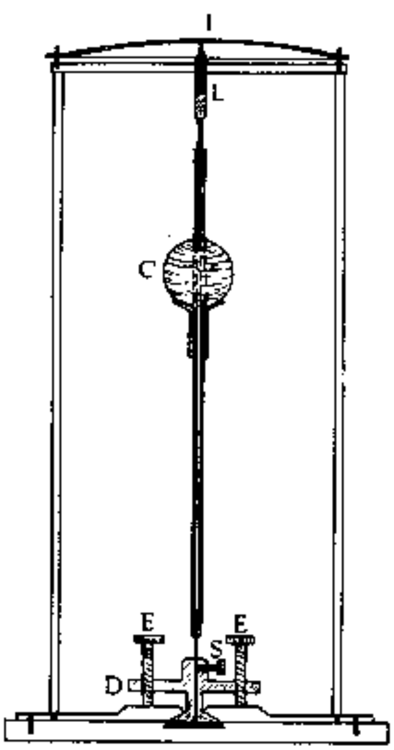
Seismometry

From ancient seismoscope to modern Beer-bottle alarm system



Forbe's pendulum design

The most significant instrument resulting from the committee's work was an inverted-pendulum "seismometer", designed by James Forbes (Forbes, 1844). It consisted of a vertical metal rod having a mass *C* moveable upon it. The rod was supported on a vertical cylindrical steel wire. The wire could be made more or less stiff by pinching it at a greater or lesser height by means of a screw *S*. By adjusting the stiffness of the wire, or the height of the ball, the free period of the pendulum might be altered. A pencil *L* placed on the prolongation of the metal rod wrote a record on a stationary, paper-lined, spherical dome *I*.

Albuquerque Seismological Laboratory

1962

2011

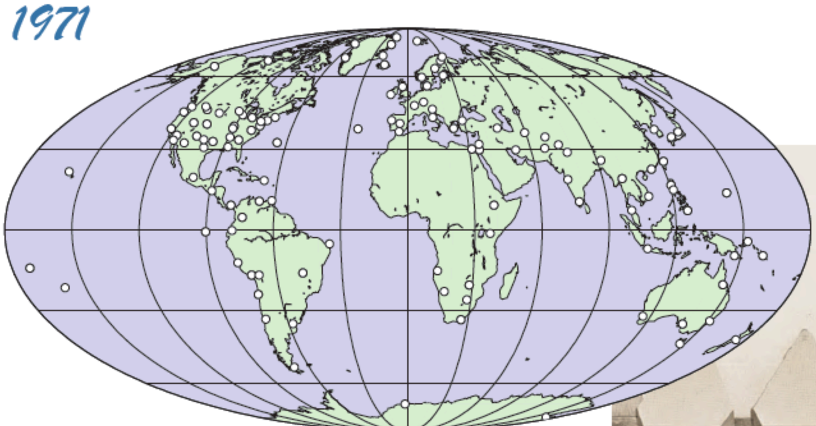
Cite of IRIS Passcal Center (center for IRIS temporary deployments)

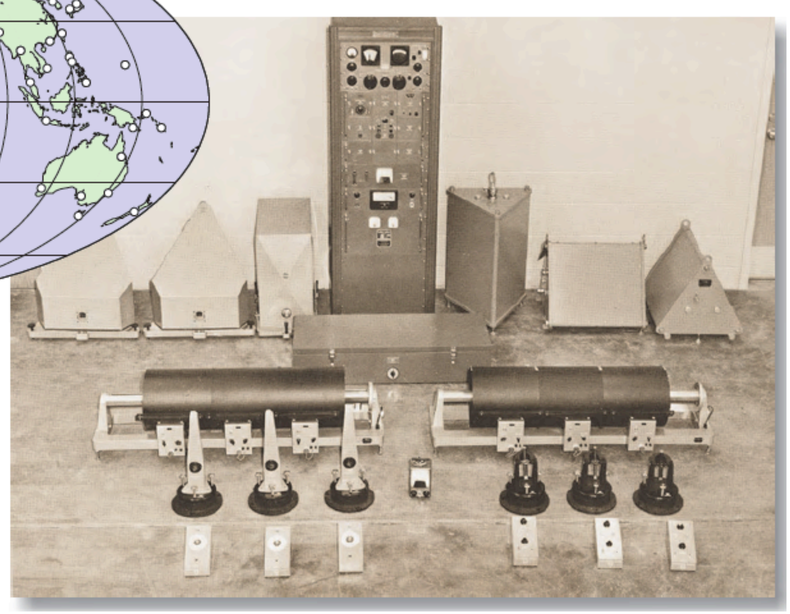
WWSSN (World-wide Standardized Seismic Network)

Started around 1960 and completed in 1971, consisting of 120 continuous (not digital), 3 – component seismographs (generally short-period instruments).

