# Activities in the Homestake mine

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LIGO-G080475-00-R


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# The three minesketeers!

**and D’Artagnan**

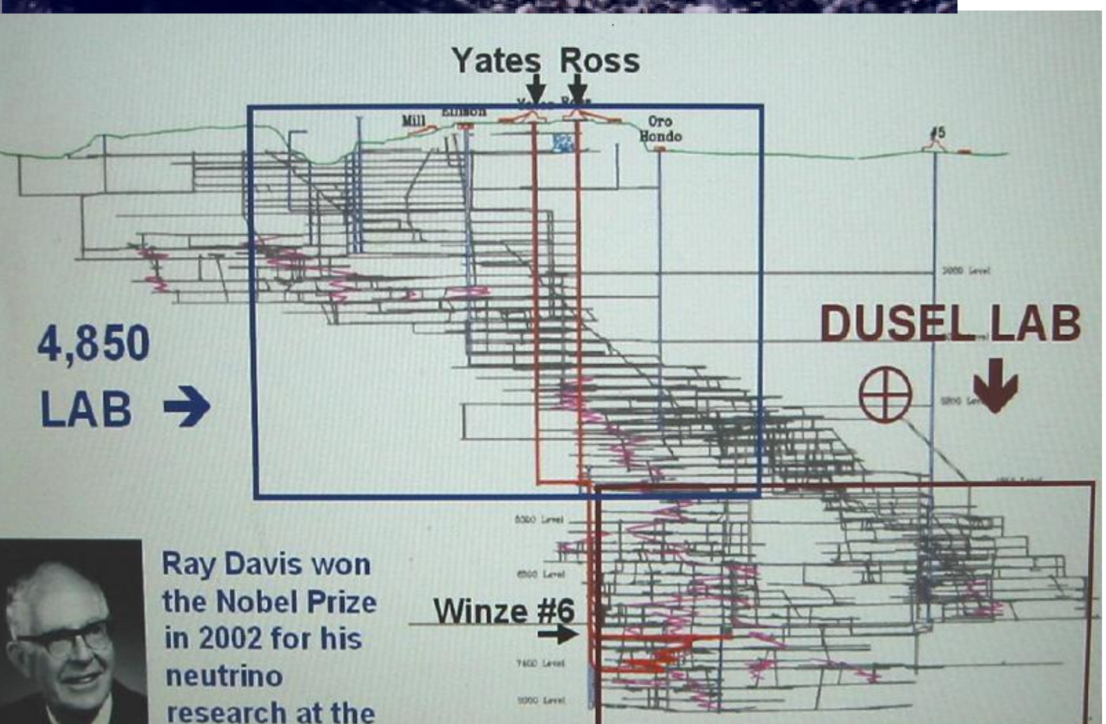
Jan Riccardo Angelo Vuk

# Who helped us

- Tom Trancynger

- Jason Van Beek, Bill Roggenthen,
- Gary Anderson, Robert Hanson,
- Trudy Severson, Bill Harlan, Kathy Hart, Tom Regan, Susan Von Stein,
- the shaft crew
- and many more

# What's Homestake mine?




- A little bit of history of this mine, former gold mine, for 125 years, then a site for science
- How big it is
- How important it is for local society (symbol)

# The big funnel

- The rain collects in this big open cut and flows in the mine
- During the inactivity years the mine filled with water
- Presently the water level is at the4535 feet level.
- Pumps are working to drain water out.
- Draining rate limited by the water processing times

# Why did we come to Homestake?

- We want to study the seismicity of this mine in order to verify if it can be a good site for an Underground Gravitational Waves Detection Observatory.

# Newtonian Noise

- We study the seismicity in order to study the Newtonian Noise (NN)
- NN is a fluctuation of the gravitational field
  acting the mirror test masses
  caused by masses in seismic movement.
- Surface movements and density fluctuations are the two main causes of NN on the
  GW Interferometer TM

# How do we do that?

We want to establish:

- a matrix of coherent sensor stations to measure seismic wave propagation

- From a vertical array we expect to measure the attenuation as function of z
- From a horizontal arrays we will study wave propagation

# What we’ve done:

- We already set up three seismic stations: 300ft, 800ft, 2000ft
- We got some preliminary data

# Activities:

- Physical work (building huts,pour cement..)

# Activities:

- Data acquisition (composition, calibration, elaboration)
- Network (private network, radio bridge, fibers)
- Timing (absolute time & synchronization)
- Mine culture (safety, language)

# The rules in the mine:

- An experienced miner always escort us underground
- Safety training necessary to use the shaft
- Appropriate personal protection equipment mandatory: SCSR, helmet, boots, light
- Access to the mine only in miners schedule, usually at 7:30, 12:00, 16:30, 21:00.
- Brass in/out system
- Tag in/out system

# Safety

- We had a week of safety training
- An average of 65 miners die every years working in US mines.
- “Everyone come home safe and healthy” is the motto of the mine
- Different way of thinking: more care in what you do
- Specific knowledge (PPE, SCSR, refuge chambers,scaling, etc..)

# Some dangers in the mine:

- Rock falling vs scaling
- Fire burning vs fire extinguisher & MSDS
- Poison gases vs SCSR
- Human falling vs falling protections
- Wounds & hits vs PPE
- Alternate evacuation routes vs  Mine Rescue Chambers

