Seismological Discrimination of Blasts and Natural Earthquakes

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Some Sources for Seismic Waves

Natural Earthquakes (faulting)

Landslides

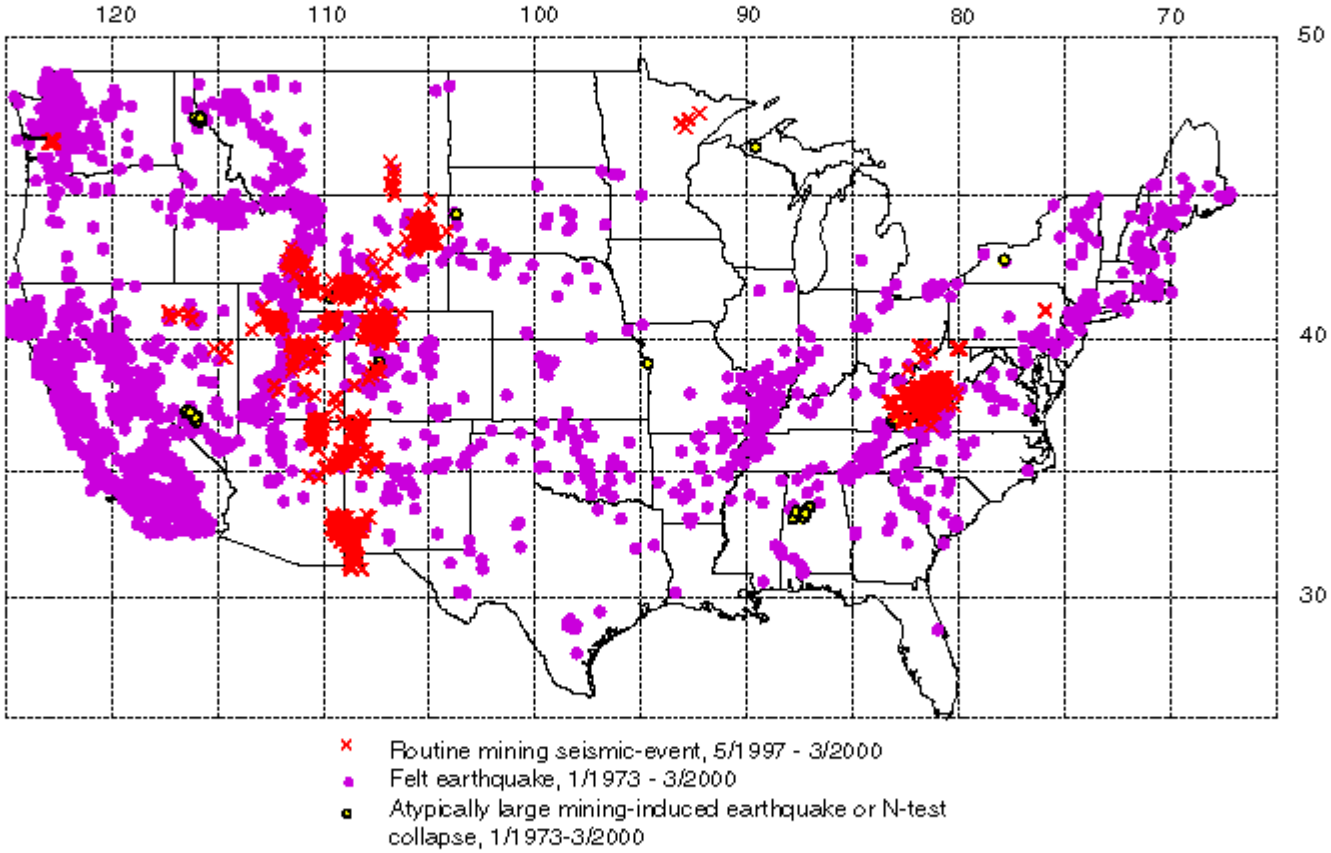
Volcanic Explosions

Man-made Explosions

Reasons to Discriminate between Natural Earthquakes and Mining-Related Events

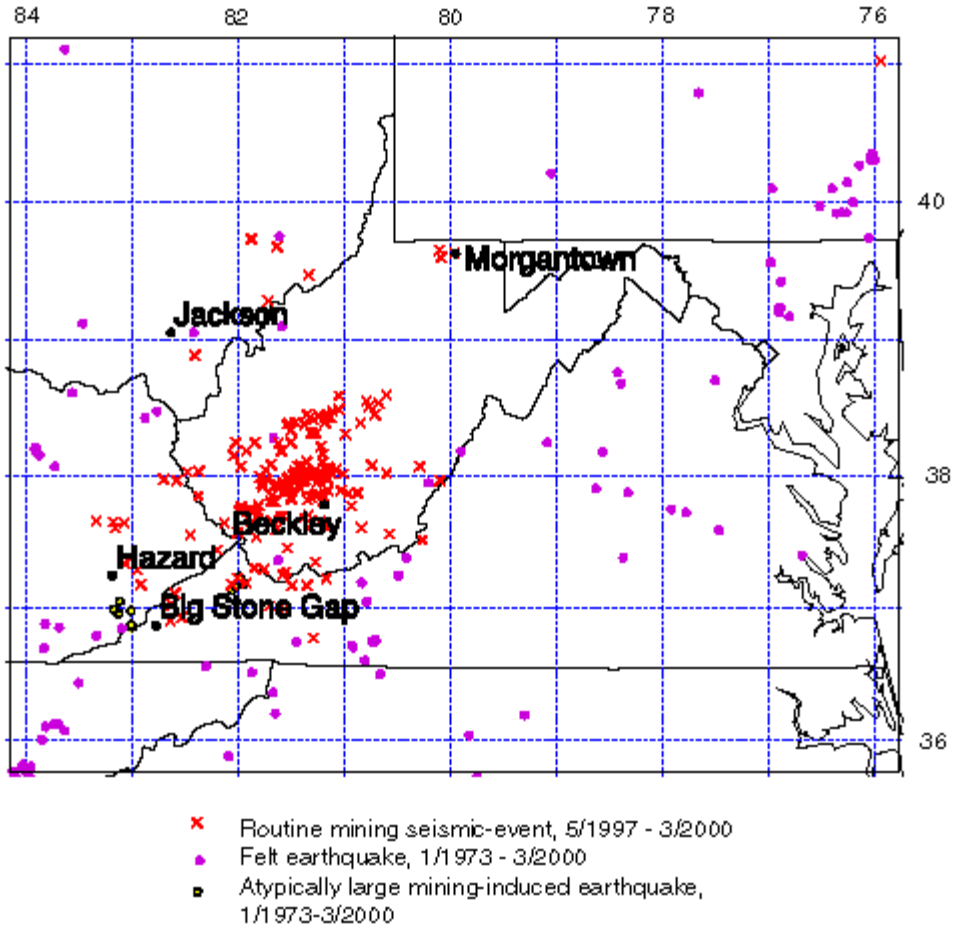
- Seismic Hazard Assessment
- Discrimination is a basic requirement for study of mining-related seismic events, both from surface and underground mine operations

Earthquakes from 1973 - 2000 and Mining-Seismic Events from 1997 - 2000



source: U.S. Geological Survey

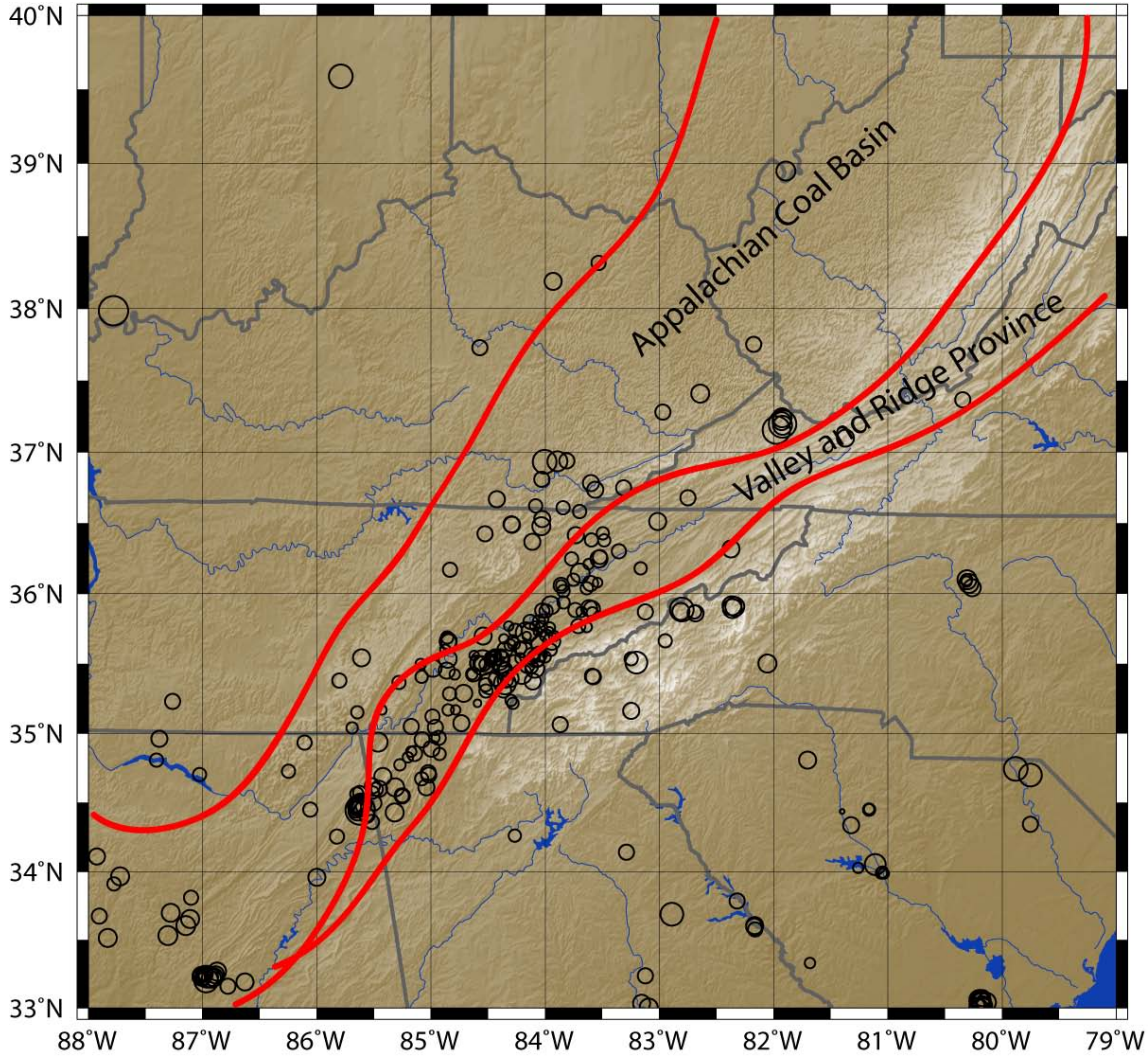
Earthquakes and Mining-Seismic Events in the Central Appalachians



source: U.S. Geological Survey

The Result of Earthquake/Blast Discrimination

Earthquakes from 1/1/2002 - 4/30/2007



source: seussn catalog
http://www.geol.vt.edu/outreach/vtso/anonftp/catalog/

Basic Discrimination can be Achieved Because

- The forces acting at the source of an explosion are very different from those acting at the source of a natural earthquake.

- Natural earthquakes usually occur at depth.

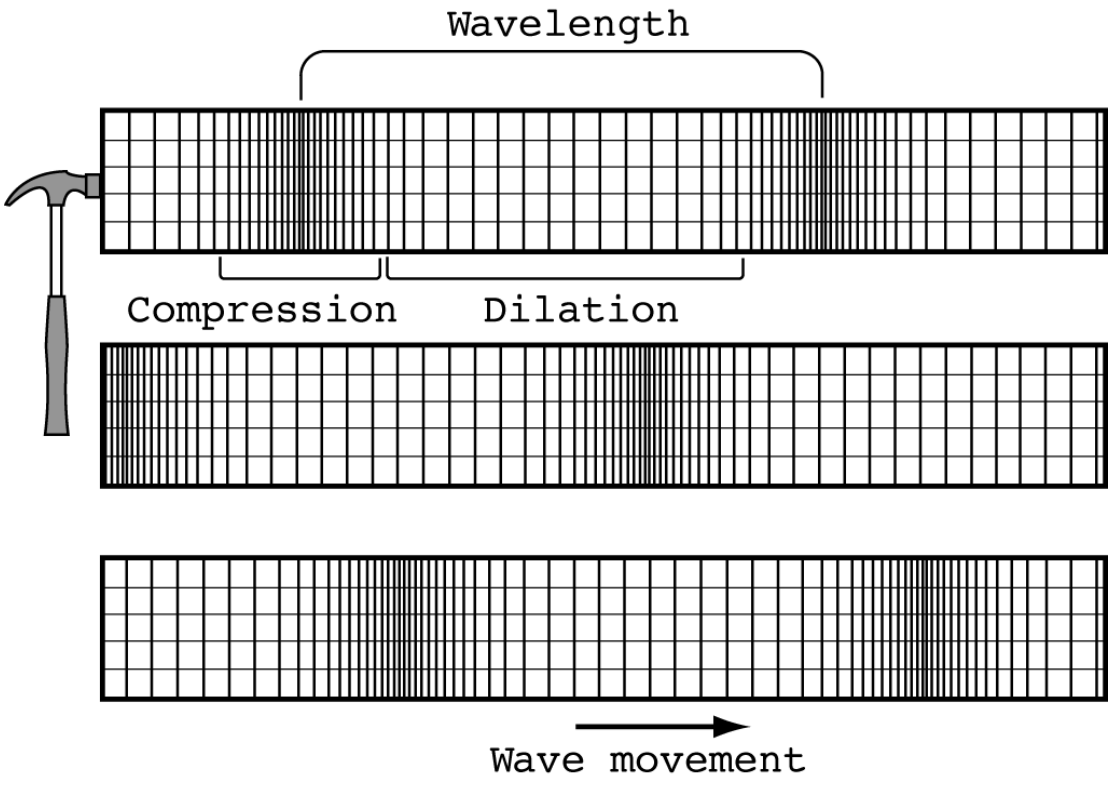
- Larger industrial blasts are usually designed to release energy over an extended period of time. This "delay-firing" introduces recognizable characteristics to the seismic signal that can be readily interpreted.