Around 1971, long-period (1-25 sec) instruments are deployed and the digital age truly arrives. The new network was termed ***Global Digital Seismic Netowrk (GDSN), the predecessor of GSN as we know it today. .***

1971





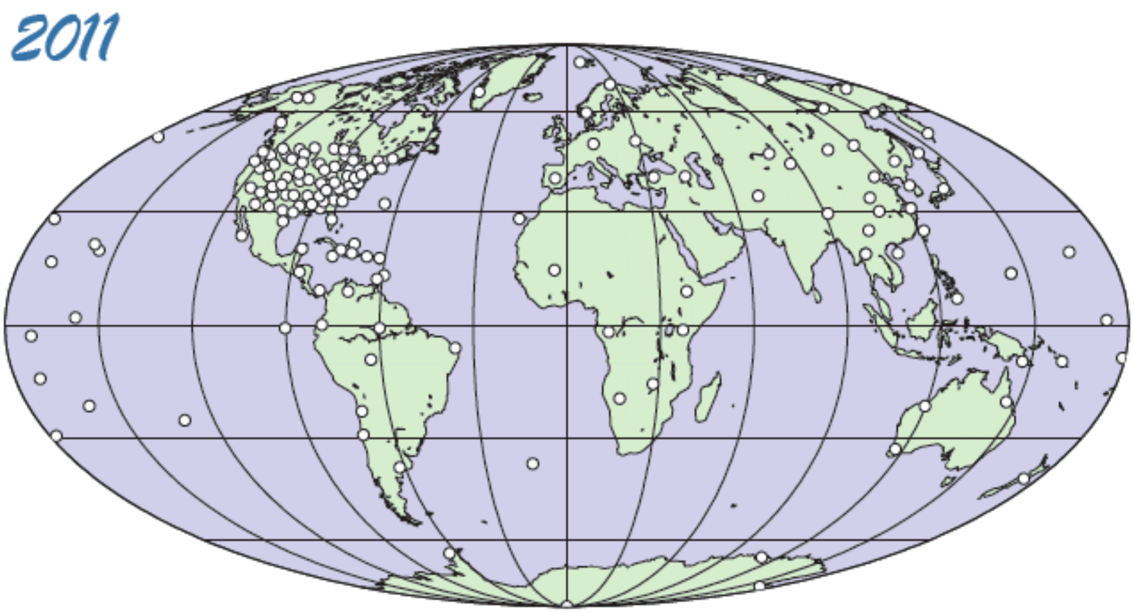
(**Top**) Stations of the World-Wide Standardized Seismograph Network (WWSSN), installed 1962–1971.

(**Right**) The WWSSN System, including seismometers, galvanometers, drum recorders, and timing console.

Global Seismic Network

3-component, broadband, global seismic network. The number of stations grows to 160 or more, but the speed of increase has *slown down*.

<u>Reason</u>: Modeling strategy change. Global analysis of seismic structure is moving to a new direction ----- Regional Seismic Networks monitored by individual countries but with connections (e.g., data exchange) with IRIS