# Scaling

Scaling of overhanging loose stones is necessary before passing by

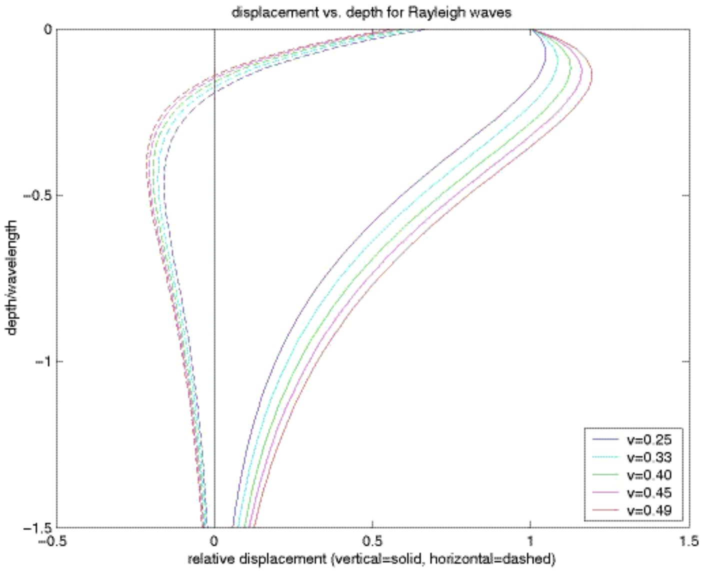
The rocks gets weaker

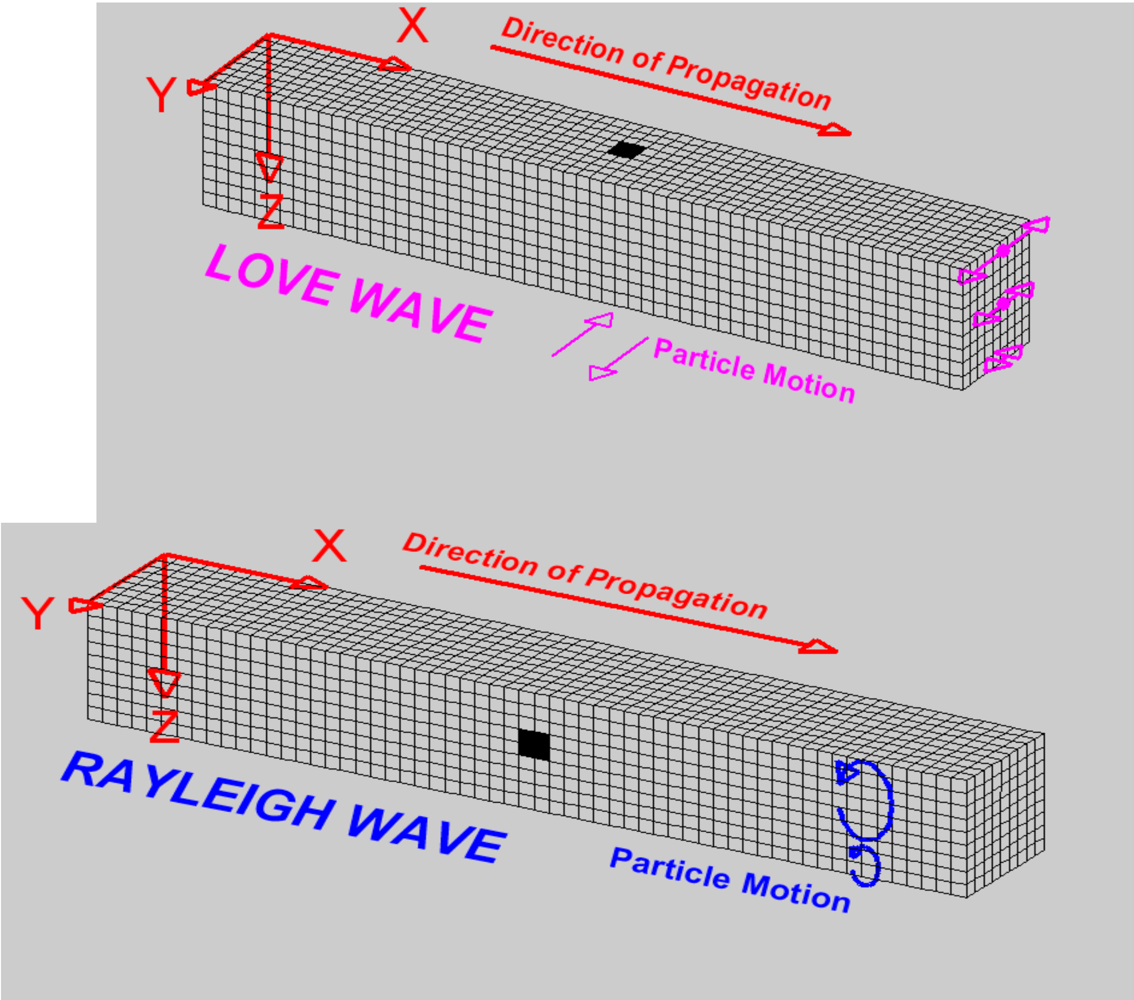
because of oxydation (mainly pyrite turning into limonite [rust] between layers)

They are loosened by the cycles of the moon that causes low frequency (quasi static) stresses.

# Something more about seismic waves:

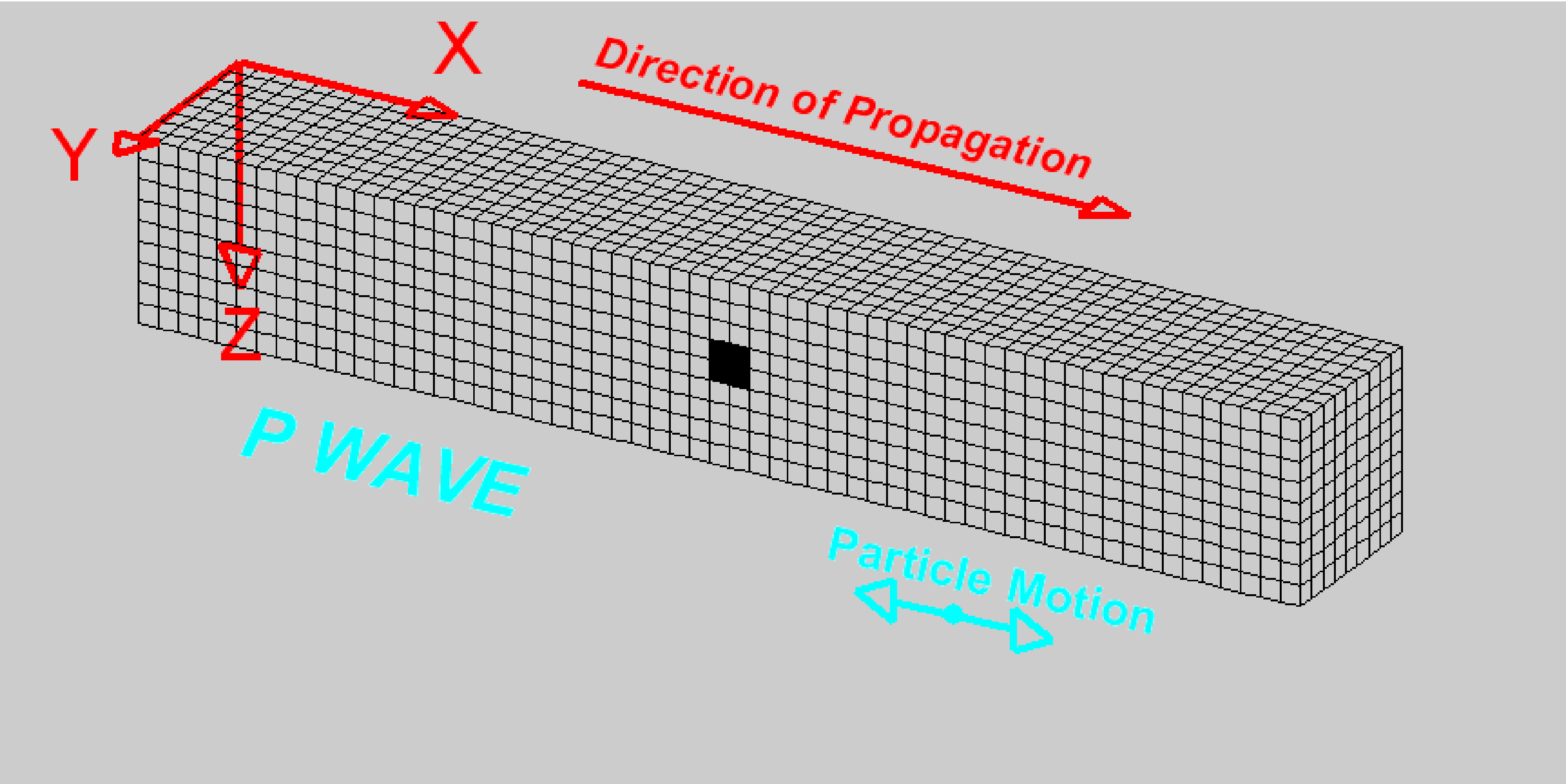
- *Some about attenuation with depth* (why does it attenuate?)
  – Raleigh and Love waves are only surface waves, and attenuate exponentially with distance from surface