- Mining operations are usually conducted in well-defined regions containing resources. Natural earthquakes may or may not occur in those regions.

Different Kinds of Seismic Waves

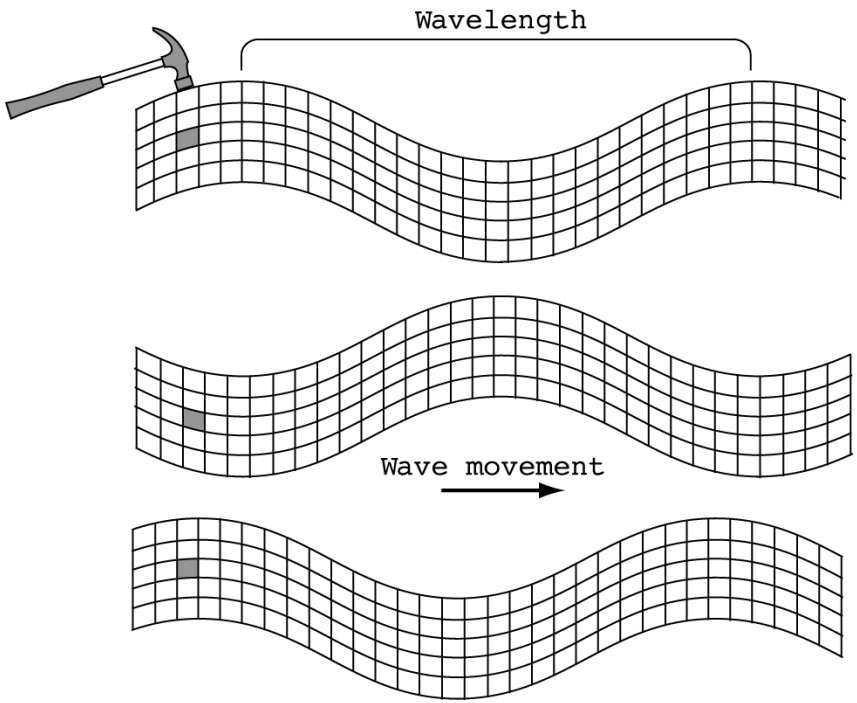
P waves get their name because they are the first, or "primary" waves to arrive from an earthquake.

A piece of rock undergoes compression and dilation when a P wave passes. Thus, P waves are sometimes referred to as "COMPRESSIONAL"waves.



S waves get their name from the fact that they are often recognized as the “secondary” waves on seismograms from distant earthquakes.

They arrive after the P waves because their velocities are only a little more than one-half that of the P wave in hard rock.



SURFACE WAVES

John William Strutt, Lord Rayleigh

(1842-1919)

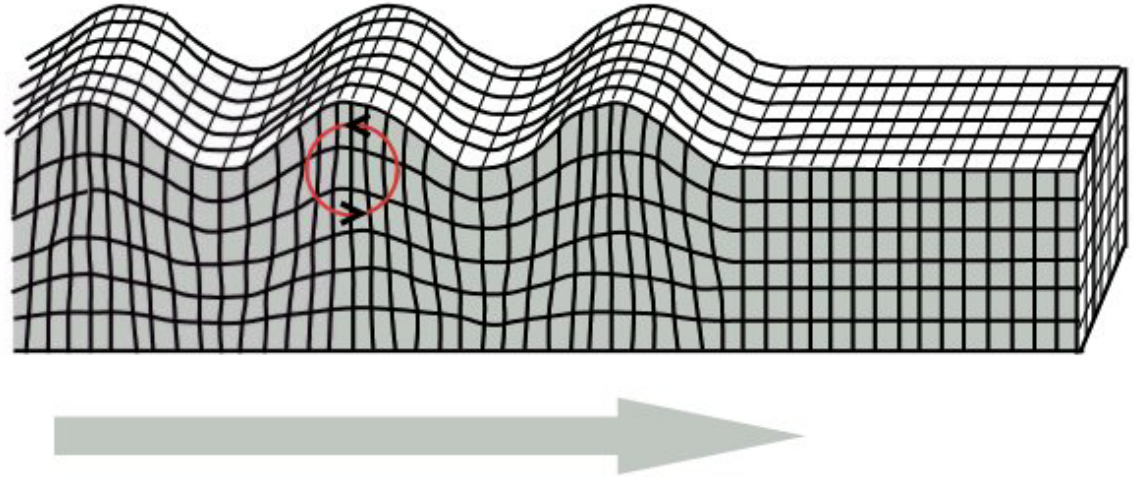
- Discovered the element Argon: (Nobel prize,1904).
- Explained why the sky is blue (a phenomenon now known as Rayleigh Scattering).
- Predicted the existence of seismic surface waves now known as **Rayleigh Waves**.

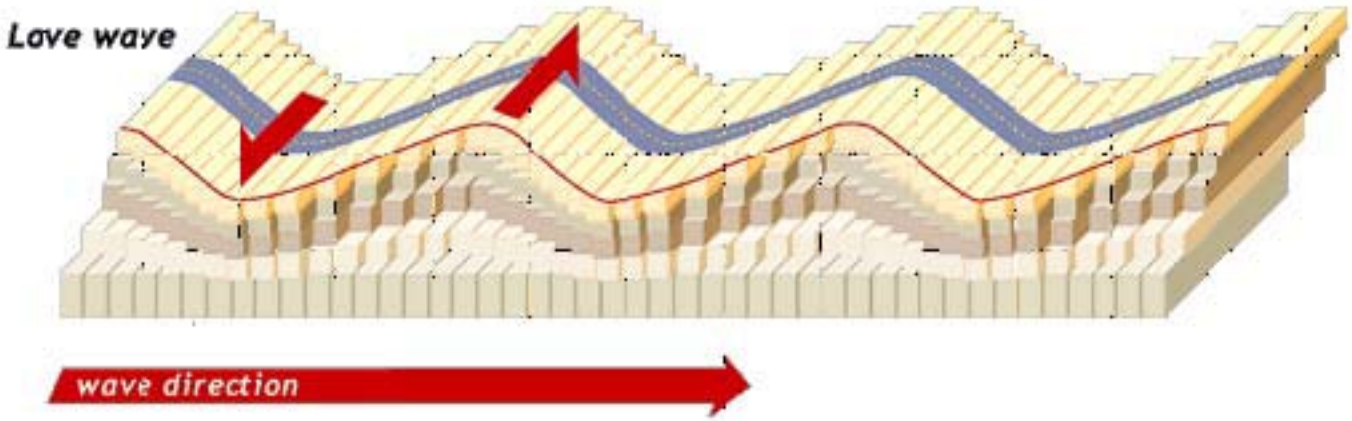
Augustus Edward Hough Love

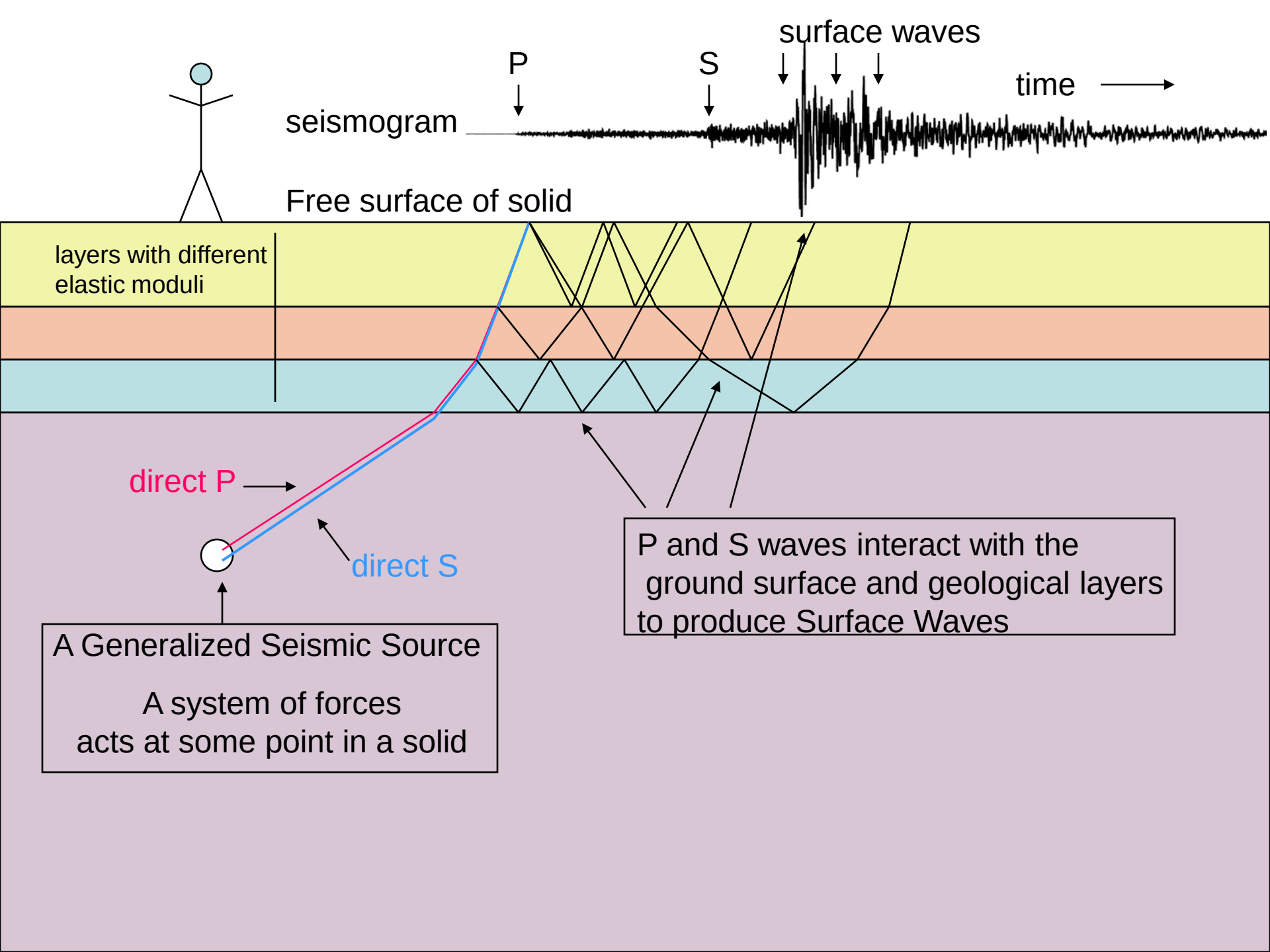
(1863 - 1940)

- Mathematician famous for his work on the theory of elasticity.
- Developed the theory for transverse seismic waves on the surface of a layered Earth model. These waves are known today as **Love Waves**.

Rayleigh Wave

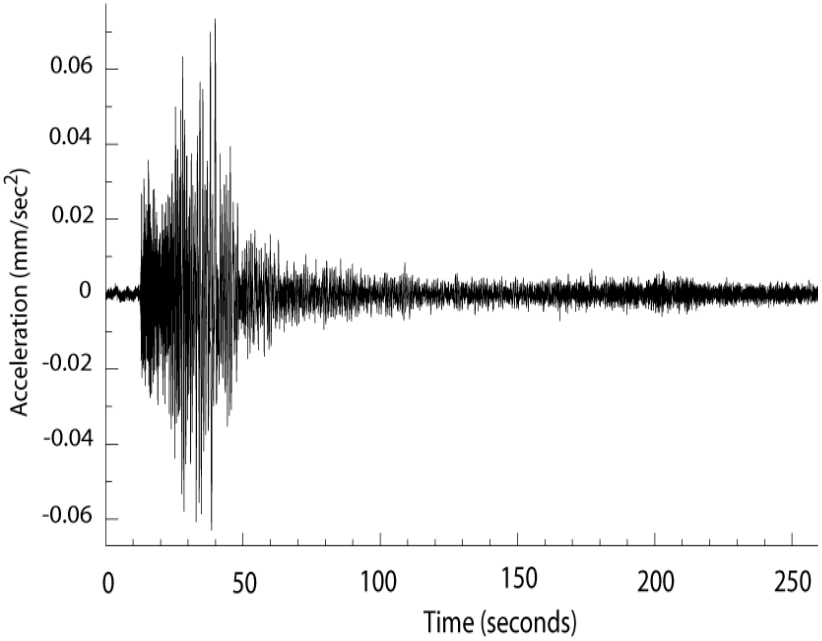


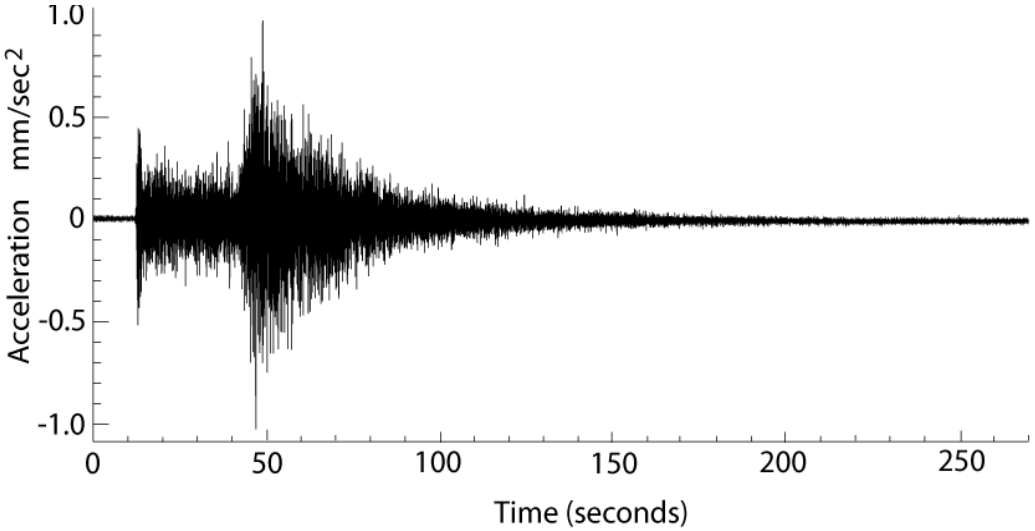



surface waves
P
S
time
seismogram
Free surface of solid
layers with different
elastic moduli
direct P
direct S
P and S waves interact with the
ground surface and geological layers
to produce Surface Waves
A Generalized Seismic Source
A system of forces
acts at some point in a solid