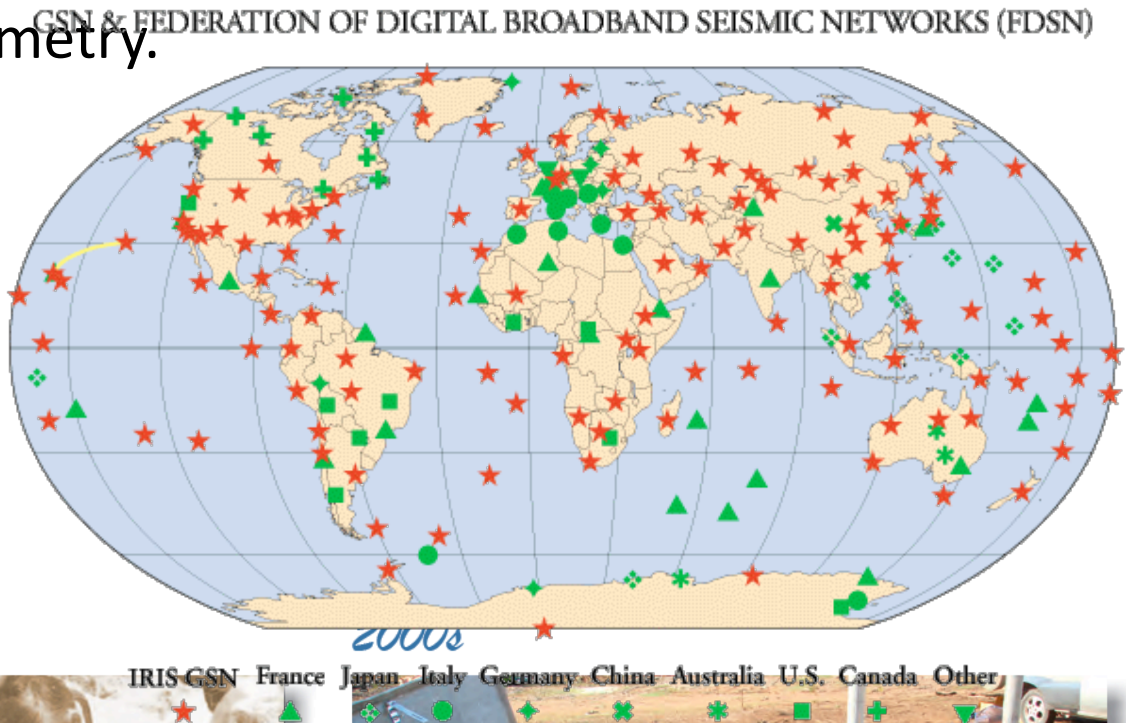


(**Top**) Stations for which the ASL was responsible in June 2011, including the Global Seismographic Network, the Caribbean Network, and the Advanced National Seismic System backbone network.

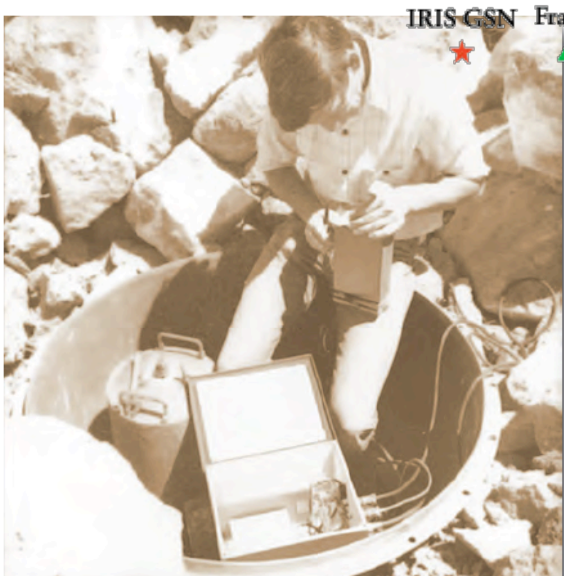
(**Right**) Two of the seismometers used in the GSN: Geotech KS-54000 borehole seismometer (far right) and Streckeisen STS-1 vertical seismometer.

Deployment then vs. now.

Differences: Greater instrument quality, larger storage, better timing with GPS, better vault insulation and noise reduction (though this quite arguable as many of the old vaults are still being used), telemetry.



