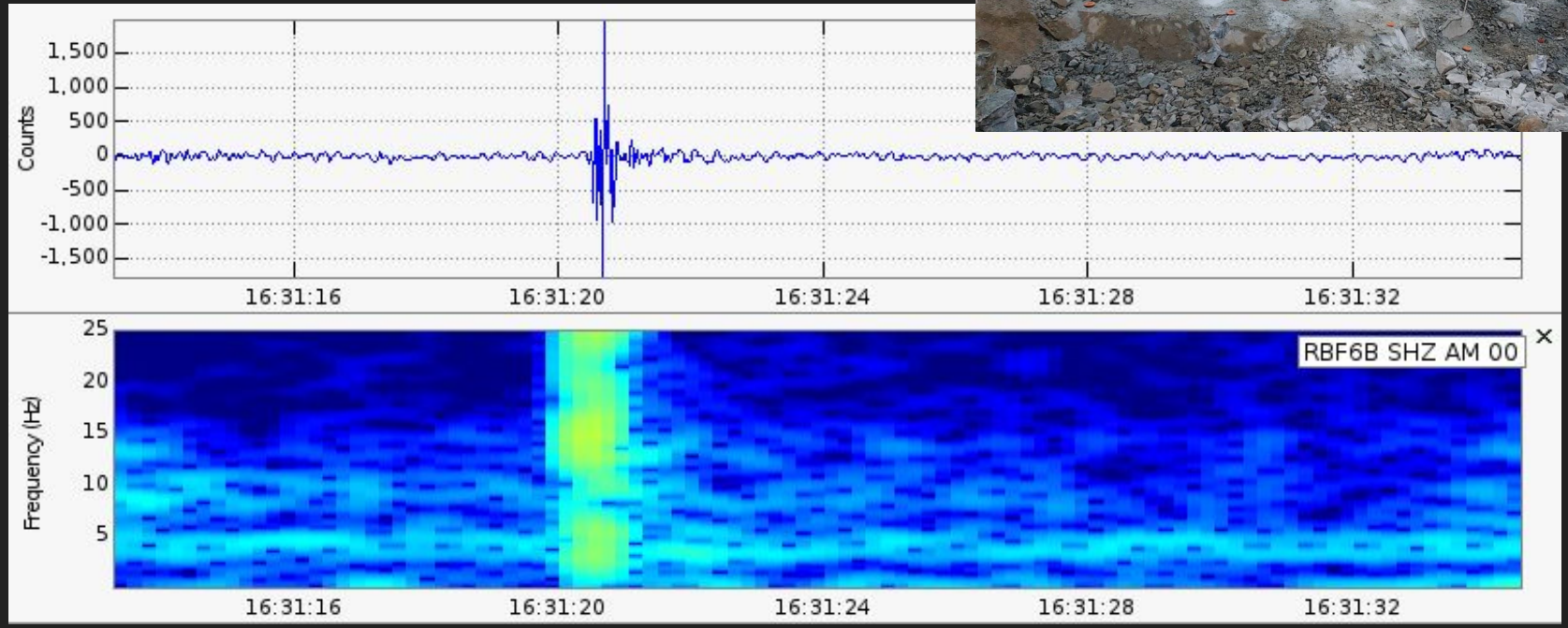
Extra Slides


Oct 1

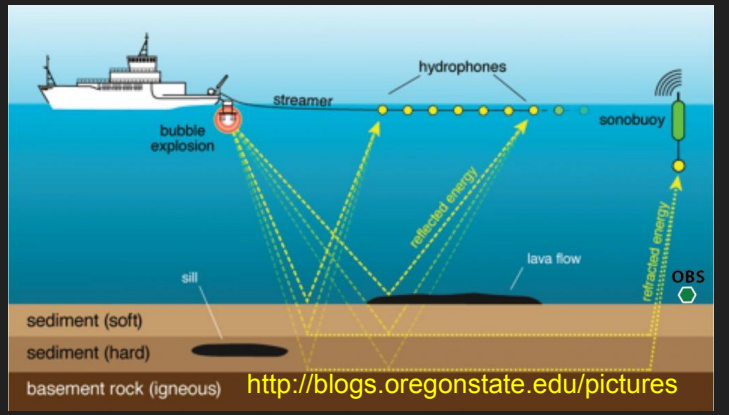

Oct 3

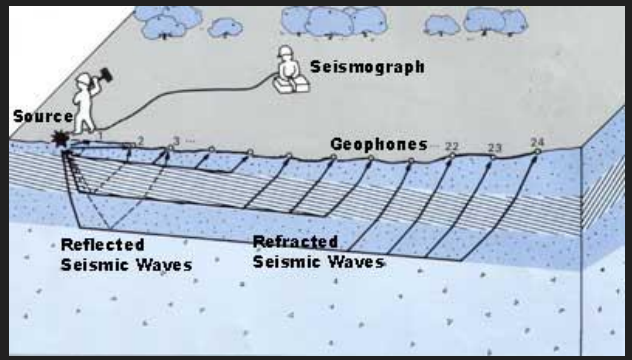

Oct 4

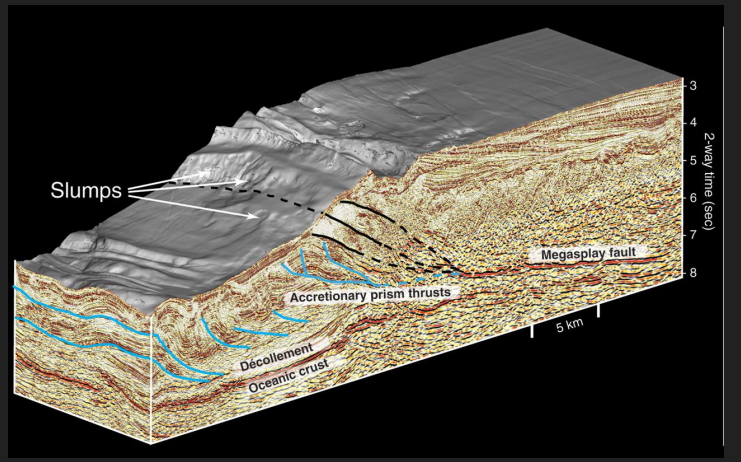

Oct 10