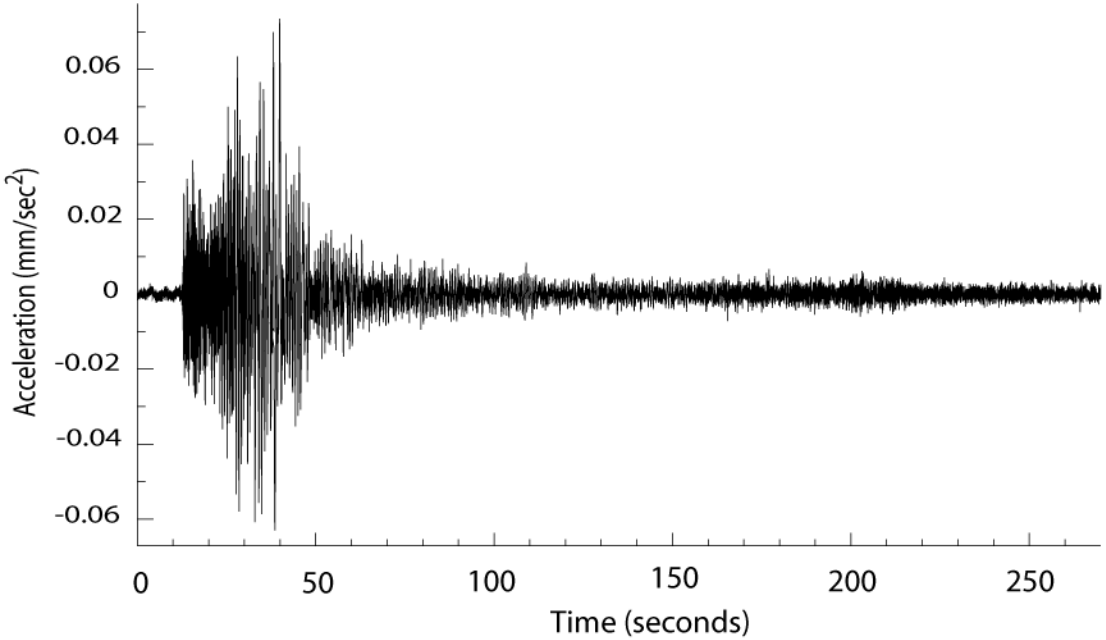
Which is the
Blast, and which
is the Earthquake?

Both were recorded at the
same seismograph station
in southern West Virginia

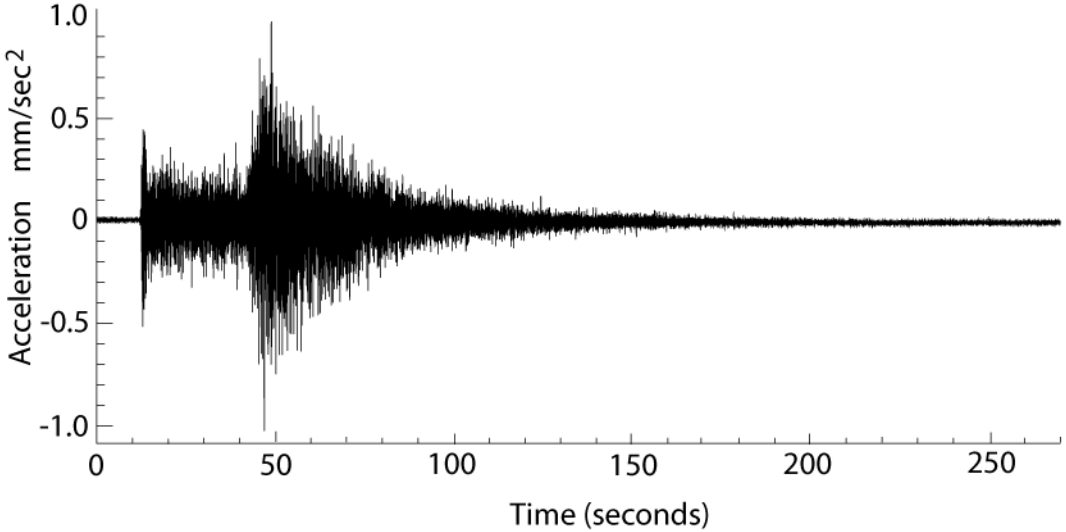




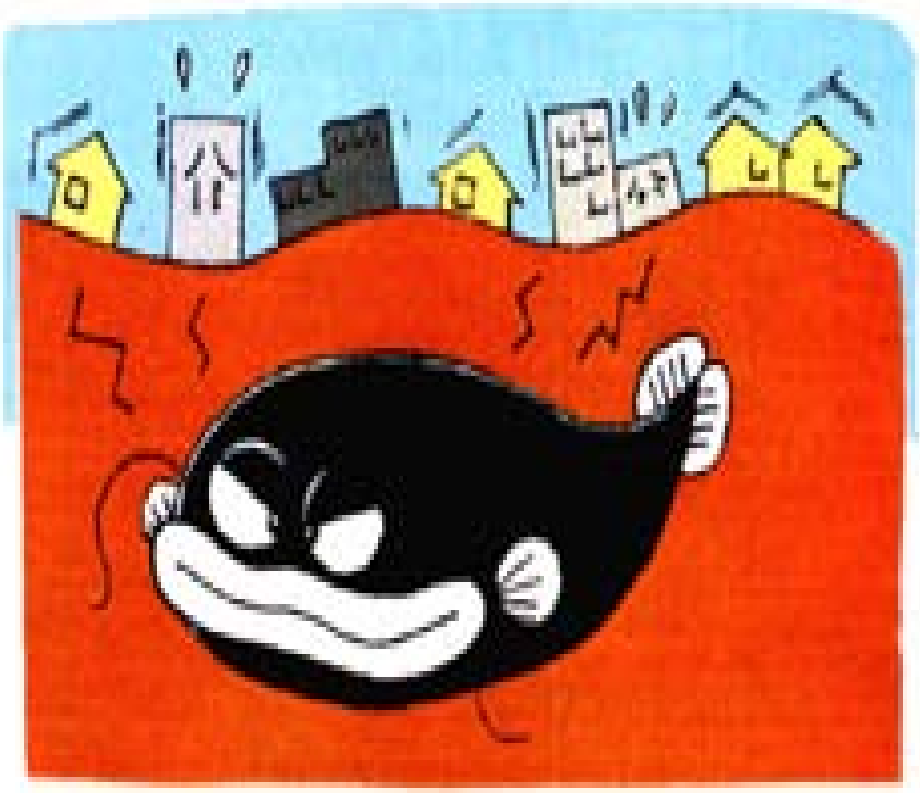
Surface mine blast in southern West Virginia



Earthquake in the Mountains of North Carolina



What is the seismic source involved in an Earthquake?



A SHEAR DISLOCATION OR FAULTING

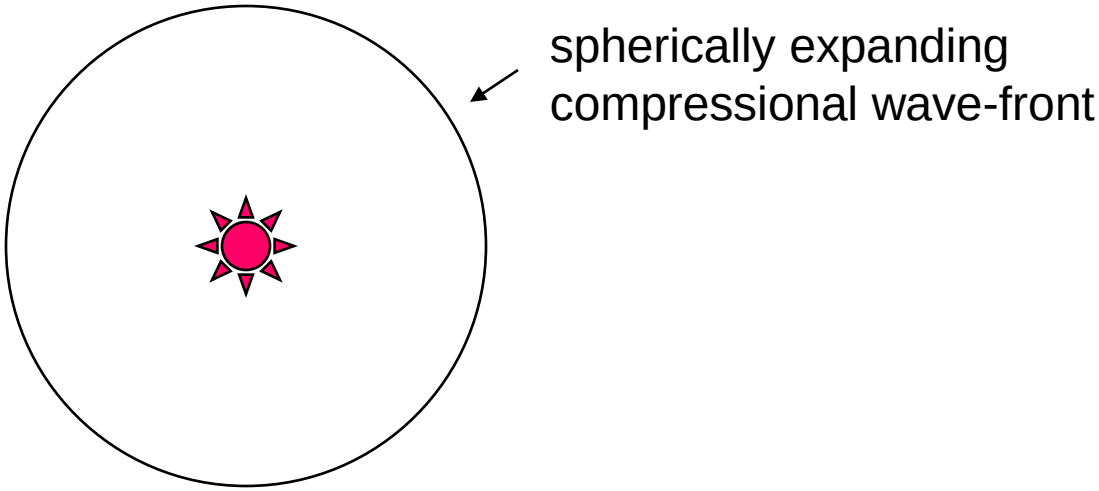
C

D

What is an Explosive Seismic Source?

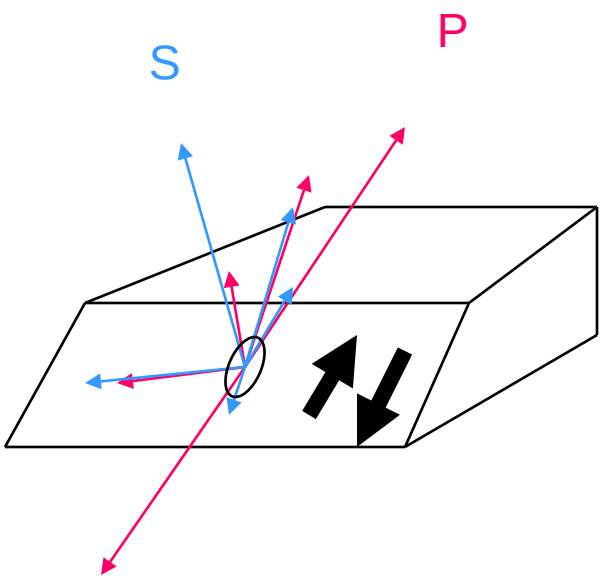
The idealized explosive source is instantaneous pressurization of a spherical cavity.

In an homogenous and isotropic Earth, such a force system generates a very simple wavefield, consisting of P waves only.



Seismic Source Mechanisms

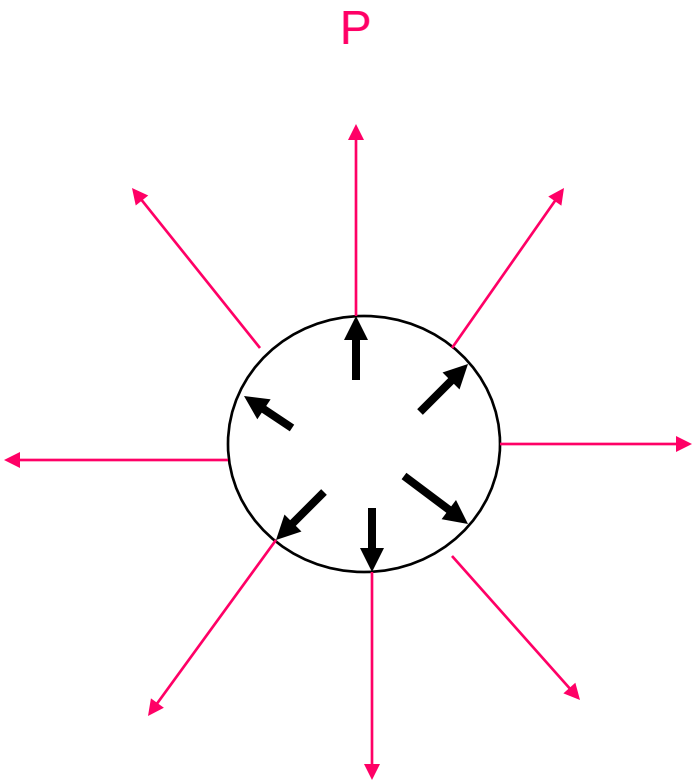
Earthquake



Seismic radiation from an earthquake is due to a shear traction across the fault plane.

Both P and S waves are radiated in all directions, but with amplitude highly dependent upon the direction of fault slip and the orientation of the fault surface.

Explosion



Seismic radiation from an explosion is due to pressurization of a cavity. Only P waves are radiated, with equal amplitude in all directions.

Considerations

Real Earthquakes do not consist of slip at a point.
In large shocks, slip occurs on many square miles of fault surface.

Industrial blasts usually do not involve a single explosion. Most blasts involve many individual explosions fired sequentially over an extended area.