1960s



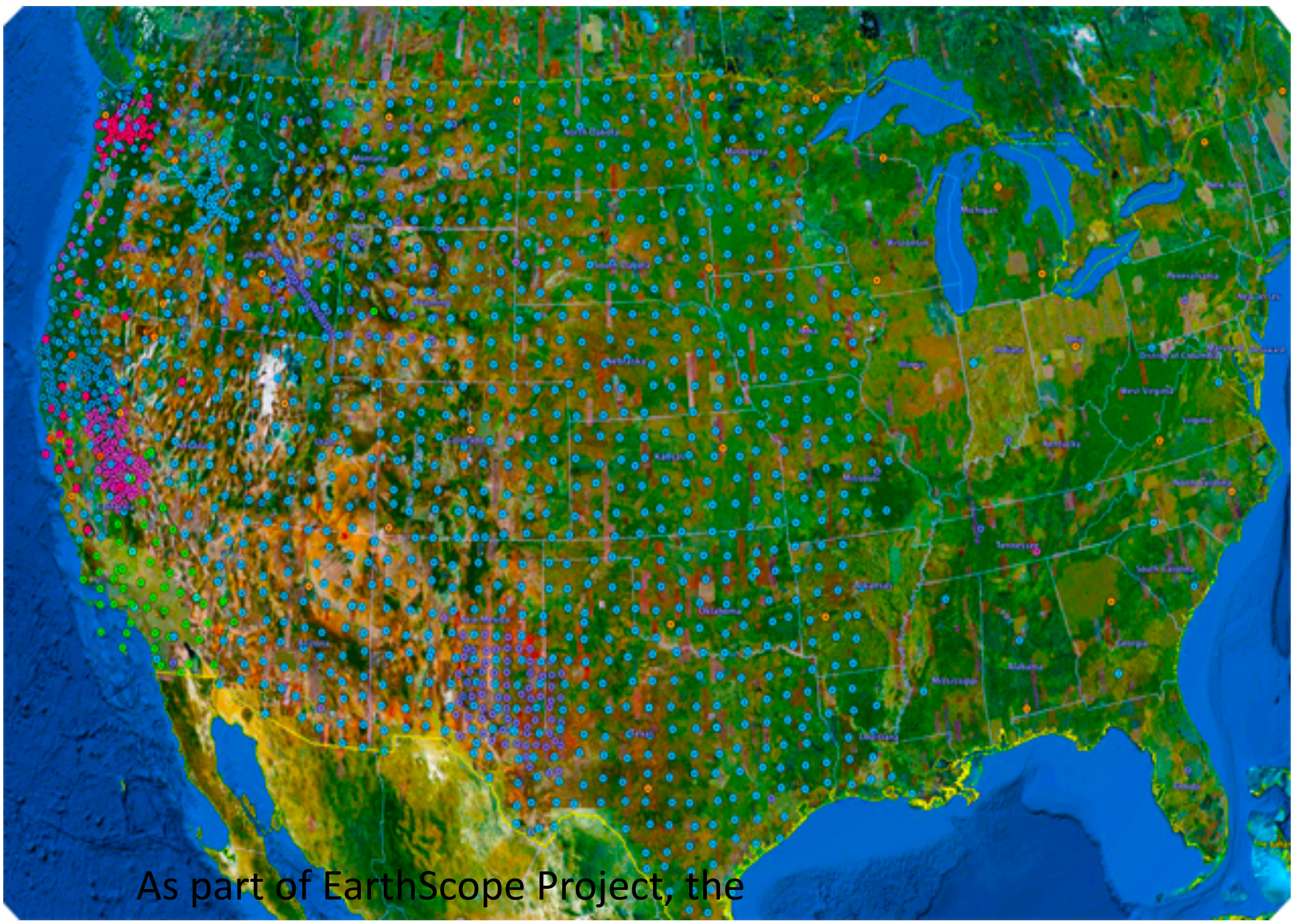
Larry Jaksha working in a shallow seismometer vault.

2000s

Shallow seismometer vault at station ANWB (Barbuda) of the Caribbean Network. Shown are the station operator, Devon Warner, and helpers.

New Phase of Earthquake Analysis: Regional Arrays

Below: USArray deployent (>400 temporary stations). The schedule is changing every two years, moving to the east one patch at a time every two years.