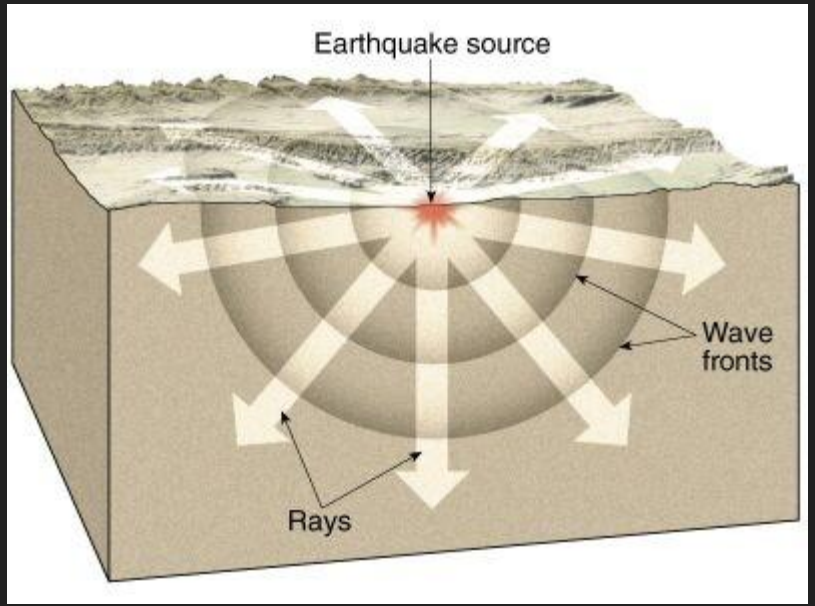

Counts
1,500
1,000
500
0
-500
-1,000
-1,500
16:31:16
16:31:20
16:31:24
16:31:28
16:31:32
Frequency (Hz)
25
20
15
10
5
RBF6B SHZ AM 00
16:31:16
16:31:20
16:31:24
16:31:28
16:31:32