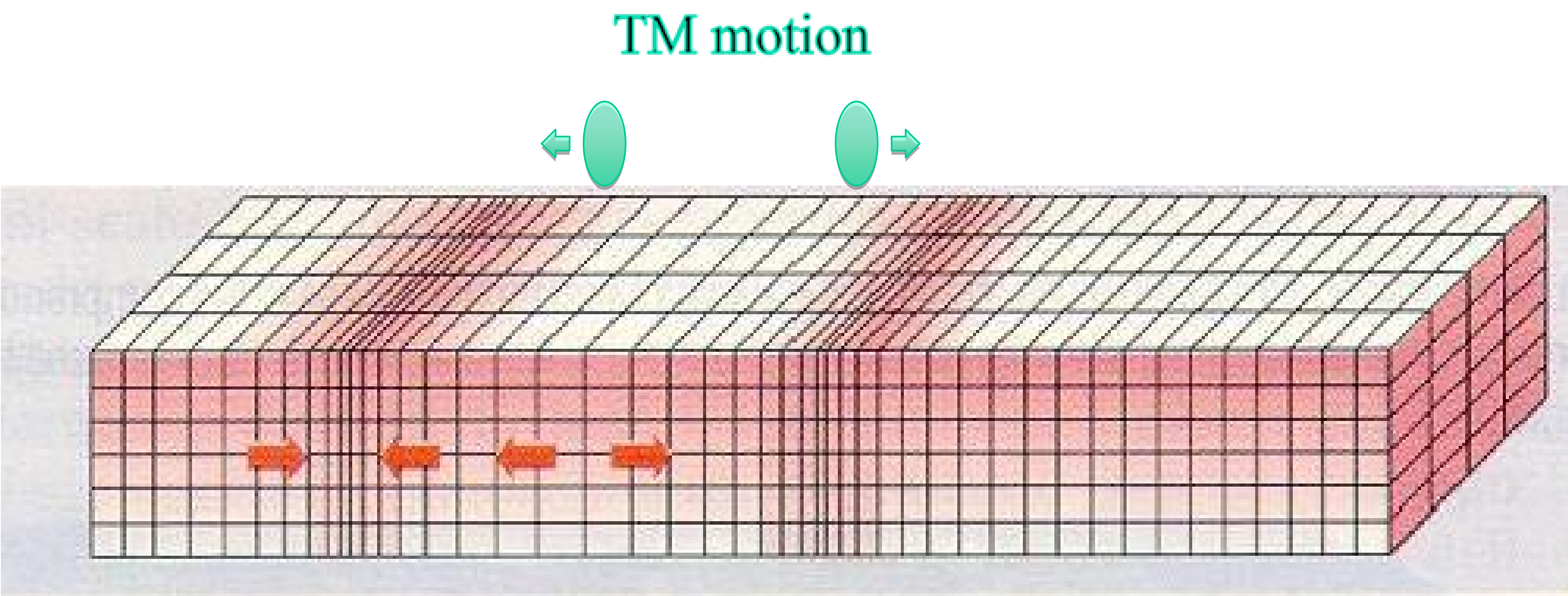
# P waves

–Near the surface the pressure wave increase because of the higher compressibility of rock (smaller sound speed) but after the rock becomes rigid (high speed) this gain fades.

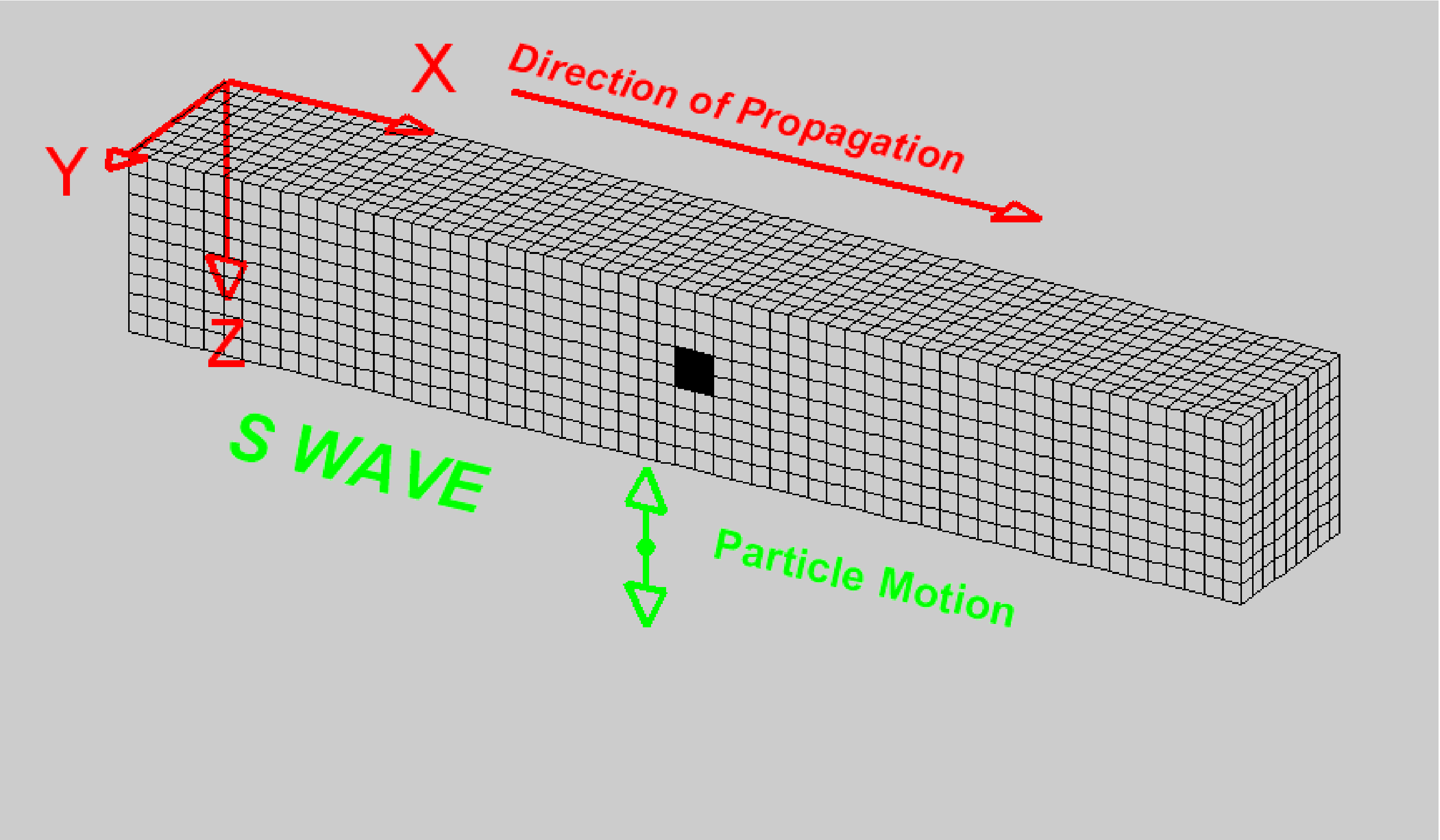


# Most relevant seismic signals:

- Pressure waves generate denser rock in front and behind the test mass,
- Mainly important when propagating along the beam line



# S waves

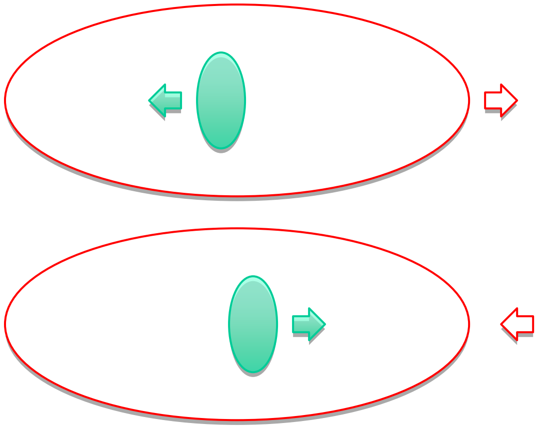


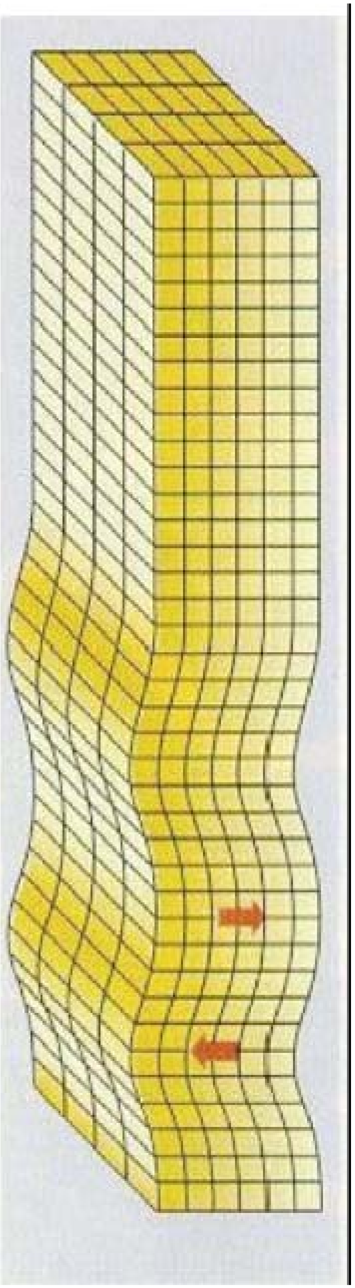
# Most relevant seismic signals:

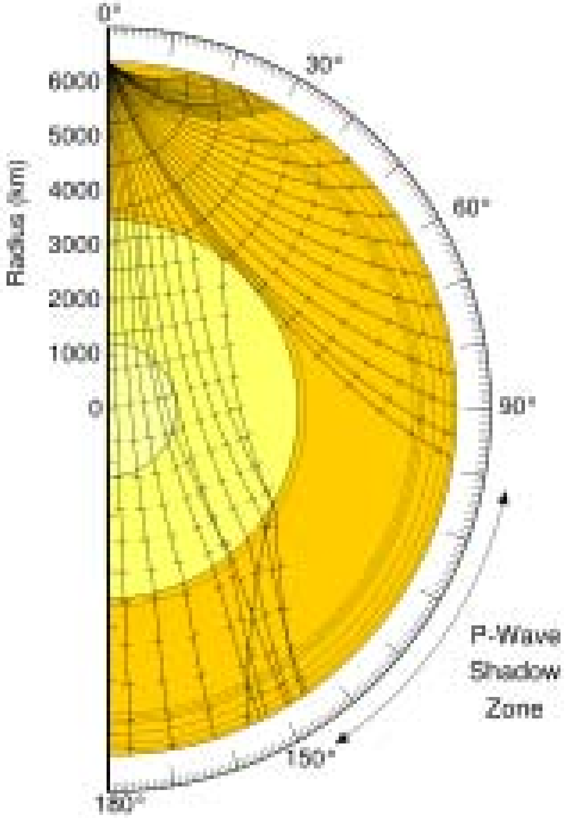
- Shear waves generate effects by moving the surfaces of the experimental cavern
- Mainly relevant when propagating across the beam line

Cavern moves right – TM left

Cavern moves left– TM right








- P waves comes from below
- Amplitude increases
  - with reflection,
  - for lower rock density
  - and for lower propagation speed

# Something more about seismic waves:

- *Pressure and shear waves eventually dominate at depth*

- *Optimal depth*

  Approximately when $v_{sound}$ saturates, the cross over point is close

  the surface waves are small, body waves start dominating

  All fractures /microfractures in the rock are closed

  We don’t need to go any deeper (cost)

# Subtraction

- Only residual solution is measure seismic activity and subtracting its NN effects

- Models are insufficient and site dependent
- Best to measure rock density and position than its acceleration
- Need local measurements

# Seismic sources

- We are interested in seismic activity in quiet periods
- Sum of all noises in the world with arbitrary delays (silent earthquake, tide creak, etc)

# Wavelenght

- $v_{sound}$ =5 km      f=1 Hz      $\lambda$=5km
- waves can see only defects comparable or greater then $\lambda$ /2*$\pi$

- Microcracks invisible
- Short wavelenghts mass density fluctuation invisible

# What else can we measure with the seismometers?

- Broadband Seismicity

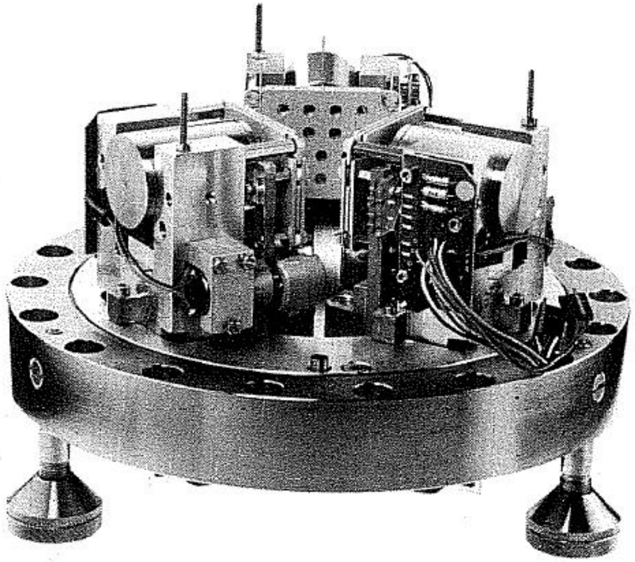
- Settling activity of the mine as it is pumped dry

- Monitor microseismic peak variations (one of the deep locations farthest from all oceans)

- Etc.

# STS-2


*STS-2 - High-Performance*



The main features of the STS-2 seismometer are:

Bandwidth suitable for general-purpose teleseismic and regional recording: corners at 120 sec and >50 Hz

Small size (235 mm dia. x 260 mm) and low power consumption (< 1.8 W)

The STS-2 is a single sealed, all-metal tri-axial sensor package that includes all essential electronics

Quick installation and setup using no special tools or instruments. Setup features include a built-in bubble level, an automatic recentering circuit, and conversion to 1-second free period operation to reduce transient response time during centering and levelling adjustments

Wide temperature range operation: minimum ± 10° C without recentering

Robust transport locking mechanism actuated by rotation of an externally accessible screw for each sensor without opening the sealed sensor package

Enhanced resolution of short periods using a capacitive displacement transducer

Strong electromagnetic feedback giving high dynamic range in the mid-frequency range of 0.1 - 10 Hz, where local and regional events generate high peak amplitudes

No external pressure shielding required for most broad-band and long-period applications

The relevant characteristics of response and gain are fully calibrated by the manufacturer. Neither internal nor external nor computational adjustment is needed for proper operation

GURALP SYSTEMS

# GÜRALP CMG-40T

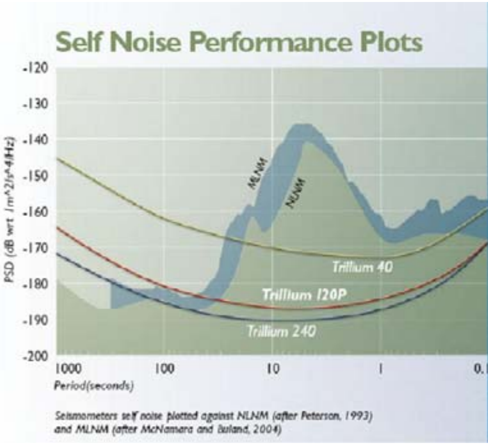
## BROADBAND SEISMOMETER

- Truly portable seismometer with lifting handle, and easy access to electric connection.
- Direct velocity output broadband feedback seismometer.
- Suitable for local, regional and teleseismic recording.
- Mass clamp not required.
- Mass centering not required.
- Adjustable feet with sapphire tips to reduce analogue ground loops.
- High and low gain differential velocity outputs.
- Long period response; 10, 20, 30, 60 and 120 seconds options.

- Short period response up to 50 Hz.
- Low power consumption, 0.5 Watts.
- Stainless steel construction.

## Trillium 240

The Trillium 240 is an exceptional very broadband low noise seismometer ideally suited to portable and fixed network applications. Trillium 240 has a response flat to velocity from 240 seconds to 35 Hz and a self-noise below the NLNM from 100 seconds to 10 Hz.




### The benefits:

- Very broadband performance from a portable low power seismometer
- Web browser interface replaces breakout box
- Factory calibration stored on seismometer, accessible via browser interface
- Extremely low power consumption, advantageous for remote installations
- Switchable XYZ/UVW output to provide independent calibration of sensor elements and electronics
- Thermal design optimized for temperature-insensitivity allows external thermal insulation requirements to be reduced

The Trillium 240 is an advanced force feedback seismometer with a velocity response flat from 240 seconds to 35 Hz. Self-noise is below the NLNM from 100 seconds to 10 Hz, allowing the instrument to take advantage of quiet sites, recording more of the earthquake spectra at longer periods.

The Trillium 240 is simple to deploy and operate. Nanometrics' field proven mass suspension system means there is no mass lock to forget when shipping. Once onsite, an integrated bubble level and truly accessible leveling feet allow for quick deployment in vault or post hole installations.

One-touch mass centering ensures the masses are centered the first time, every time, with no possibility of the mechanism sticking or jamming. Mass position outputs and a mass centering control line are accessible via the single seismometer connector mounted on the base of the unit.

# Our Stations:

Structure of the stations' system:

- computer hut
- instruments hut

Stations connected through fibers:

- synchronization of the clocks!