1. P and S wave radiation pattern for an Earthquake

   a) Point Source

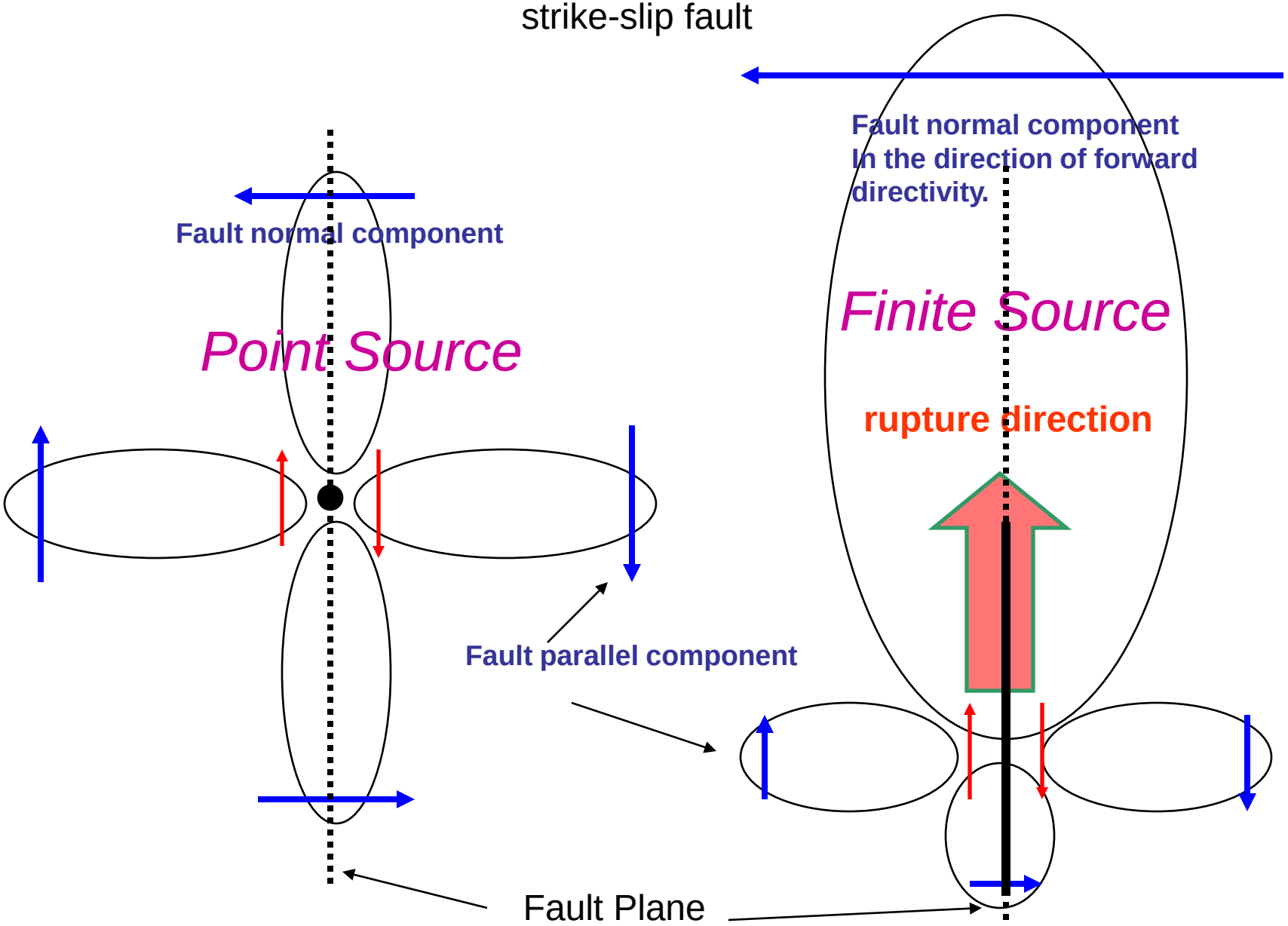
   b) Finite Source

2. P wave radiation pattern for an Explosion

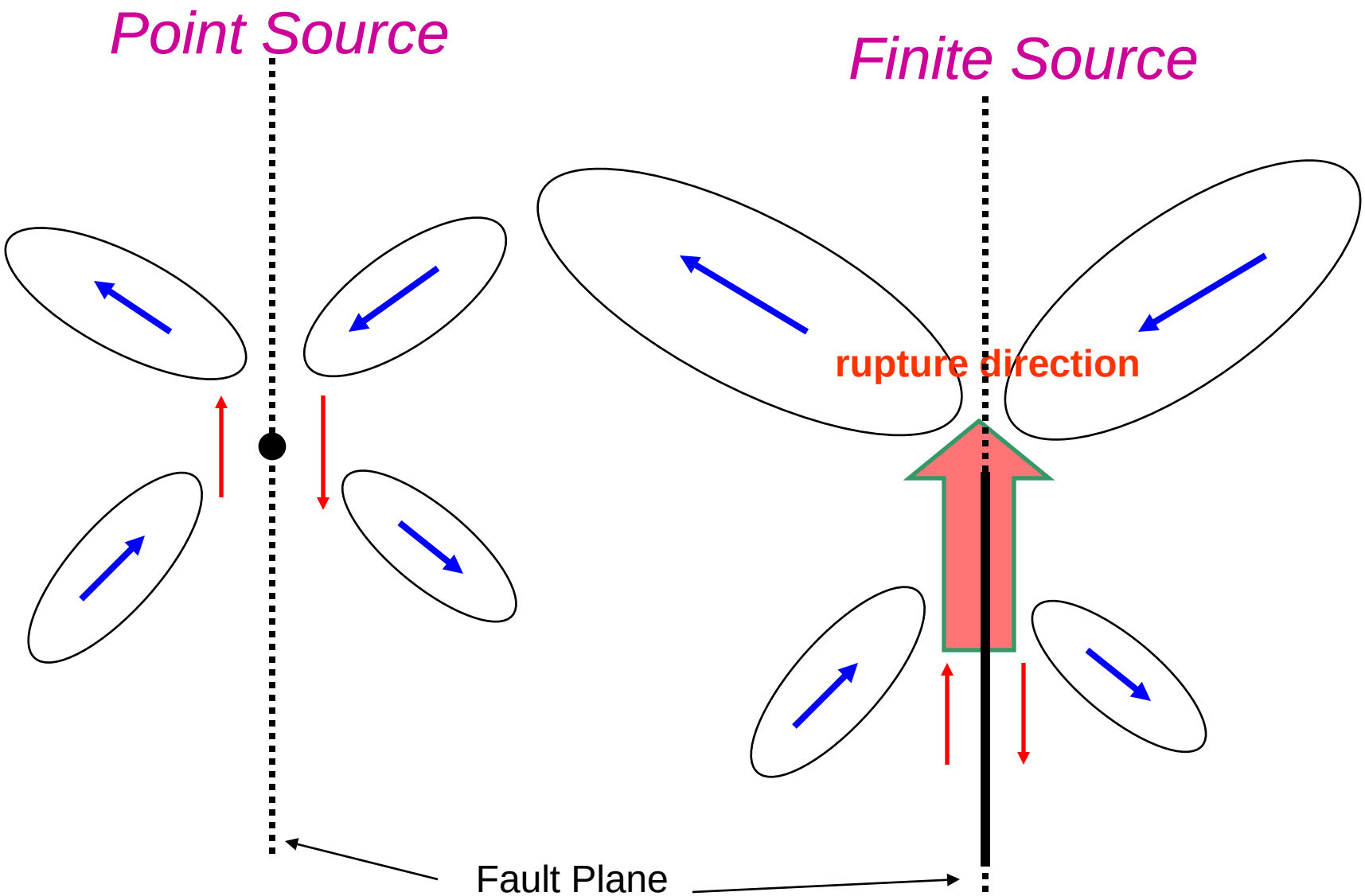
   a) Point Source

   b) Delay-fired Source

Sh radiation from a vertical strike-slip fault

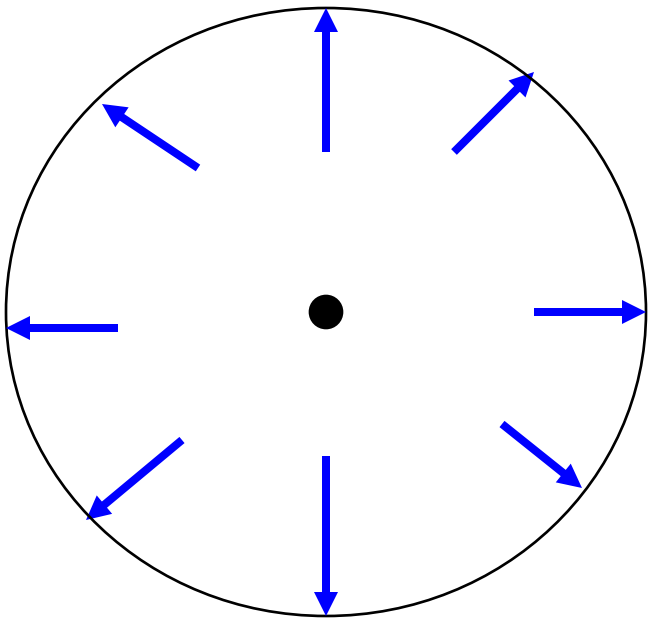


P and Sv radiation patterns
Vertical Strike-Slip Fault



Radiation Pattern From A Single Explosion

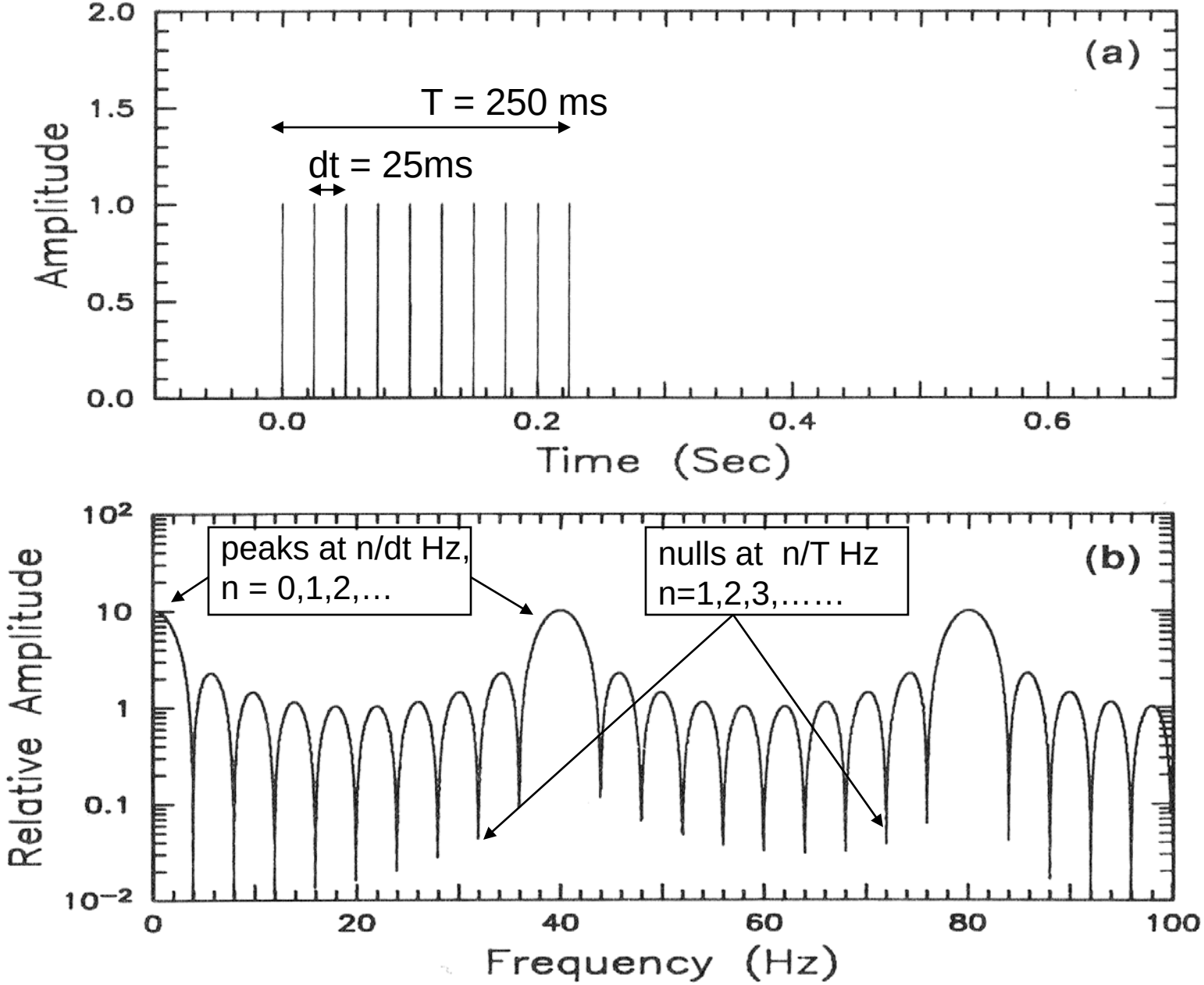
P waves



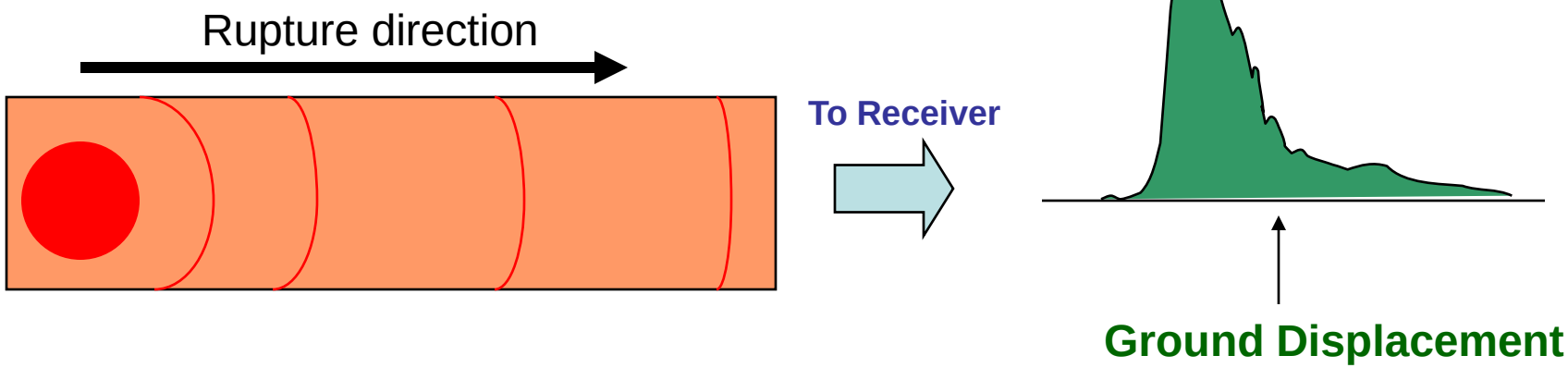
S waves

Unlike an earthquake, an explosion at a point would create only P waves in a homogeneous, isotropic Earth