Artificial seismic sources

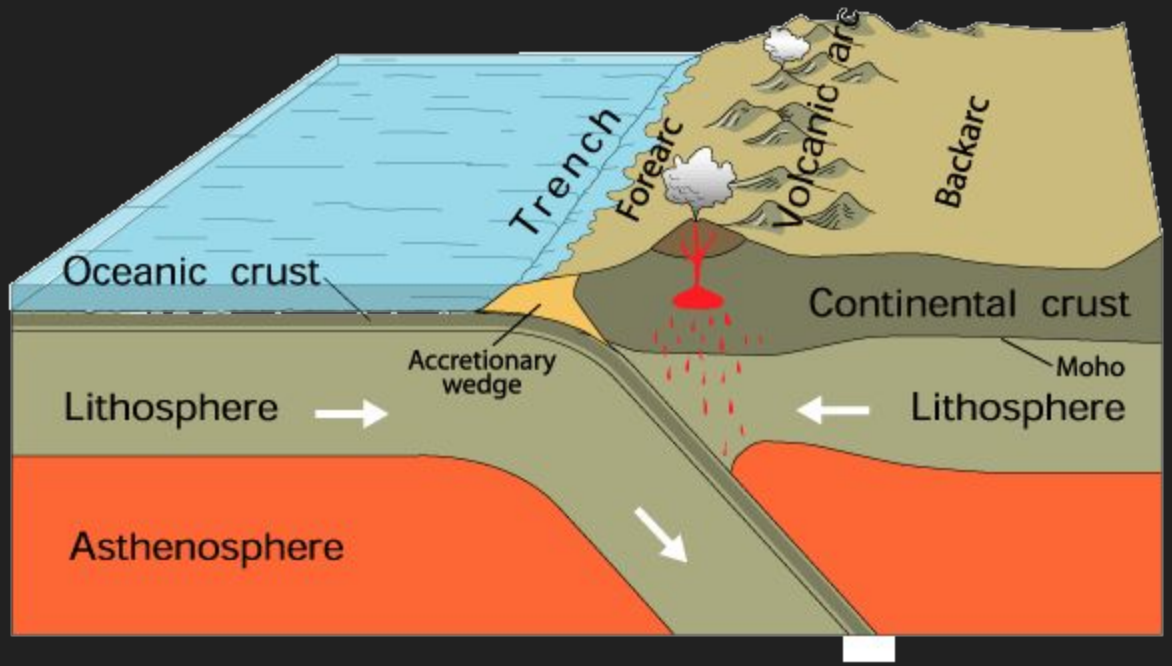








Waves in the Earth



A figure showing the oceanic plate sliding beneath the continental plate. Credit: USGS

Between 1 μm and 10 μm:

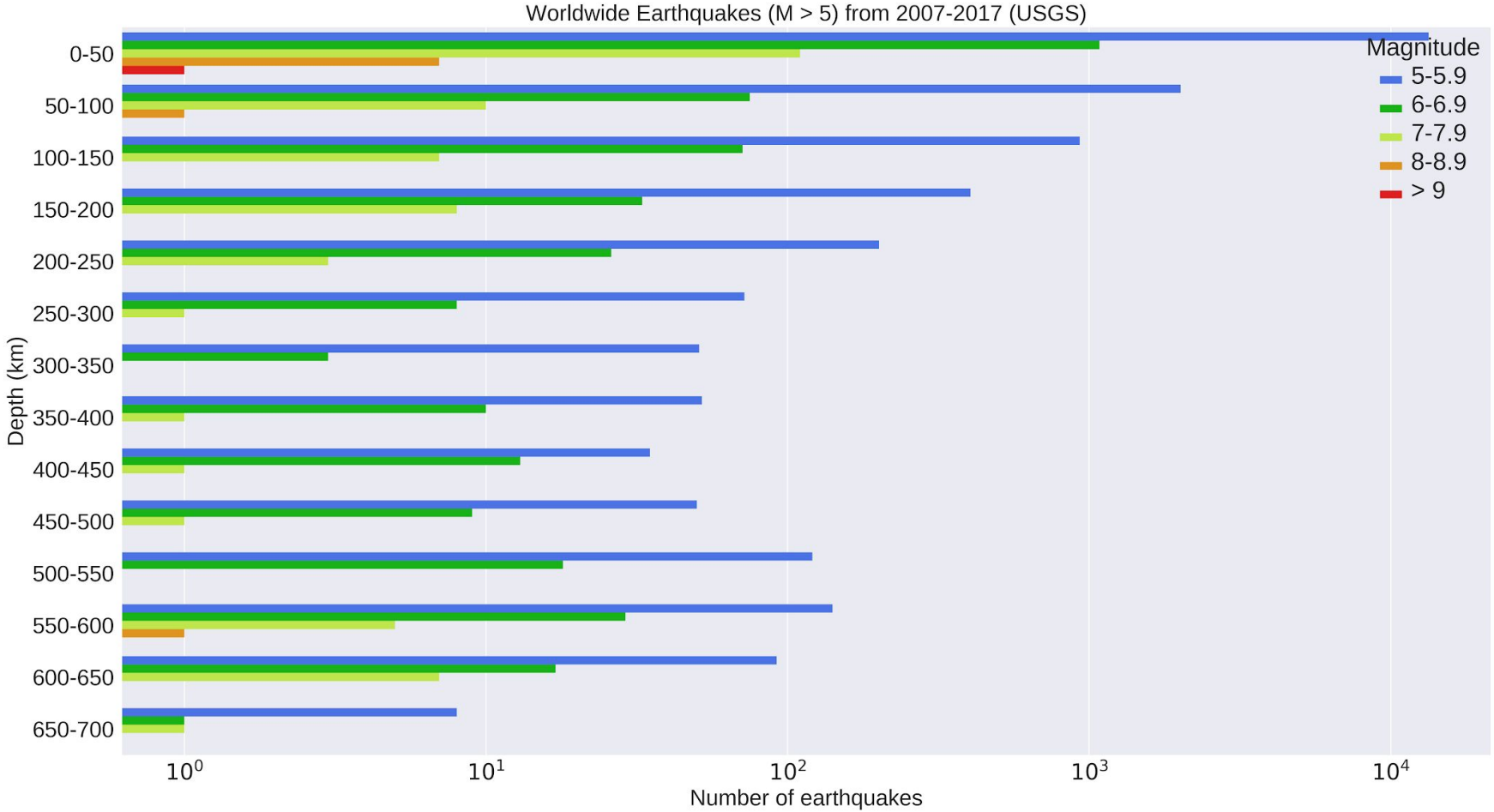
- 1–10 μm – length of a typical bacterium
- 10 μm- Size of fungal hyphae
- 5 μm – length of a typical human spermatozoon's head [3]
- 3–8 μm – width of strand of spider web silk[4]
- about 10 μm – size of a fog, mist or cloud water droplet