# Our dream spot

- Blind tunnel
- Large pad of concrete well attached to the bedrock
- No acoustic or human/artificial seismic noise

- 800 feet pretty good

# How did we design a seismic station and why?

- Mechanical Connection to Ground
- Quiet location
- Acoustic insulation
- Power
- Data acquisition
- Connectivity
- Environmental Monitoring

# Ground connection

Clean rock to insure
Binding of  concrete
to rock

# Acoustic and airflow insulation

# Suppressing local noise sources

# Thermal/acoustic insulation


- Foam panel boxes avoid rapid air-flow thermal shocks to the instruments
- Matrioska dolls to improve insulation!
- Blanket to avoid micro-convection

# Data acquisition

Taurus DAQ (from Nanometrics)

PCI  DAQ card

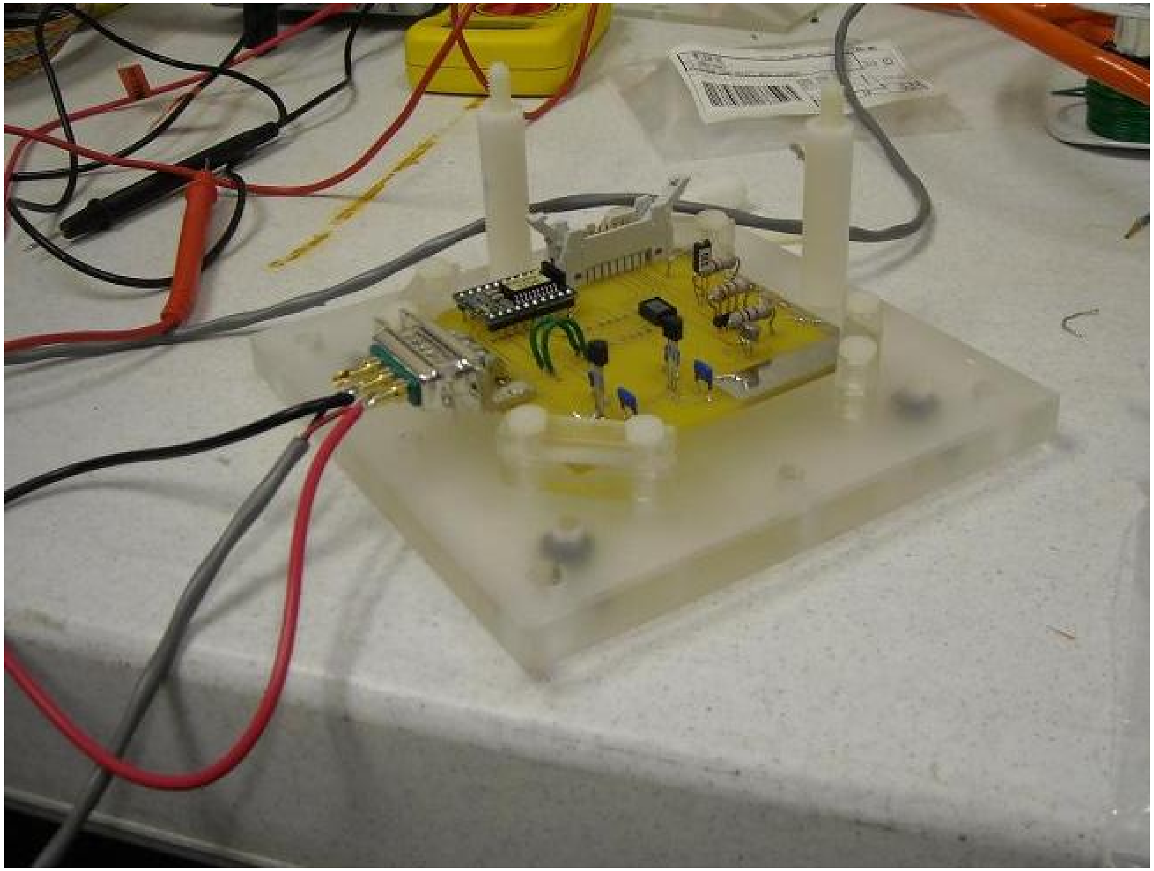
# Internet Connectivity

- Antennae as directional radio bridge down the shaft
- Fibers on each level
- private network
- remote desktop connection to control local computers and sensors from surface
- ftp to transfer data

# Timing issue

- We want synchronized clocks, consistent with the absolute time.
- 10 msec Indetermination in knowledge of absolute time
- .2 ms maximum relative error (surface/300 ft) with antenna and ethernet cable and known average delay of 2.2 msec.
- we did not start yet timing with laser pulses and fibers (which will be with ns errors)

# Environmental monitoring



Temperature
Pressure
Humidity
Magnetic field

Soon

Microphone
CO
$O_2$
Micro-anemometer

# Dry Lab

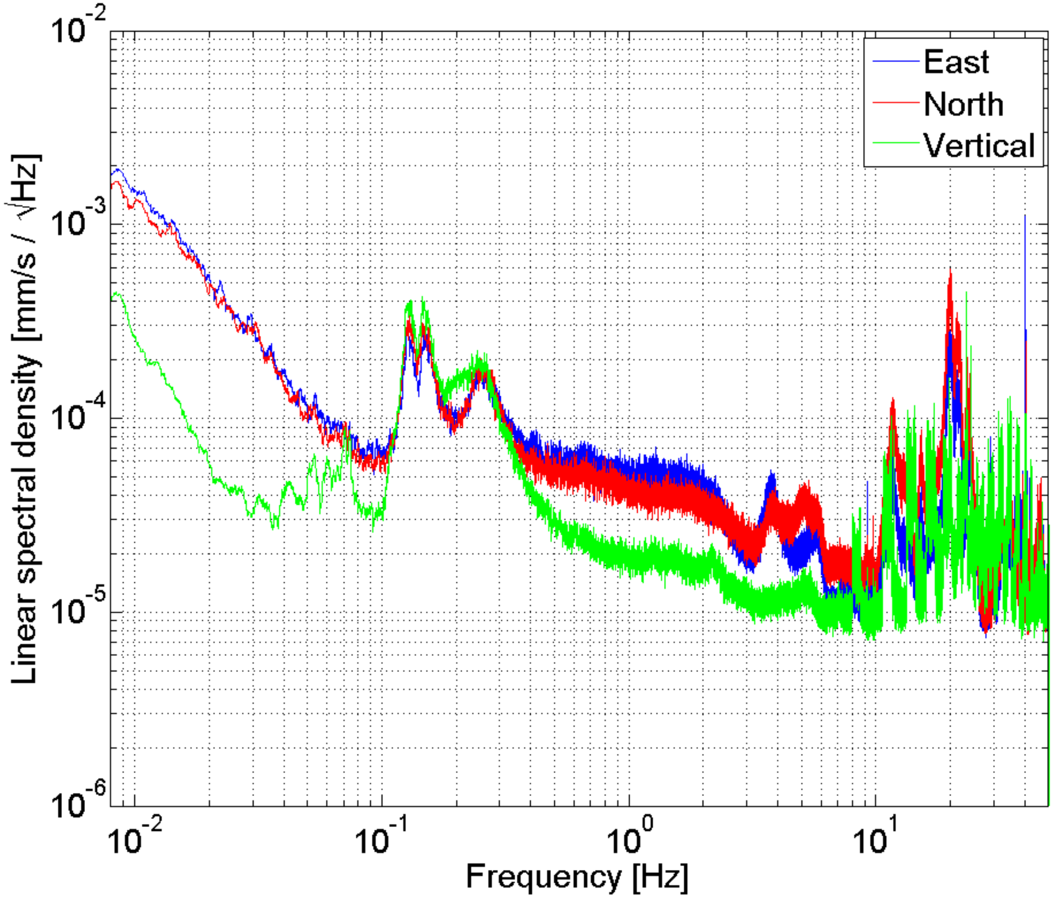
- Our surface laboratory is in a building close to the ross shaft, we called it Dry lab
- Here we tested our seismometer and we assembled our PCBs (hygrometer, thermometer, magnetometer, ground and barometer) and tested it.
- We wrote our elaboration files mainly here.

# 300 L

# 300 level

- Our site is a chamber along a drift located about 300 feet far from the Ross shaft.
- It is very wet, probably not very good for "science", is our test lab.
- We built a computer hut and an instrument hut, then a small box inside it with a thin layer of concrete to fight against water.
- We carried internet via 2 antennae that work as a directional radio bridge.