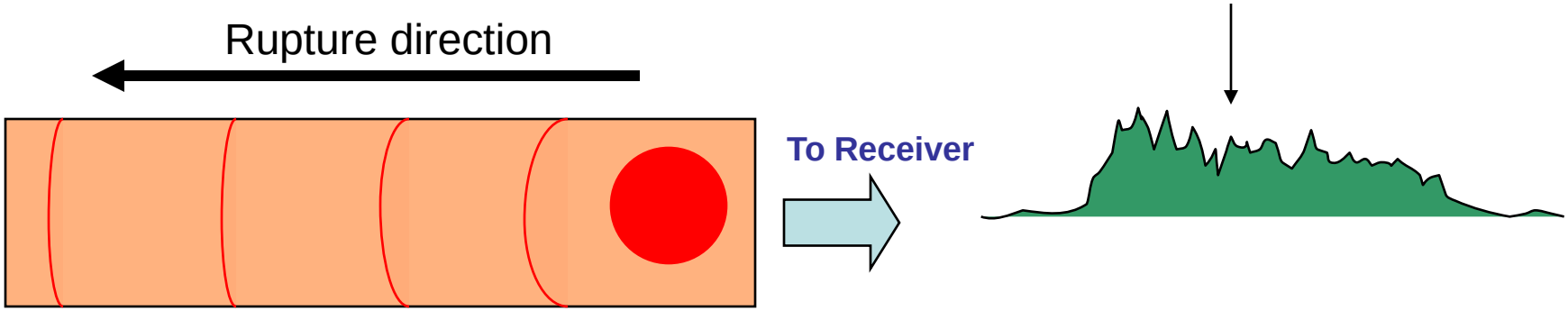
time series for a delay-fired explosion sequence



Forward directivity



Backward directivity



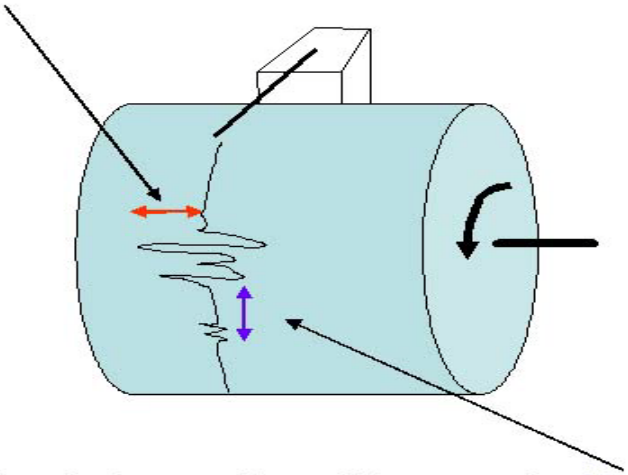
The areas under the far-field displacement pulses are equal, but the amplitudes and durations differ. This has major effects on the ground velocity and acceleration.

What is Magnitude?

Can earthquake magnitudes
be compared with blast magnitudes?

Example of how a seismologist would determine the Local (Richter) magnitude of an earthquake.

Maximum trace amplitude of Wood-Anderson seismogram is 100 millimeters. Therefore, A=100.



The time between S and P waves is 11 seconds. The epicenter is 11 seconds X 8.3 km/sec = 91 km away.

Table 22-1, page 342, Elementary Seismology (Richter, 1958)
Trace amplitude Ao for Zero Magnitude

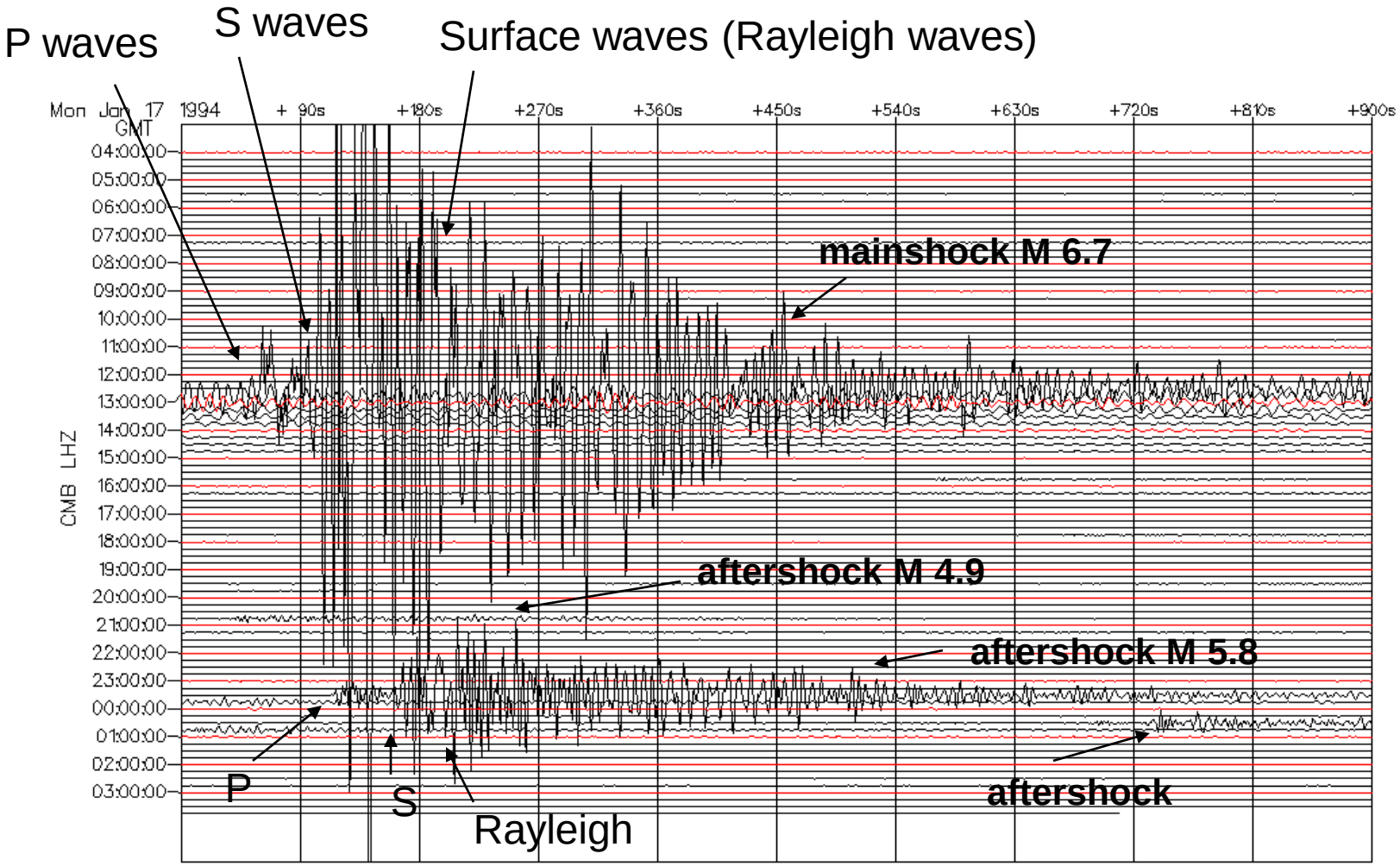
dist. (km)	log Ao	Ao (millimeters)
0.0	-1.4	0.0398
10.0	-1.5	0.0316
20.0	-1.7	0.0200
30.0	-2.1	0.0079
40.0	-2.4	0.0040
50.0	-2.6	0.0025
70.0	-2.8	0.0016
90.0	-3.0	0.0010
120.0	-3.1	0.0008

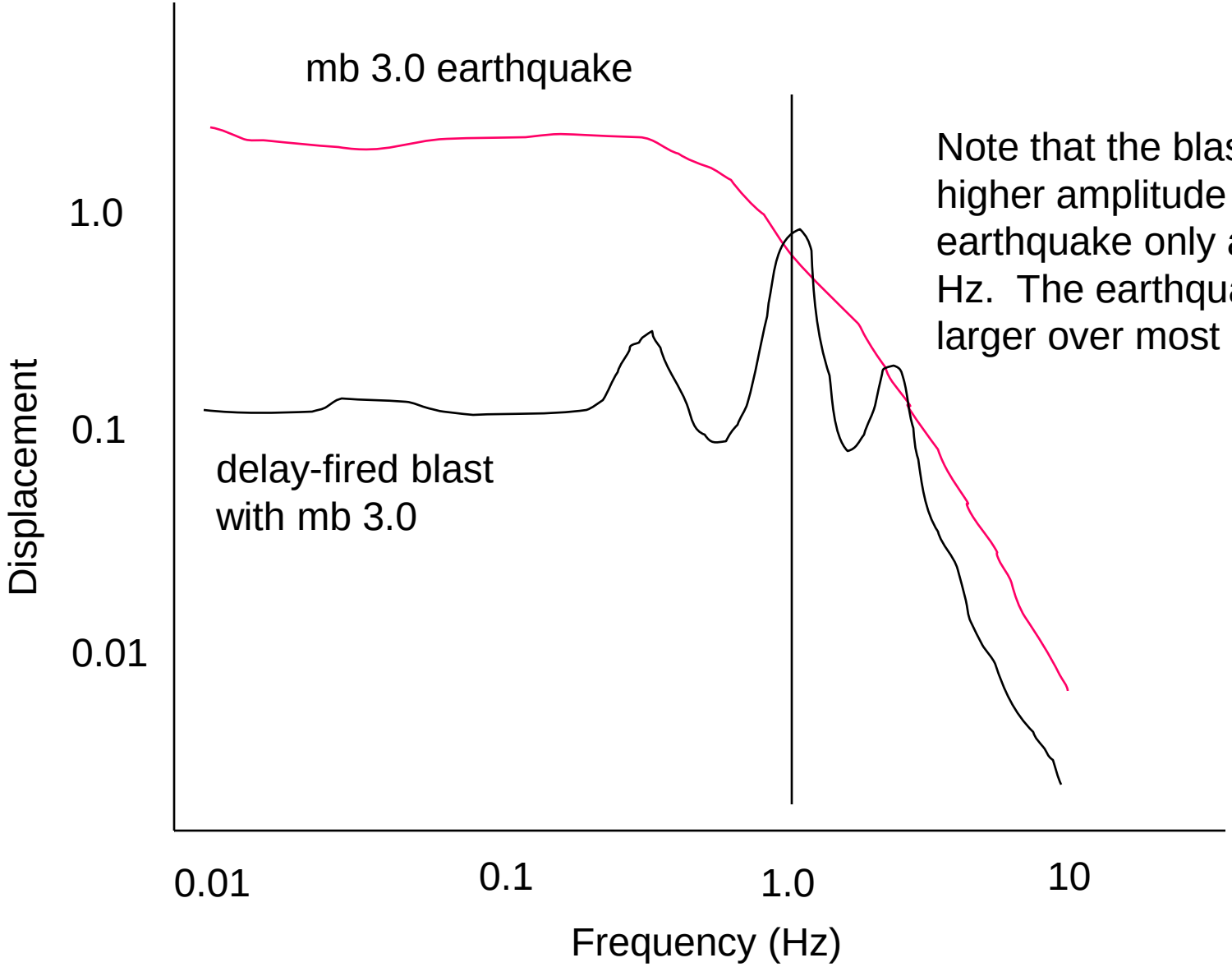
Ao=0.001 mm at 90 km.

$M_L = \log A - \text{Log } Ao$

$M_L = \log 100 - \log 0.001 = 2.0 - (-3.0) = 5.0$

Vertical component ground motion from the 1994 Northridge, CA earthquake, recorded 550 km to the north, near Berkeley, CA.



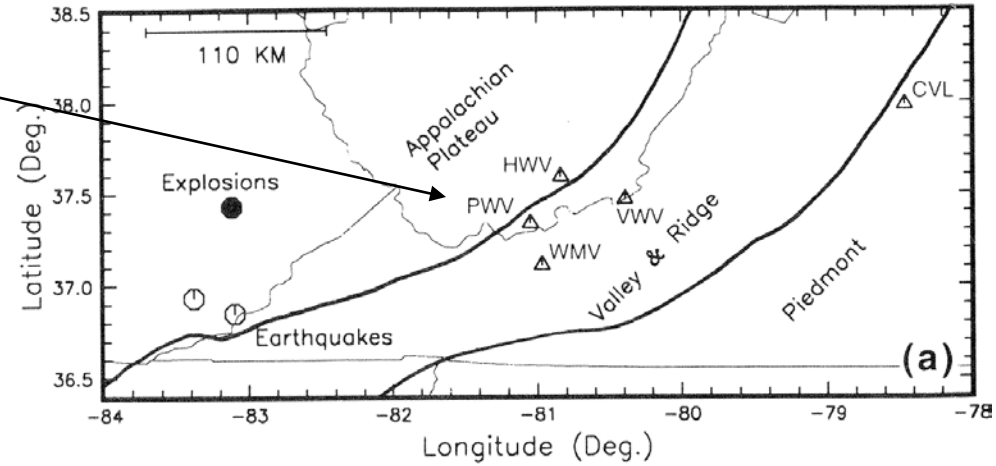


Note that the blast has higher amplitude than the earthquake only at 1 and 5 Hz. The earthquake is much larger over most of the spectrum

Comparison of magnitudes is not straight-forward in the case of delay-fired explosions and natural earthquakes.