As part of EarthScope Project, the

Temporary Deployments

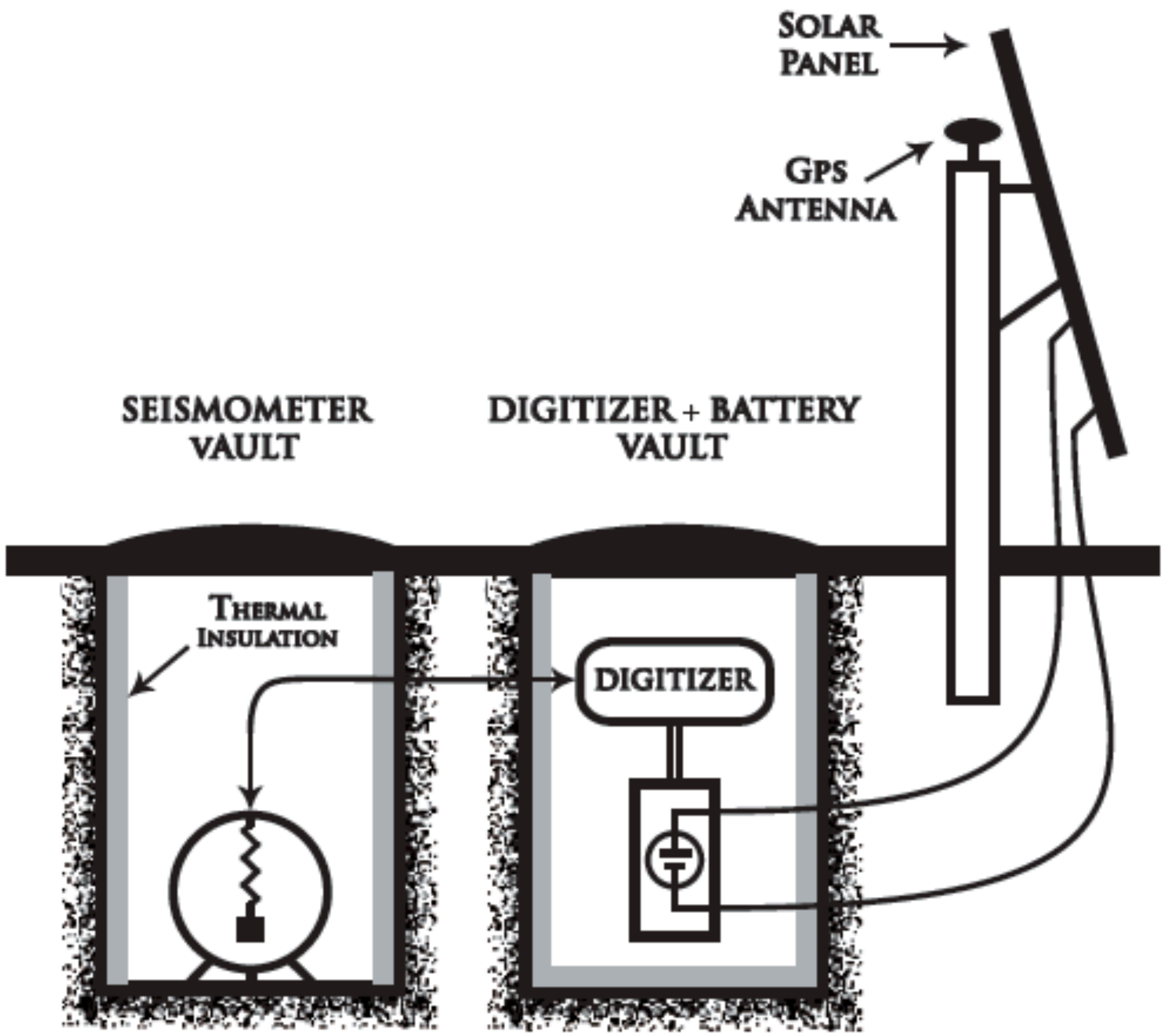
Seismometers are buried for best signal-noise ratios. The vault could be a big bucket. Concrete flooring is poured to the bottom (connected to soil) to improve leveling. Also a tile is fixed to the concrete floor.

Seismometer Vault

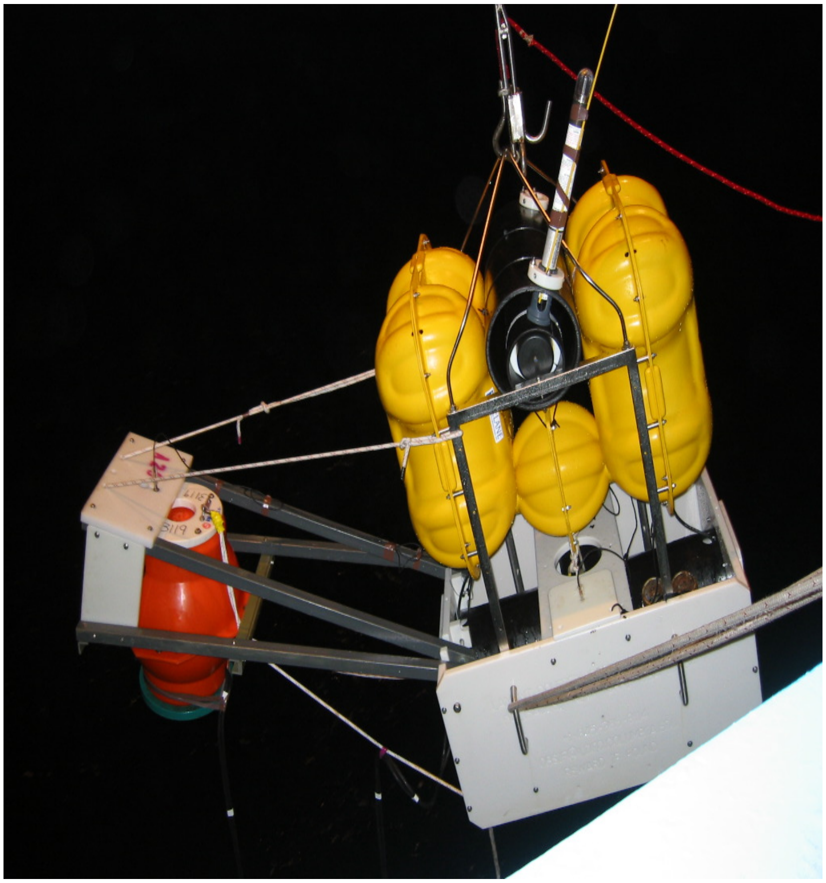
Alberta CRANE network (UofA)

Thermal insulations are added to reduce temperature effect. Then vault is closed (only a cable is extended outward to connect to digitizer.