# First data



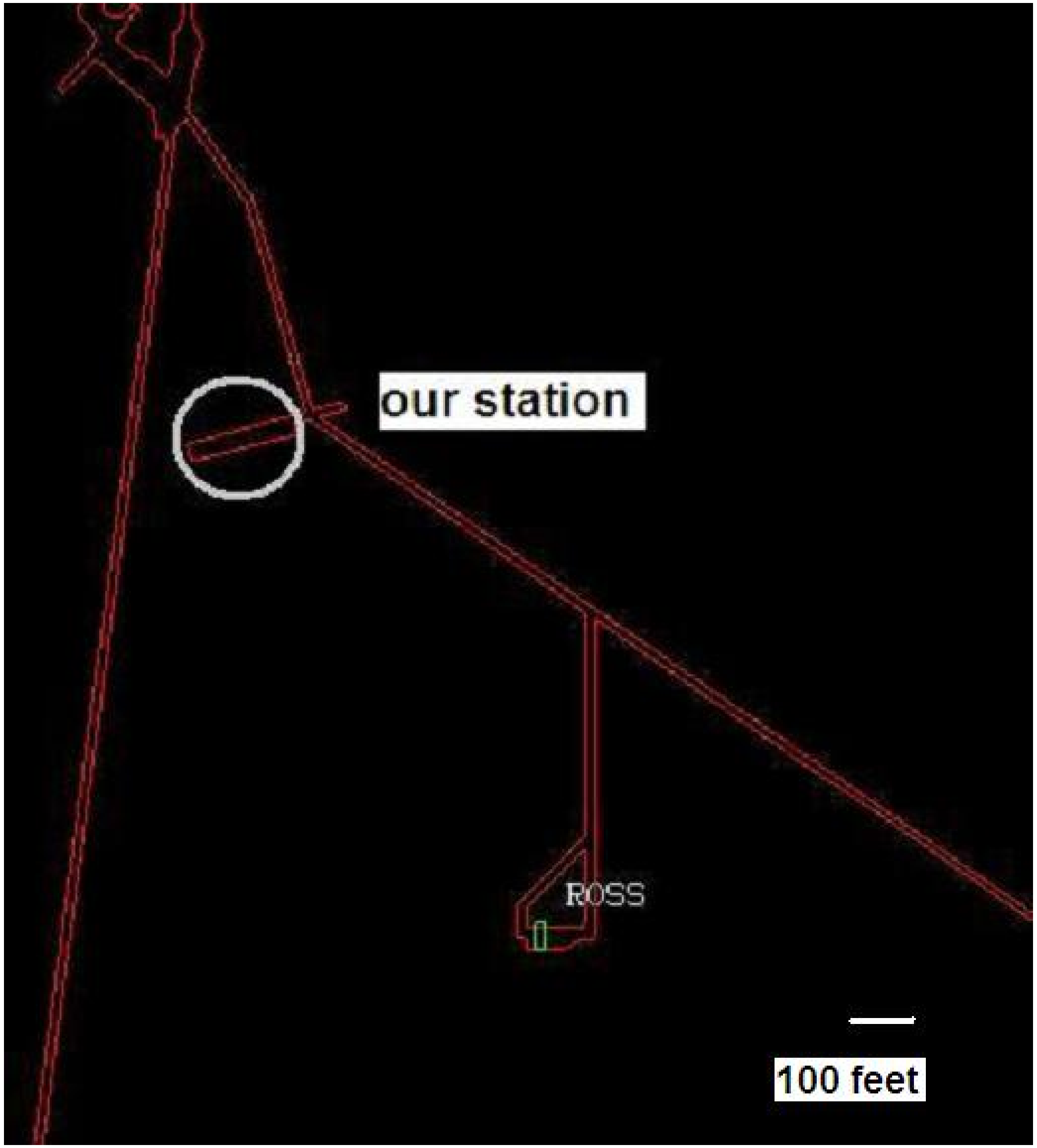

Multiple peaks from multiple oceans?

We have our first data to deal with: our instruments are running on the 300 ft site.

The thermometer, barometer and the other environmental sensors gives reasonable output: they are working!

Also after some good elaboration work we had some first graphs to show: this figure is a periodogram where each value is averaged with the 100 following values.

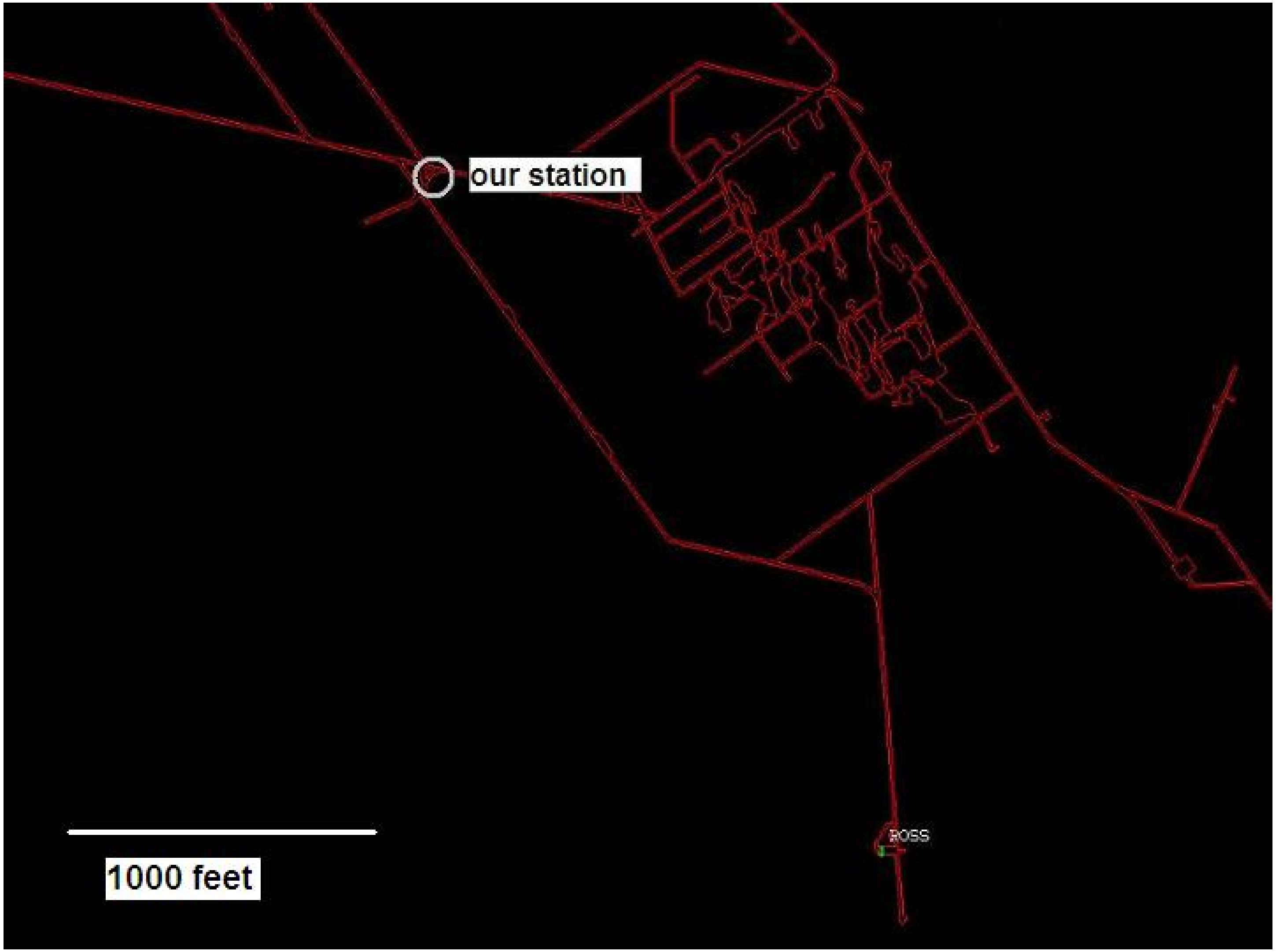
# 800 L



# 800 foot level

- Our site here is a nice and dry blind tunnel, almost ideal.
- This room was a dynamite storage, now it has only some timber shelves
- We dugour pit for the instruments, then poured cement and build the hut.
- Since it stays lower we made a nice ladder to get into.

# 2000 L



# 2000 level

Our site at 2000 level is unusual: is a bridge tunnel that joint two bigger tunnels about 2200 ft far from the Ross Shaft.