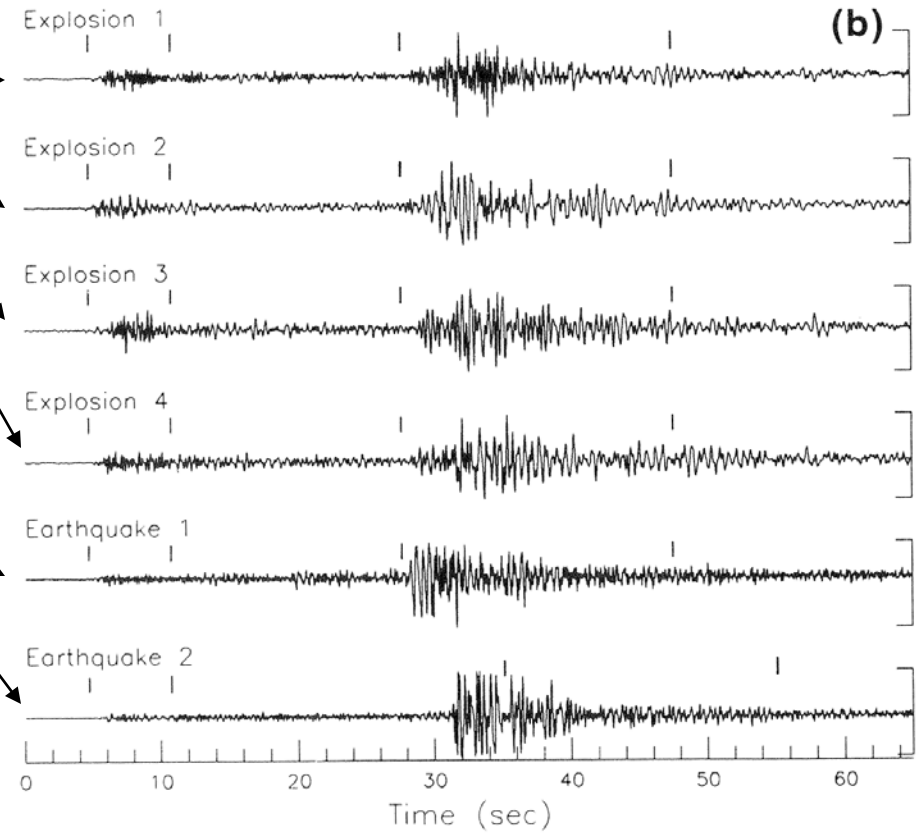
Similar magnitude estimates may be misleading in terms of total seismic energy release because of the narrow-band nature of delay-fired explosion spectra.

seismograph stations



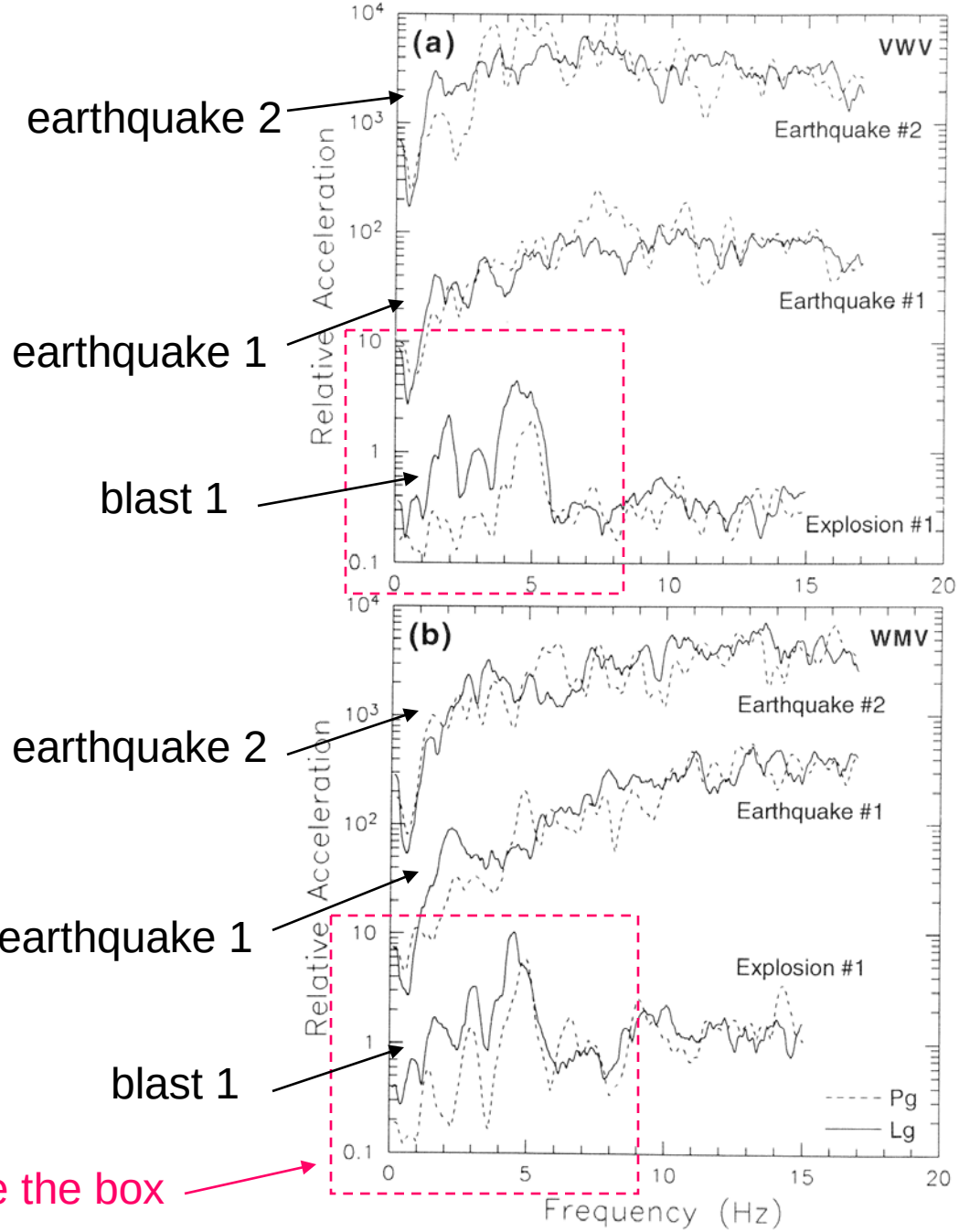
seismograms recording delay-fired blasts

seismograms recording two small, shallow earthquakes



Note: The earthquakes and the blasts look similar in the time domain

Station VWV



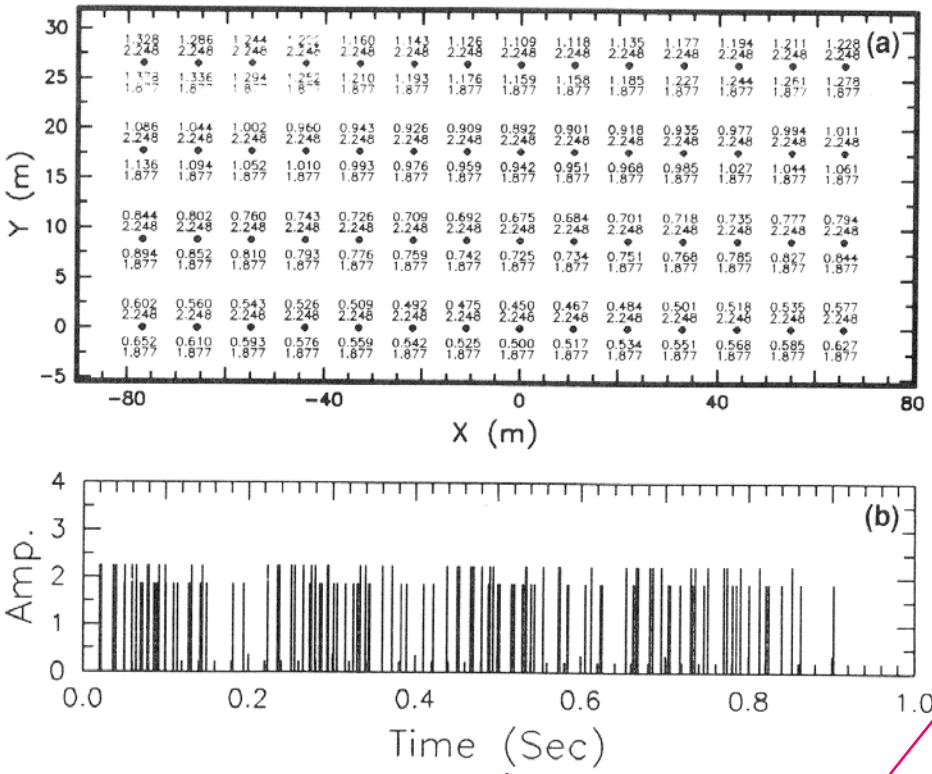
Station WMV

NOTE:

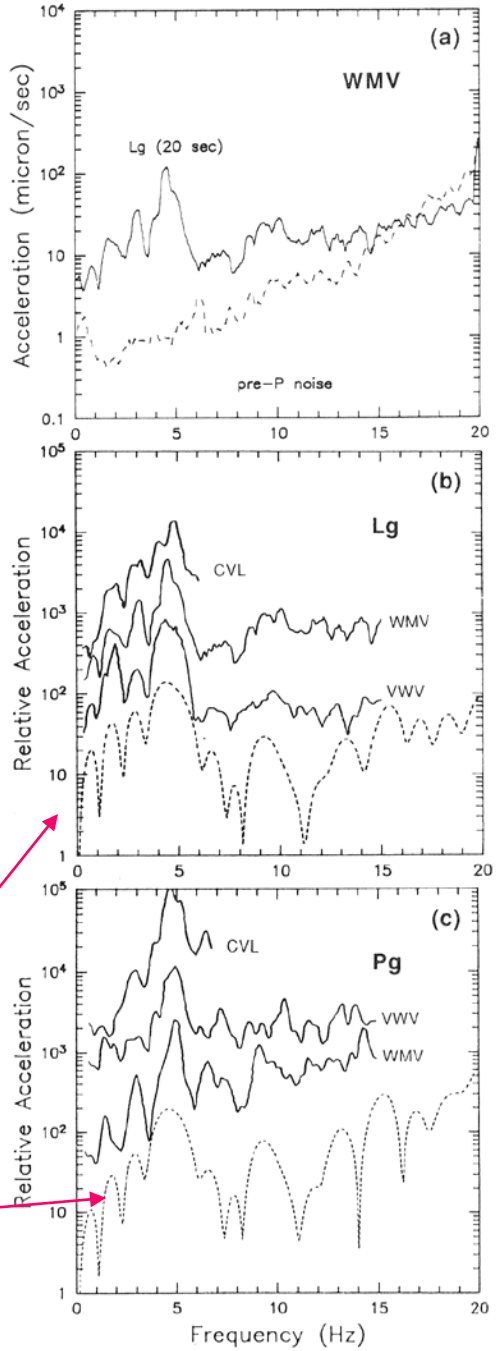
The earthquakes and the blast look a lot different in the frequency domain. Notice the modulated spectrum inside the box

The modulated spectrum indicates a delay-firing design. The strong spectral peak near 5 Hz is due the row delays. The nulls below 5 Hz are due to the total duration.