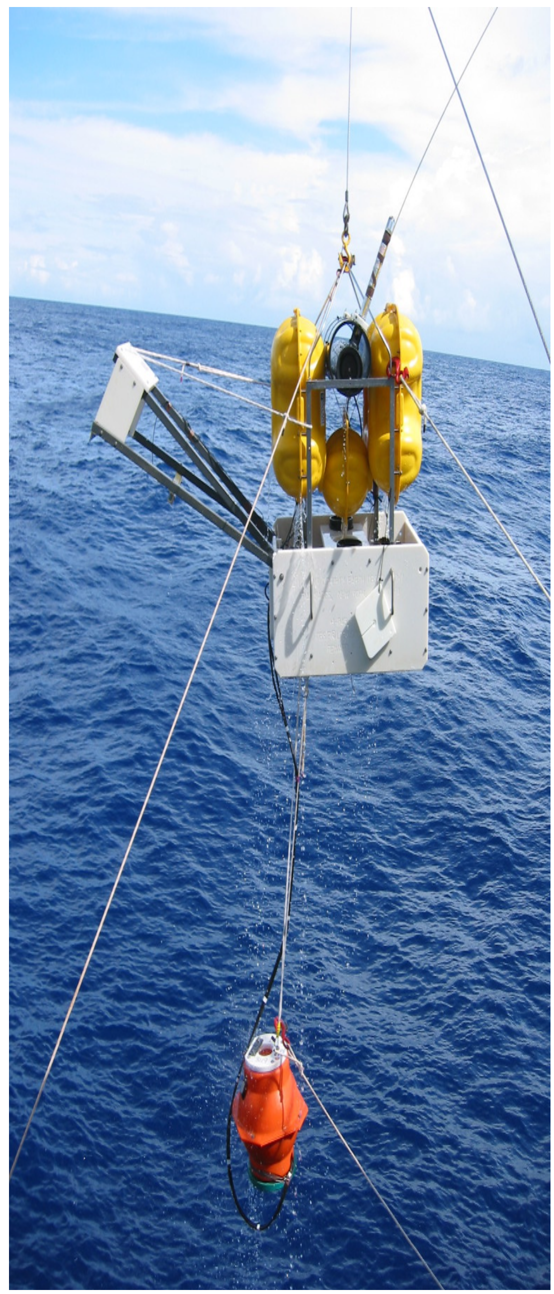
Set up at CRANE stations in Alberta



More fancy types



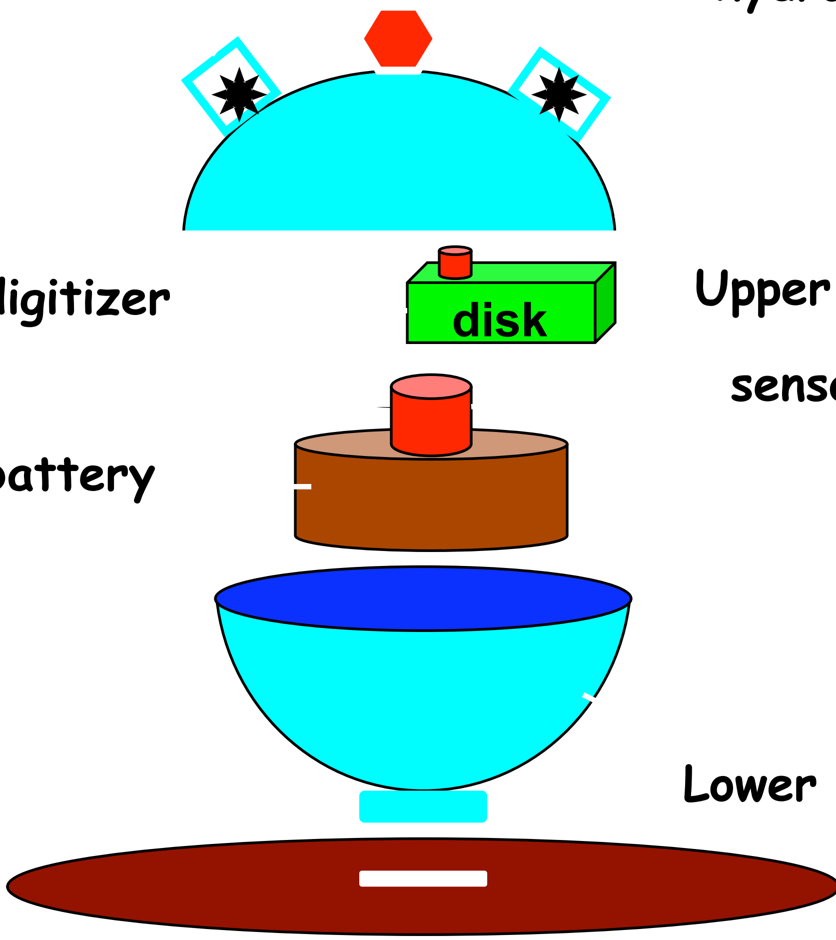
After deployment



Before deployment

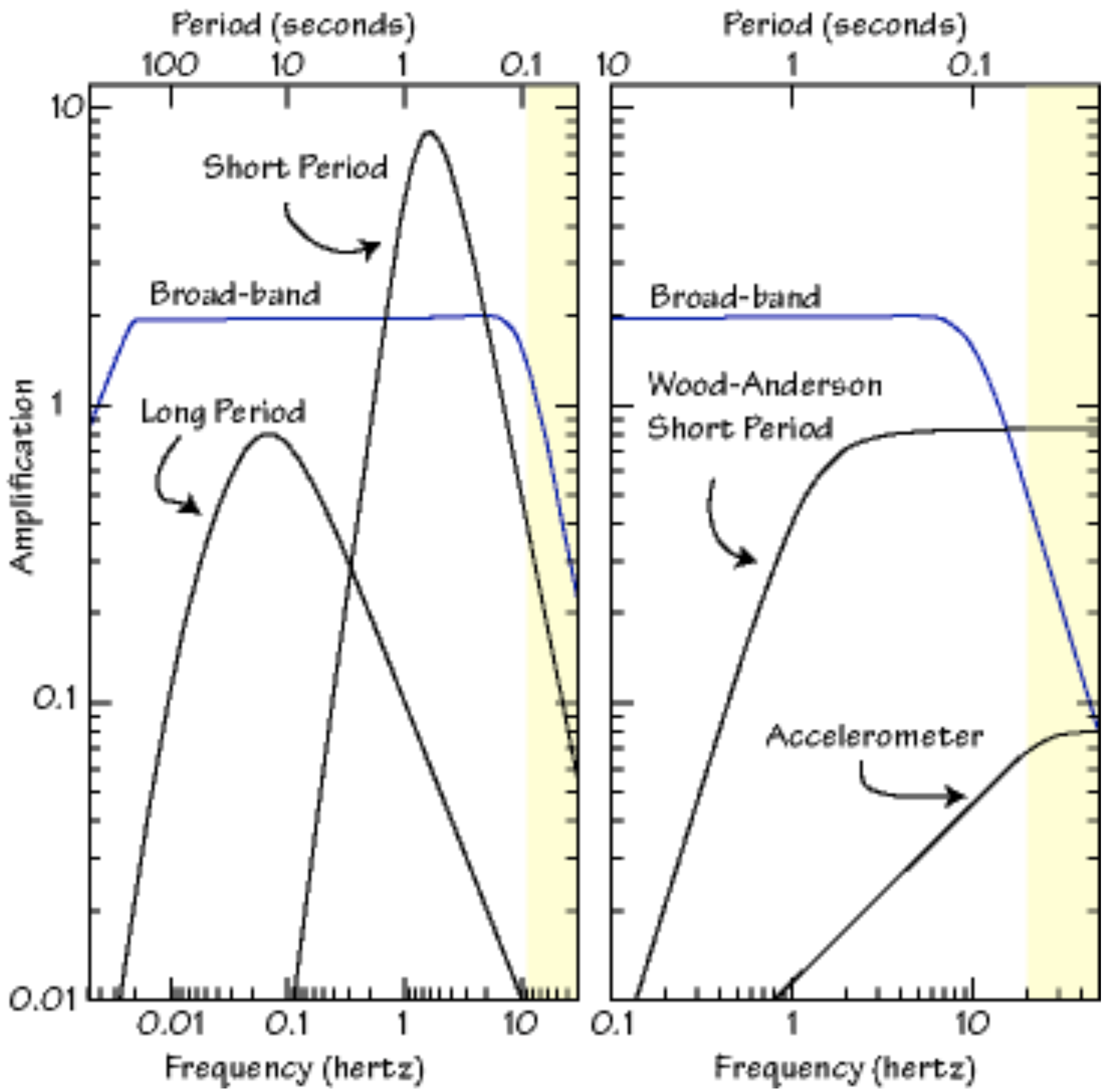
Ocean Bottom Seismometers (OBS)

Ocean Bottom Seismometers (OBS)



Instrument Reponses

Broadband vs. WWSSN seismometers



These are the response curves (meaning filtered due to the individual electronic units at a given seismic station). The WWSSN network was installed before the early 1980s, but now most instruments are broadband that incorporate good responses at both short and long periods.