We built two walls around that drift in order to stop the air flow.

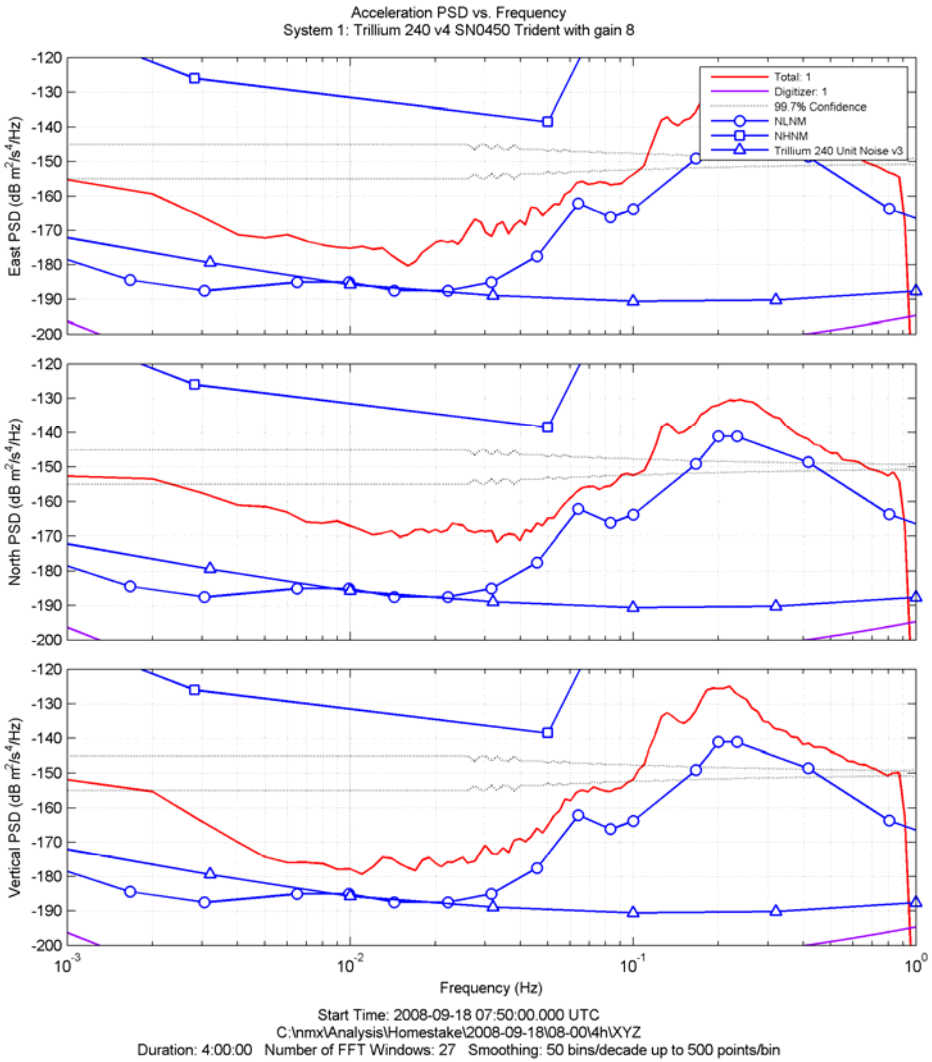
# Eliminating a hanging rock just in front of our site!

# Instruments

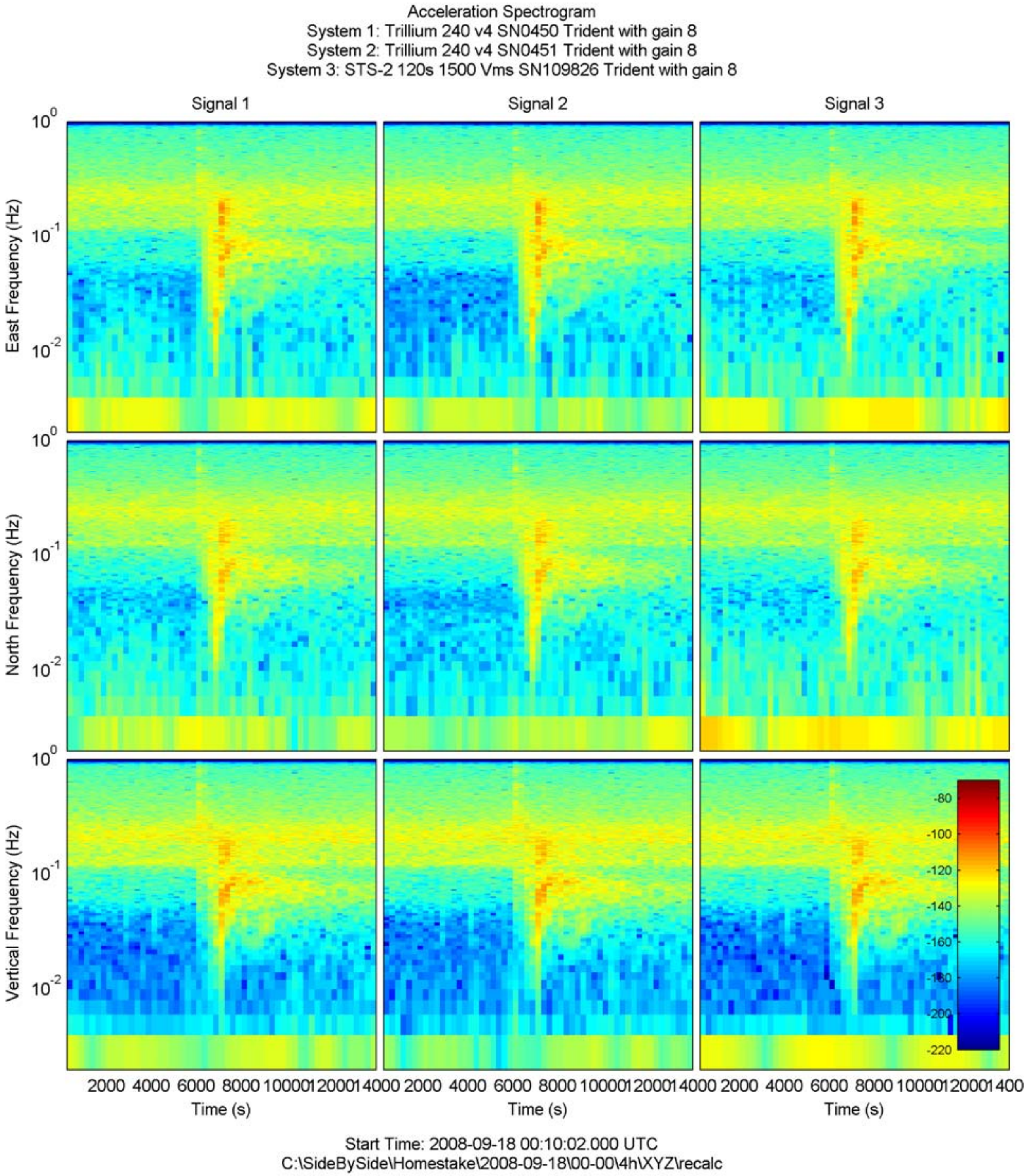

- 3 instruments to get cross-calibration and to find eventual bad installation
- 1 Sts-2
- 2 Trillium
- Taurus as digital acquisition