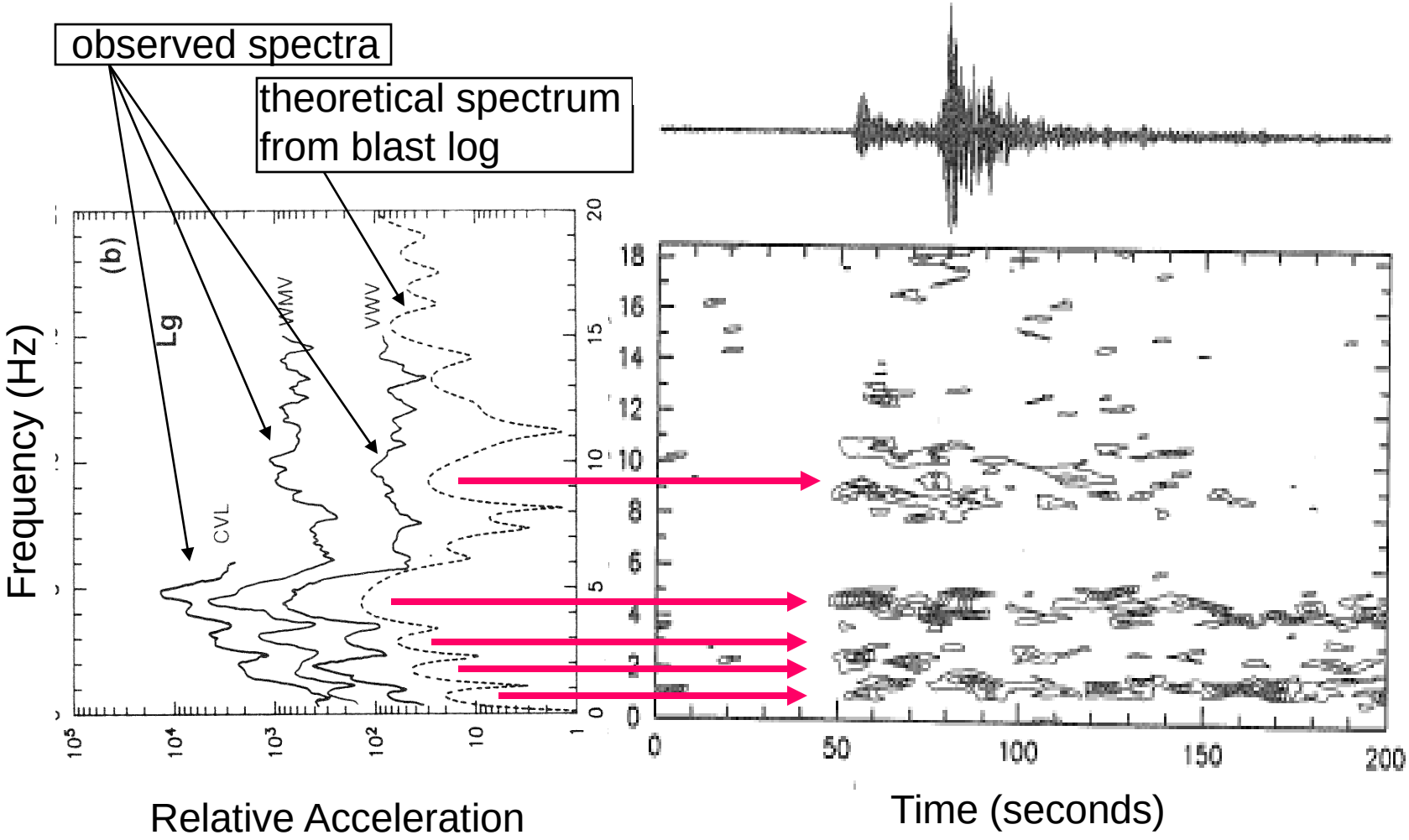
Shot design for explosion 1



Theoretical spectrum



The spectral modulation of a delay-fired blast is present throughout the signal



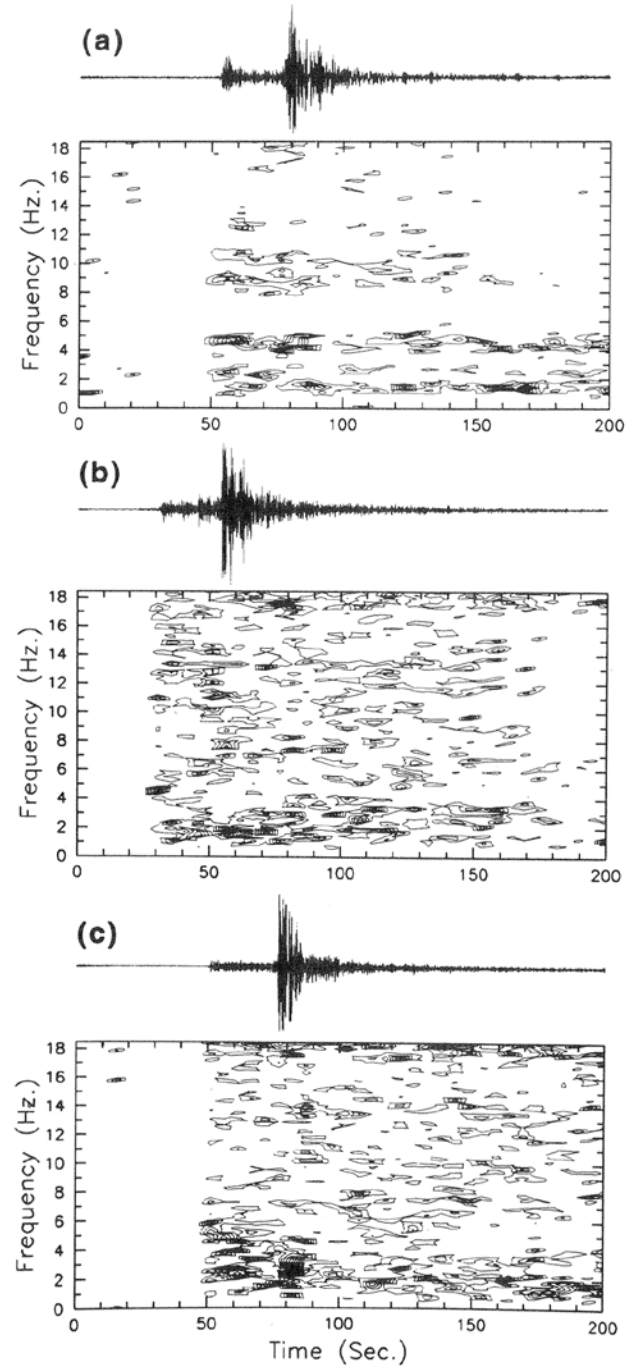
If time-invariant spectral modulation is observed, the source is a likely industrial explosion with a well-organized delay-fire design

Comparison of Earthquake and Blast Spectrograms.

Blast

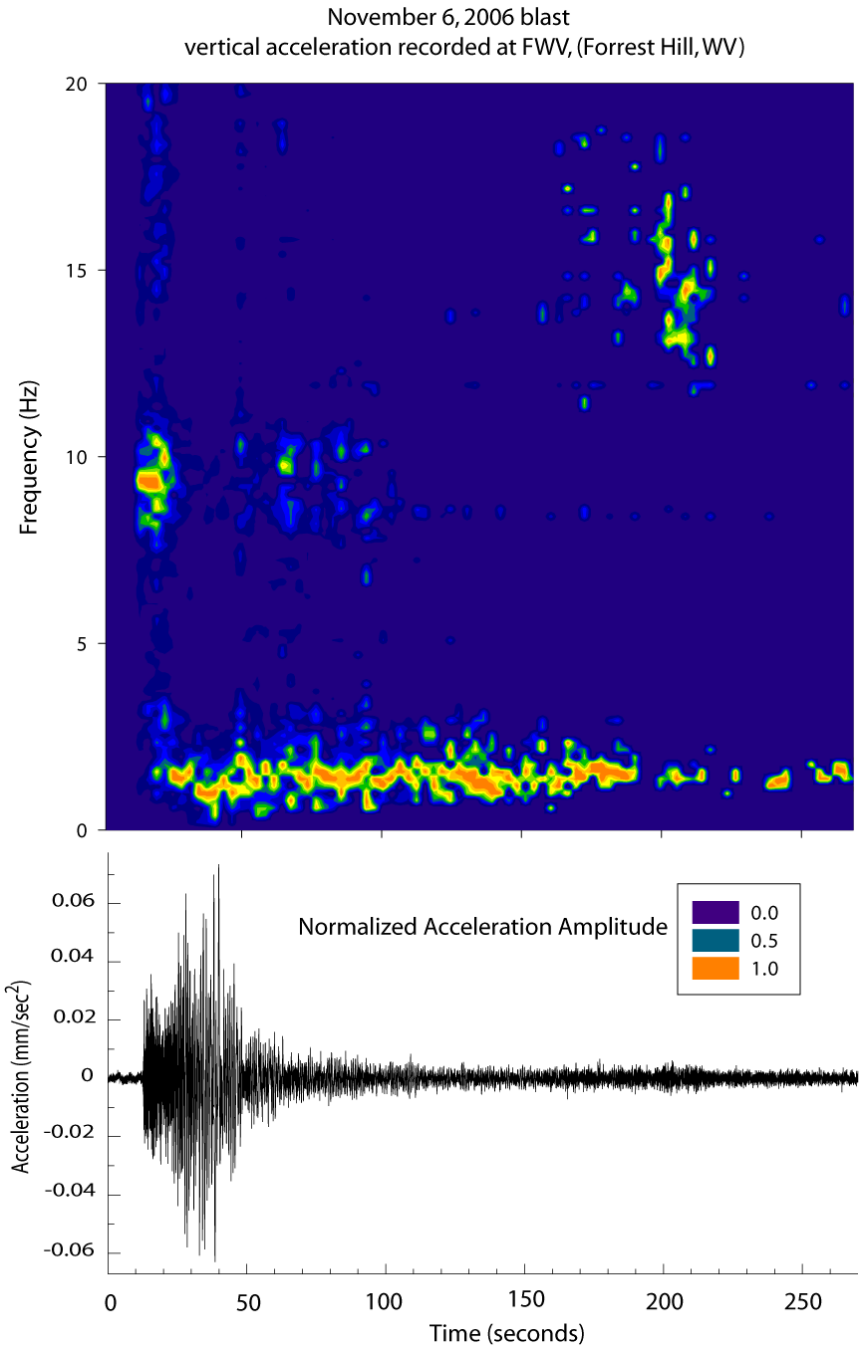
Earthquake

Earthquake



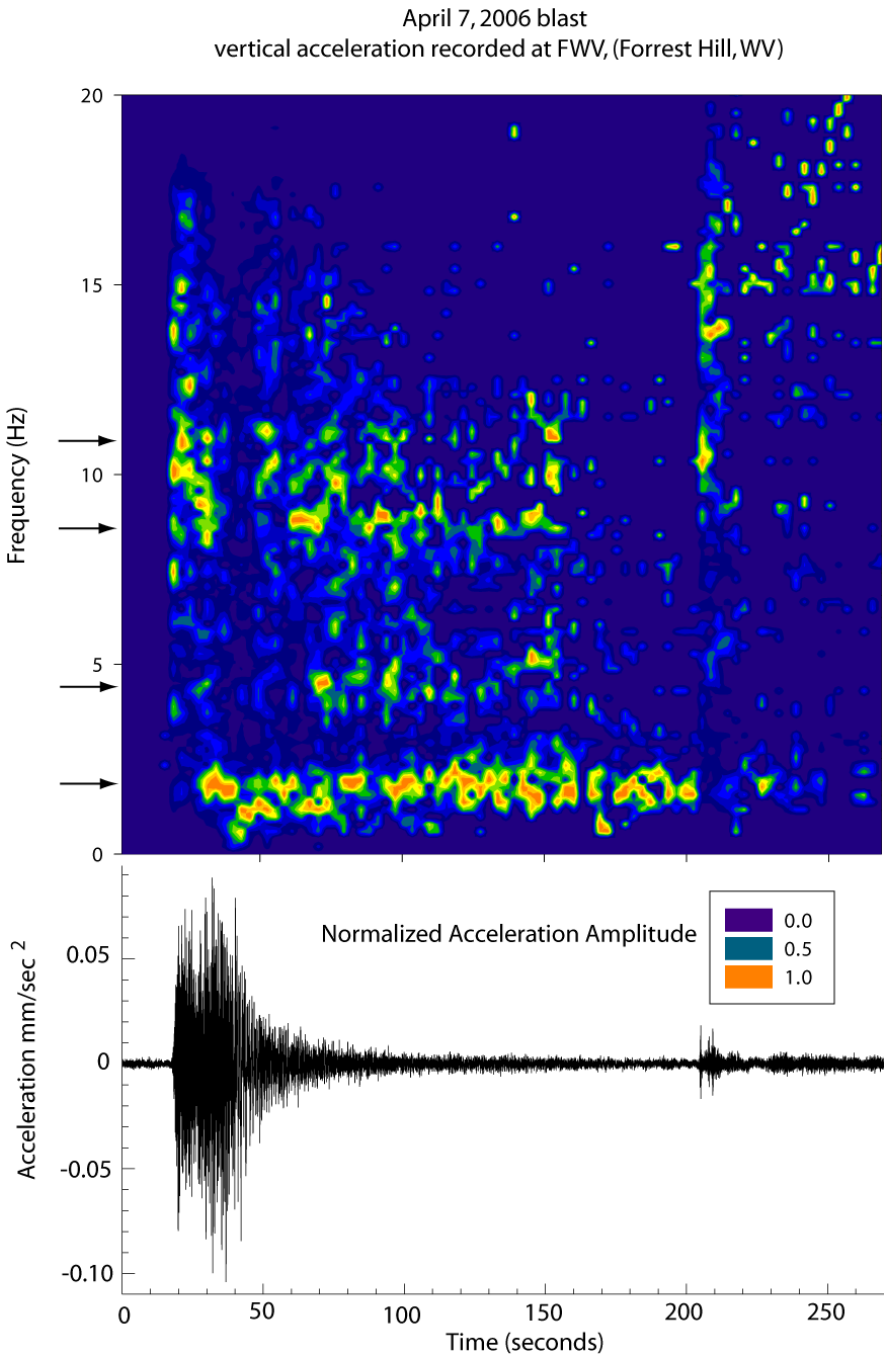
Another example of a delay-fired surface mine blast in southern West Virginia, recorded at a distance of approximately 140 kilometers.

Note strong time-invariant spectral peak at approximately 2 Hz.



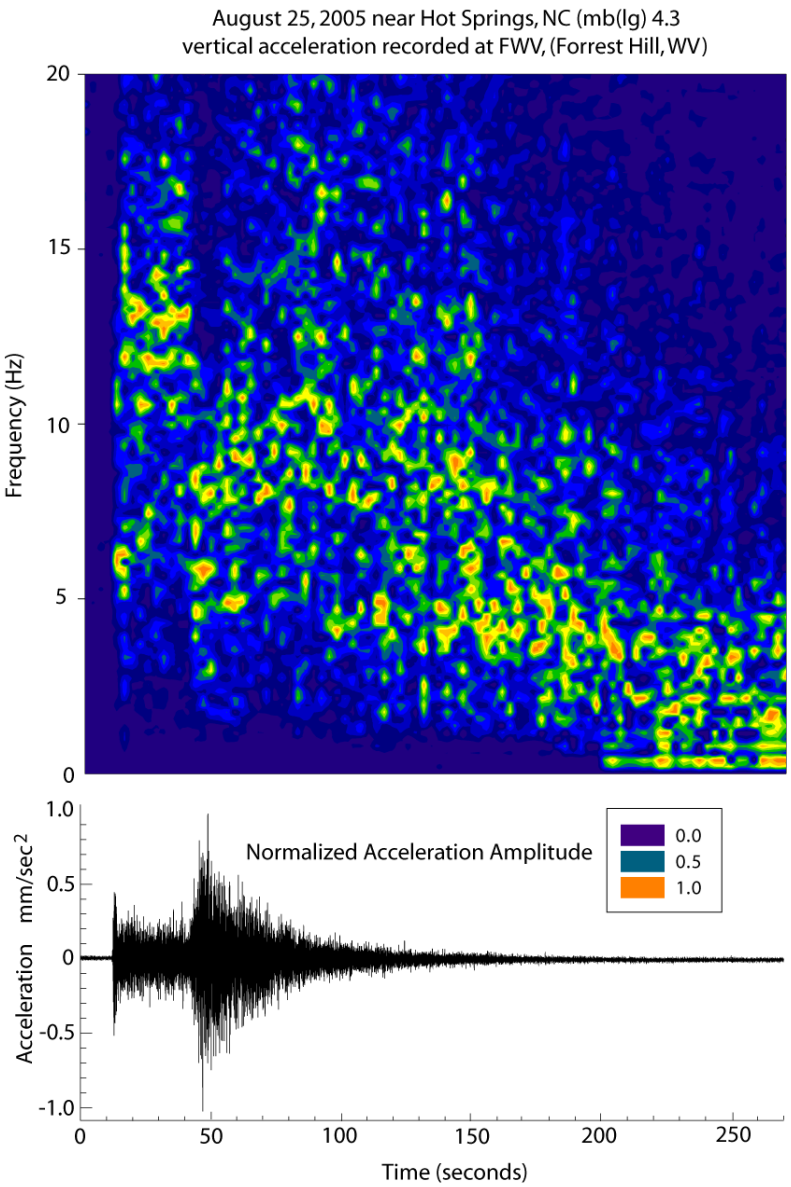
Another surface-mine blast in West Virginia, showing strong spectral peaks at 2, 4.5, 8, and 11 Hz.