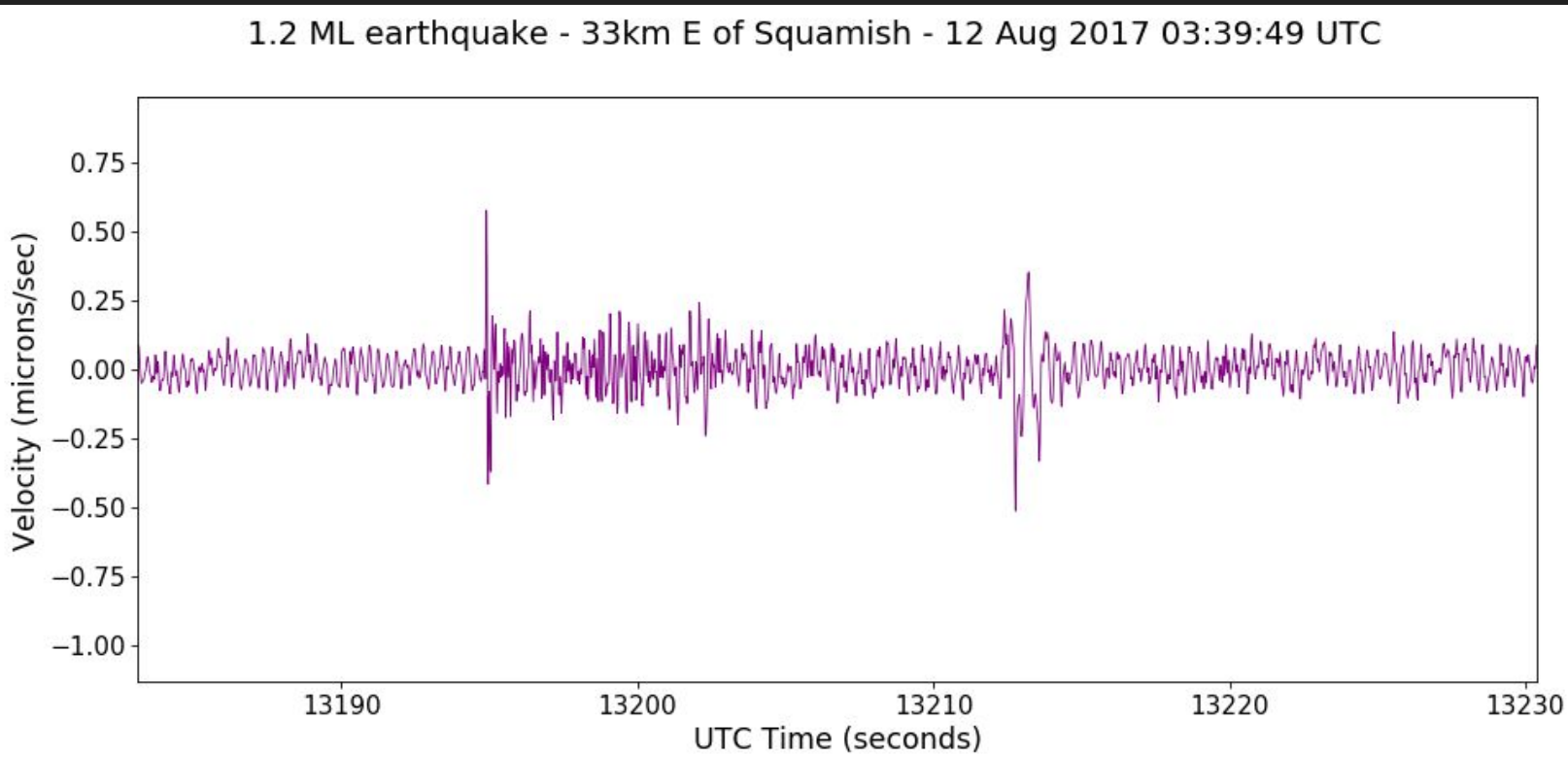
For more examples of things measuring between one and ten micrometres, see 1 micrometre.

Between 10 μm and 100 μm

- 10 to 55 μm – width of wool fibre[5]
- 17 to 181 μm – diameter of human hair [6]
- 70 to 180 μm – thickness of paper

Calibration:
A magnitude 0 earthquake would displace the needle 1 micron recorded by a Wood-Anderson torsion seismograph 100 km from the epicenter


Worldwide Earthquakes (M > 5) from 2007-2017 (USGS)
Depth (km)
0-50
50-100
100-150
150-200
200-250
250-300
300-350
350-400
400-450
450-500
500-550
550-600
600-650
650-700
Magnitude
5-5.9
6-6.9
7-7.9
8-8.9
> 9
10^0
10^1
10^2
10^3
10^4
Number of earthquakes


1.2 ML earthquake - 33km E of Squamish - 12 Aug 2017 03:39:49 UTC
Velocity (microns/sec)
0.75
0.50
0.25
0.00
−0.25
−0.50
−0.75
−1.00
13190
13200
13210
13220
13230
UTC Time (seconds)