# Installation procedure

# Trillium 240 data

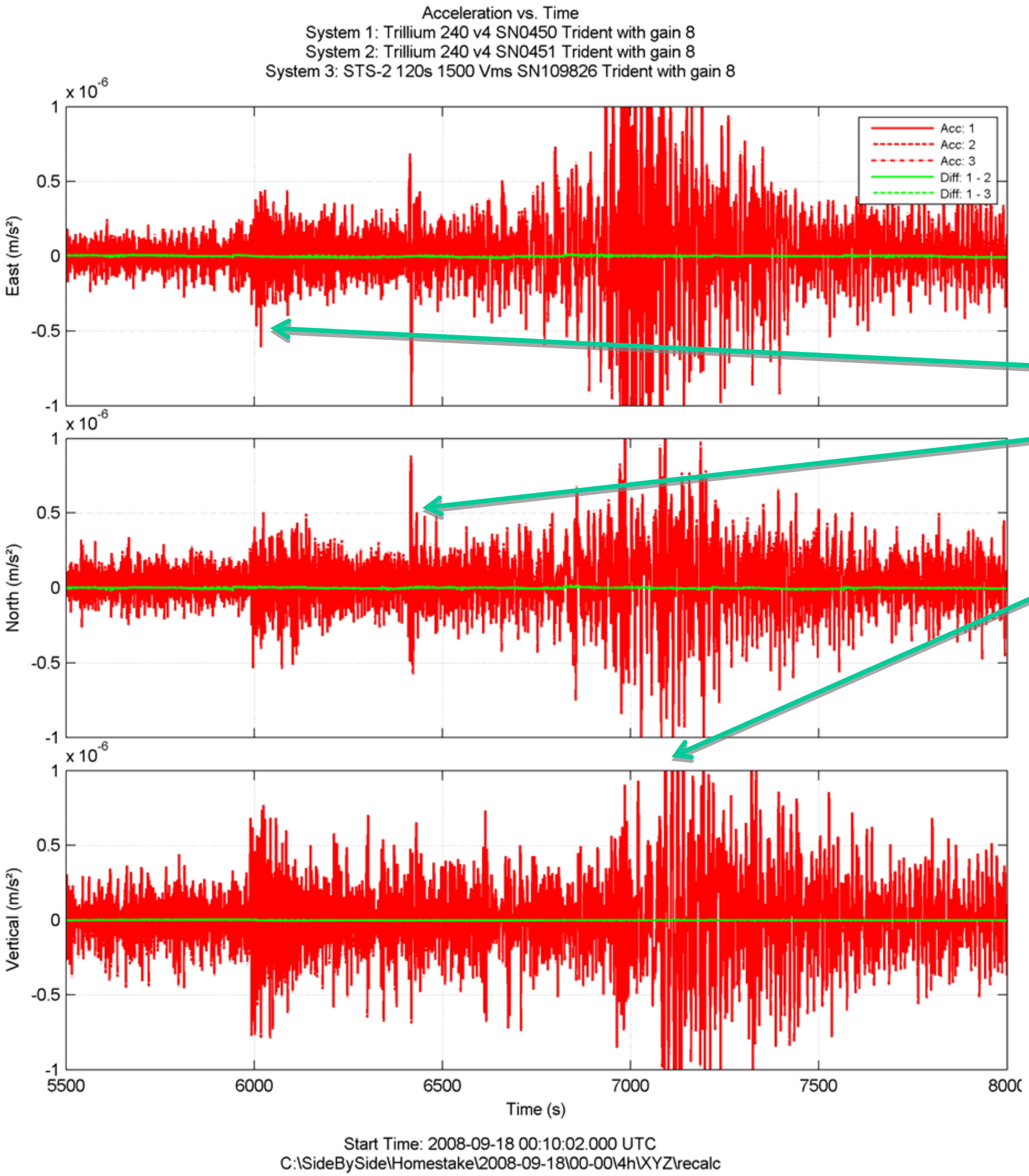



- First set up
- First two days of acquisition
- Peterson (1993)
- The result on the horizontal is just 10 dB above the NLNM on the E/W channel




# Trillium 240 and STS-2 data

- East Pacific
- 6 magnitude event




# Earthquake details

- P and S wave arrivals, surface coda
- From delays we roughly estimated 4100 km away
- To be compared to actual distance of about 5200

# Little drawbacks during the way:

- We could not go deeper then 300 ft in the first several weeks
- Water didn’t want to leave our instruments hut, despite all our efforts
- No power on the antenna on the 300ft for more than one week
- We changed our location (for safety reasons, after starting developing the sites) both on the 800 ft and on the 2000
- Long time spent waiting for the cage to come
- et cetera, et cetera, et cetera

# What to do, short term

- Switch from Taurus to PC acquisition
- Cross-calibrate instruments
- Migrate to other stations

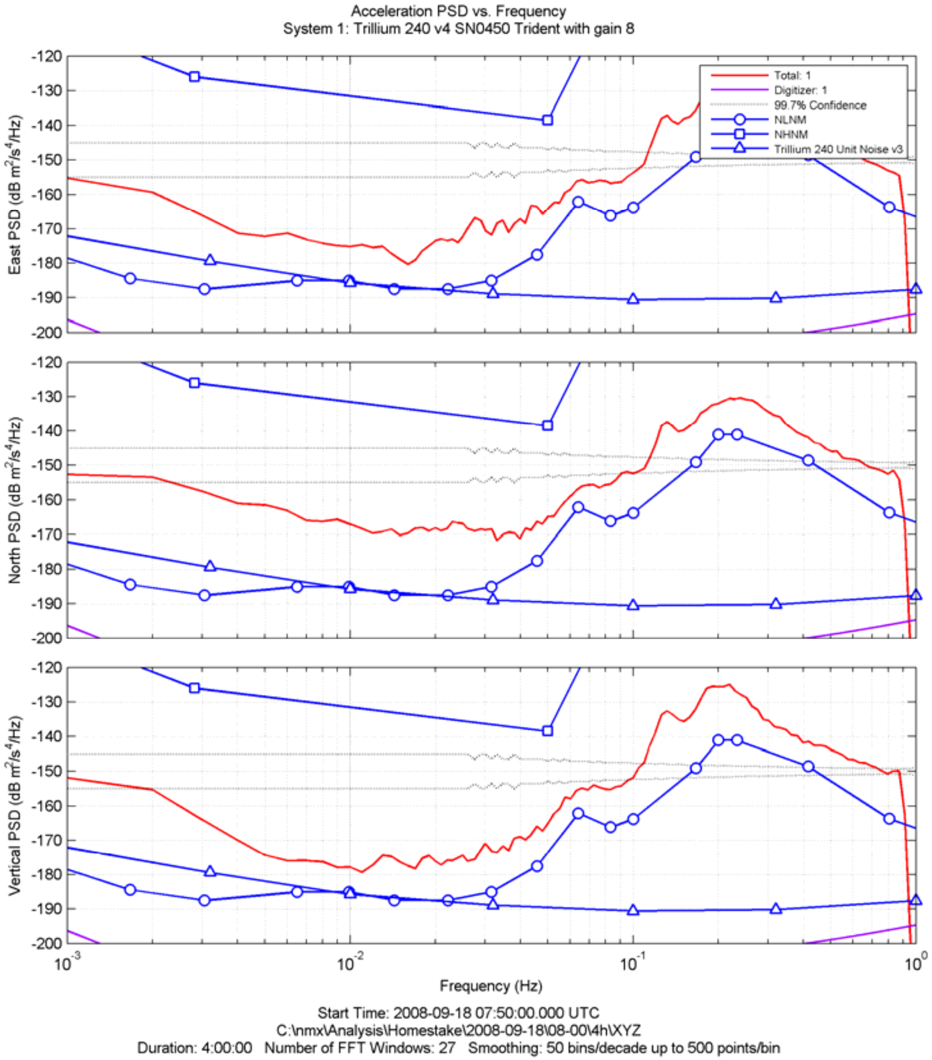
# What in future, over the years

- Establish good arrays of inertial sensors to measure movement of rock
- Develop optical bar for direct measurements of rock deformation (pressure waves)
- Develop optical bars from rock to inertial test mass (shear waves)

# Our final product

- Eventually this effort will generate a feasibility study that will tell us:
- Down to what frequency can be sensitive an underground GW interferometer
- What new astronomy will we be able to do

# First result




- Even at 2000 feet the ground motion is quiet enough to be close to the sensitivity of the best available accelerometers

# Acknowledgements

- My mentor Riccardo
- my workmate Jan,
- Tom Trancynger and Vuk Mandic.
- Jason and Virginia for the good time

For the Borrowed seismometers thanks to:

•Nelson Christensen (**Guralp)**

•Nanometrics (**Trillium)**

•**STS2** LIGO

(We expected to loan 2 or 3 spare STS2 from LIGO, but failures in working units made the additional units unavailable, thanks anyway)

Thanks to INFN
For my summer fellowship
Thanks to LIGO and NSF
For the additional support

# Borrowed seismometers

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