Definitely a delay-fired blast.



Spectrogram of a natural earthquake near Hot Springs, North Carolina, recorded in southern West Virginia.

Note the lack of spectral banding.



The amplitude of Rayleigh surface waves can be used to discriminate mining-related seismic events from natural earthquakes.

How?

Natural earthquakes typically occur at depths of a few kilometers to as much as 25 kilometers in eastern North America.

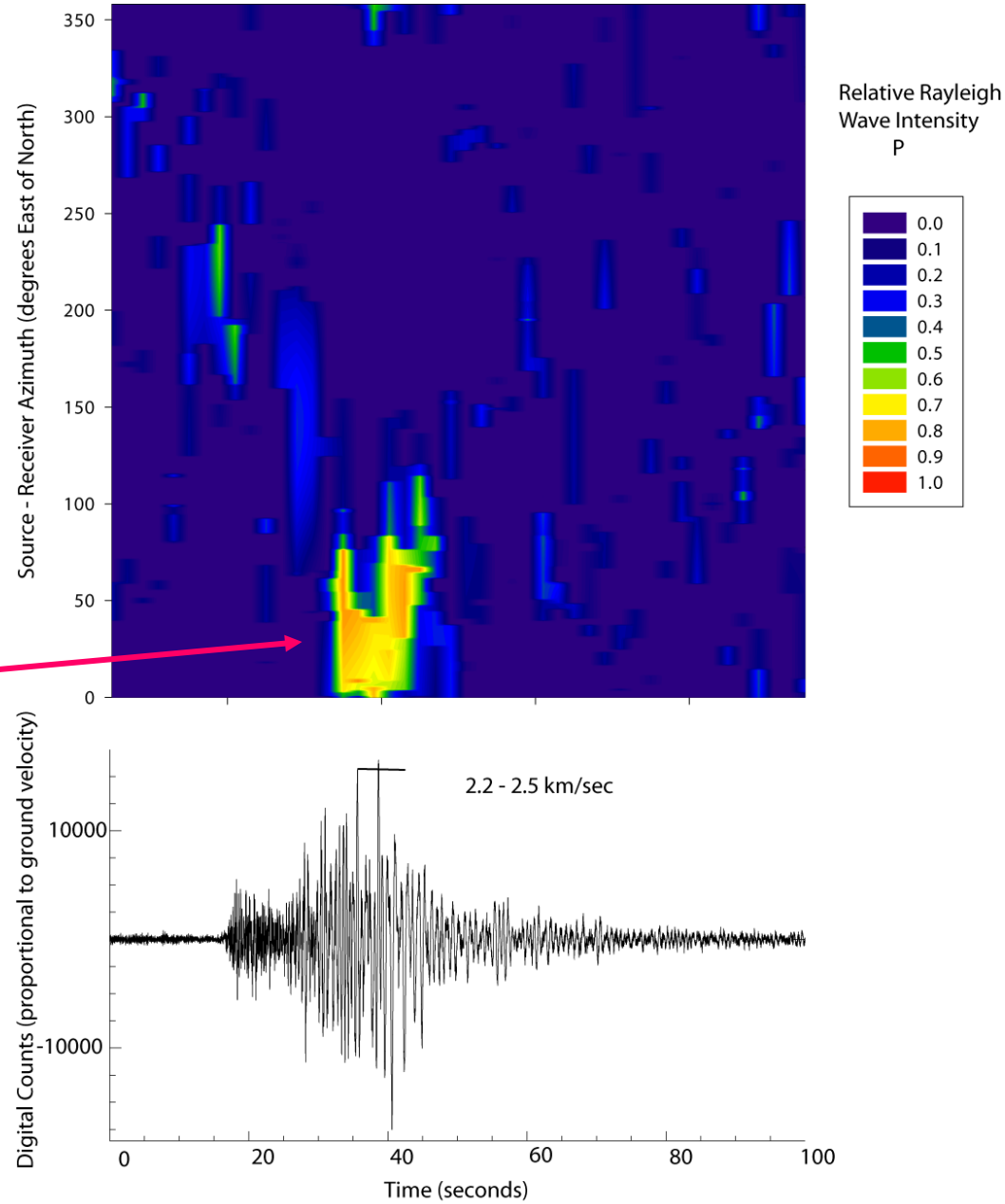
The amplitudes of Raleigh waves in the 0.2 to 0.5 Hz band are very sensitize to focal depth.

Large amplitude Raleigh waves in the 0.2 to 0.5 Hz band indicate shallow focal depth. If observed, the event may be mining-related.

Plot of Raleigh wave intensity versus time and component rotation angle.

Note the strong Raleigh wave amplitude, corresponding to an event azimuth of 35 degrees.

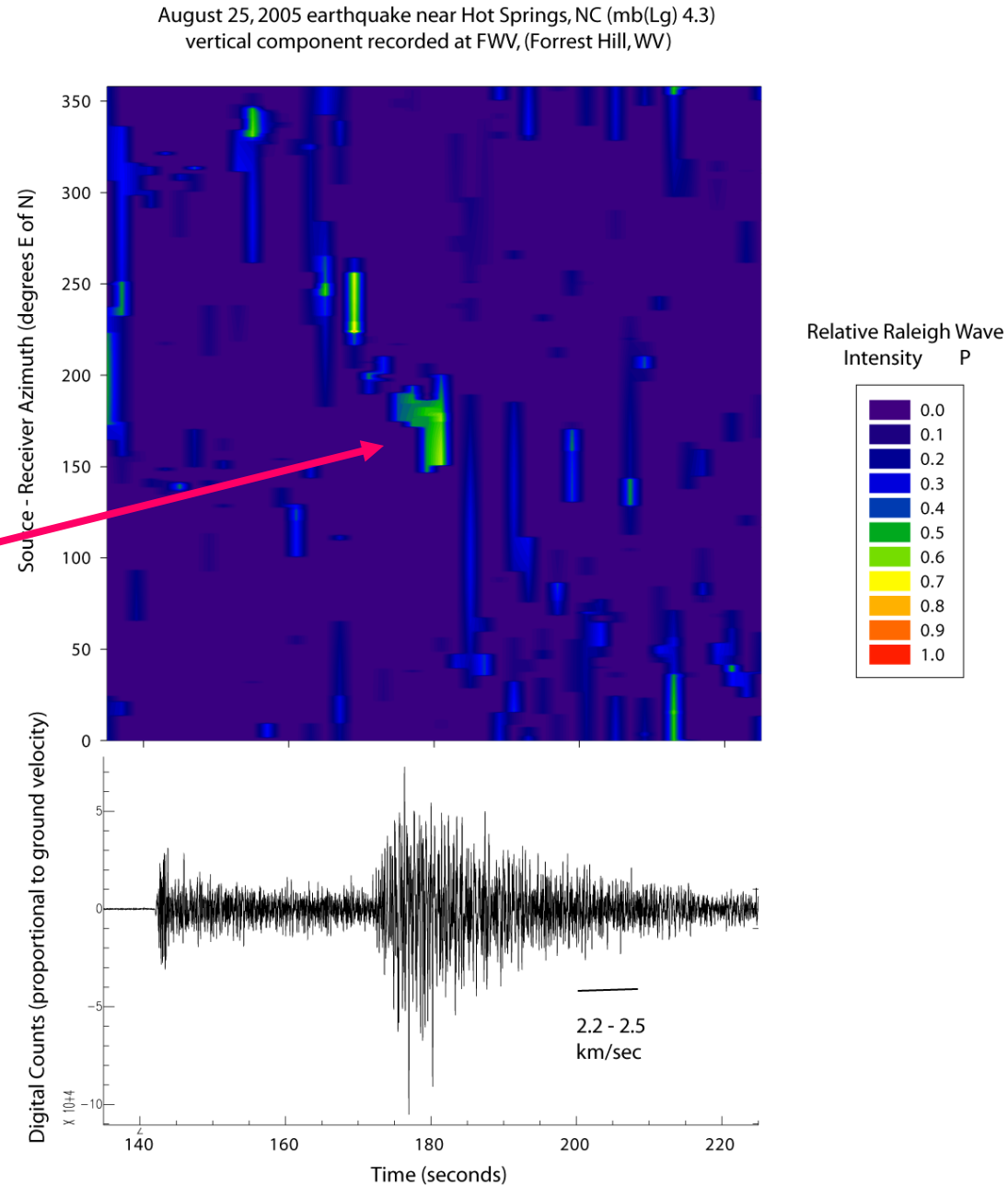
The event is a surface mine blast at an azimuth of 35 degrees from the recording station



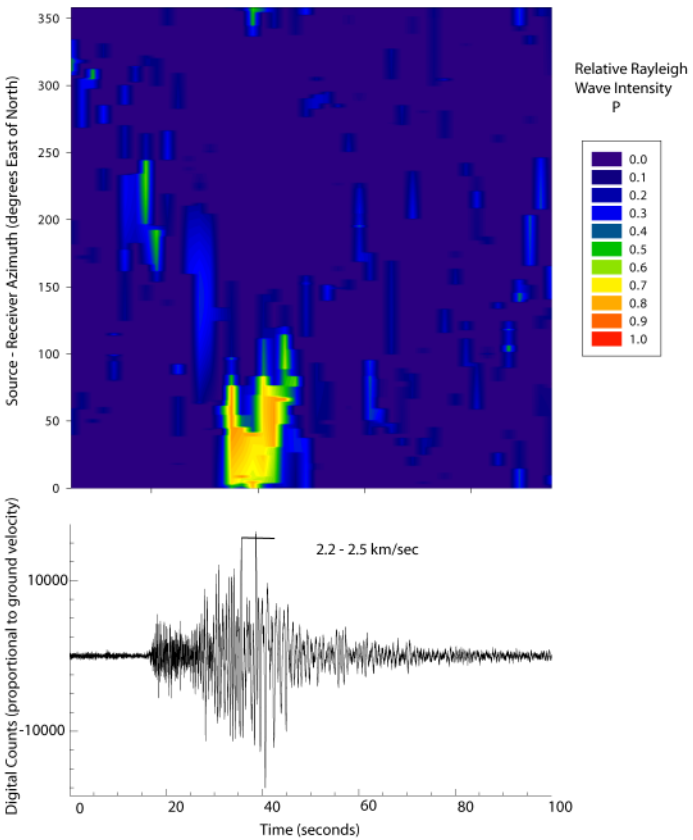
Raleigh wave intensity versus time and component rotation angle.

The analysis shows relatively low amplitude Raleigh amplitude along the event-station azimuth of 170 degrees.

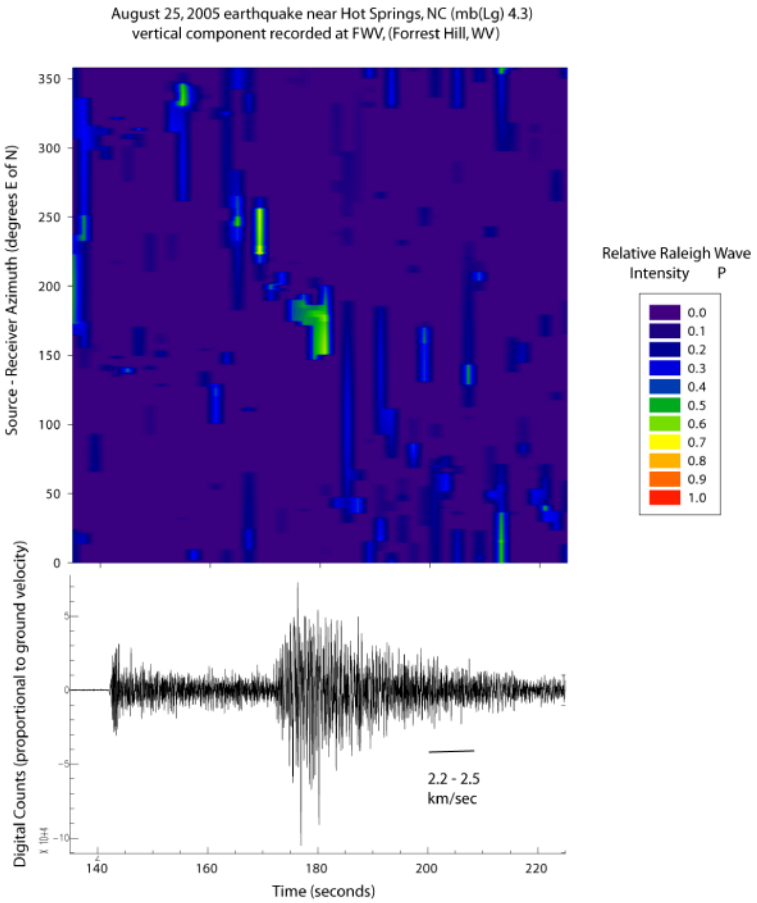
In this case, the event is the Hot Springs, NC earthquake recorded in West Viriginia. The focal depth is approximately 6 km.



Blast (shallow)



Earthquake (deep)



Conclusions

- Discrimination of mining-related events (from both surface and underground sources) is necessary to accurately assess earthquake hazard and to study the causes of mining-induced seismicity.

- Discrimination of larger surface-mine blasts is straight-forward, and makes use of nearly ubiquitous observation of time-invariant spectral modulation.

- Focal depth discrimination between all sorts of mining-induced events and natural shocks can be approached by developing discriminants based on Raleigh wave amplitude.

- Research is needed to establish a correlation between explosive charge weights, radiated seismic energy and moment magnitude for larger industrial explosions in the eastern United States.