Z-transform

A time series is a collection of data sampled at even intervals. The Z-transform of the the time series

x_n $(n = 0, \pm 1, \pm 2, \ldots)$

can be represented by a polynomial in z.

$$X(z) = \sum_{n=-\infty}^{\infty} x_n z^n \qquad \text{for n} > 0: \text{ delay} \quad \text{or n} < 0: \text{ advance}$$

Example:

1. Let x be a causal time series

	t_0	t_1	t_2	t_3
n	0	1	2	3
x	4	5	-1	-3

Z-transform is

$X(z)=4z^0+5z^1-z^2-3z^3$ **(z is continuous complex)**

2. Let x be a non-causal time series (Q infested)

	t_{-3}	t_{-2}	t_{-1}	t_0	t_1	t_2	t_3
n	-3	-2	-1	0	1	2	3
x	-1	3	4	3	5	6	-10

↑ **Sometime an arrow is used to show t=0**

Z-transform is

$X(z)=-1z^{-3}+3\,z^{-2}+4z^{-1}+3z^0+5z^1+6z^2-10z^3$

Instrument Response

Why bother?

1. Z transform is actually a generic form of Fourier Transform (if $Z=e^{iw}$)
2. Z transform can break down to small dipoles,

i.e., (1+aZ) (a is constant), which is smallest Z transform AND smallest signal (2 points)

Example of "dipolizing": $H(z) = 5-2z+z^2$

Let H = (5, -2, 1) $=(-1+2i+z)(-1-2i+z)$

Dipoles

The point being?

Z transform allows us to define the ***transfer functions***, i.e., the functions that 'transfer' input into output:

$$T(z) = Output(z) / Input(z)$$

- If seismometer electronics DON'T distort signal

Seismogram(z) = Transfer(z) x Source(z) (transfer(z) describes the effect of earth structure)

- If seismometer electronics DO distort signal

Seismogram(z) = Transfer(z) x Source(z) x Elec(z)

Removal of the effect of Electronic (Elec term):

Deconvolution in time or spectral division in frequency!

Since we are not interested studying seismometers when analyzing a record (structure and source are much more interesting), plus, we want to calibrate all seismograms together and remove instrument responses. We need to **deconvolve the response curve (in frequency) before we analyze all records.**

Usual practice: The seismometer makers do test by sending inn simple signals and see what the output of the seismometer would be. Then they write in Z transform for both and divide input from output. Along the way, they rewrite the numerator and denominator into dipoles (factorization of polynomials)

$$H(z) = \frac{(Z - z_1)(Z - z_2)\ldots(Z - z_m)}{(P - p_1)(P - p_2)\ldots(P - p_n)}$$

The zeros and poles are commonly complex and when plotted on the complex plane it is called the pole-zero plot.

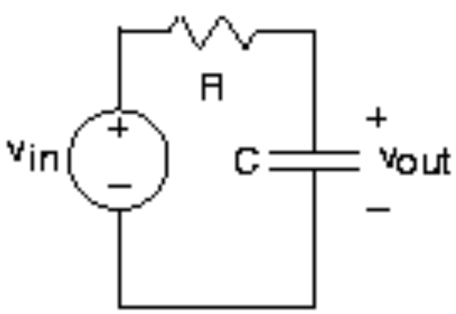
To let customers (like me) to generate a curve (so called response curve) for a given seismometer, they provide the poles and zeros (a few numbers), such that I could regenerate the curve or simply deconvolve from my seismogram to remove instrument effect!

Response file
(POLE-ZERO files)

Zeros 3
122.3   20.0
-122.5   -20.

Poles 4
-172790 263.6
-172790 -263.6
-0.1111 0.11111
-0.1111 -0.1111

Note: 1. the 3rd zero is assumed to be (0.0, 0.0).
2. Complex poles and zeros come in pairs



Sample Response curve in frequency

Response curves are really results of responses from RC circuits