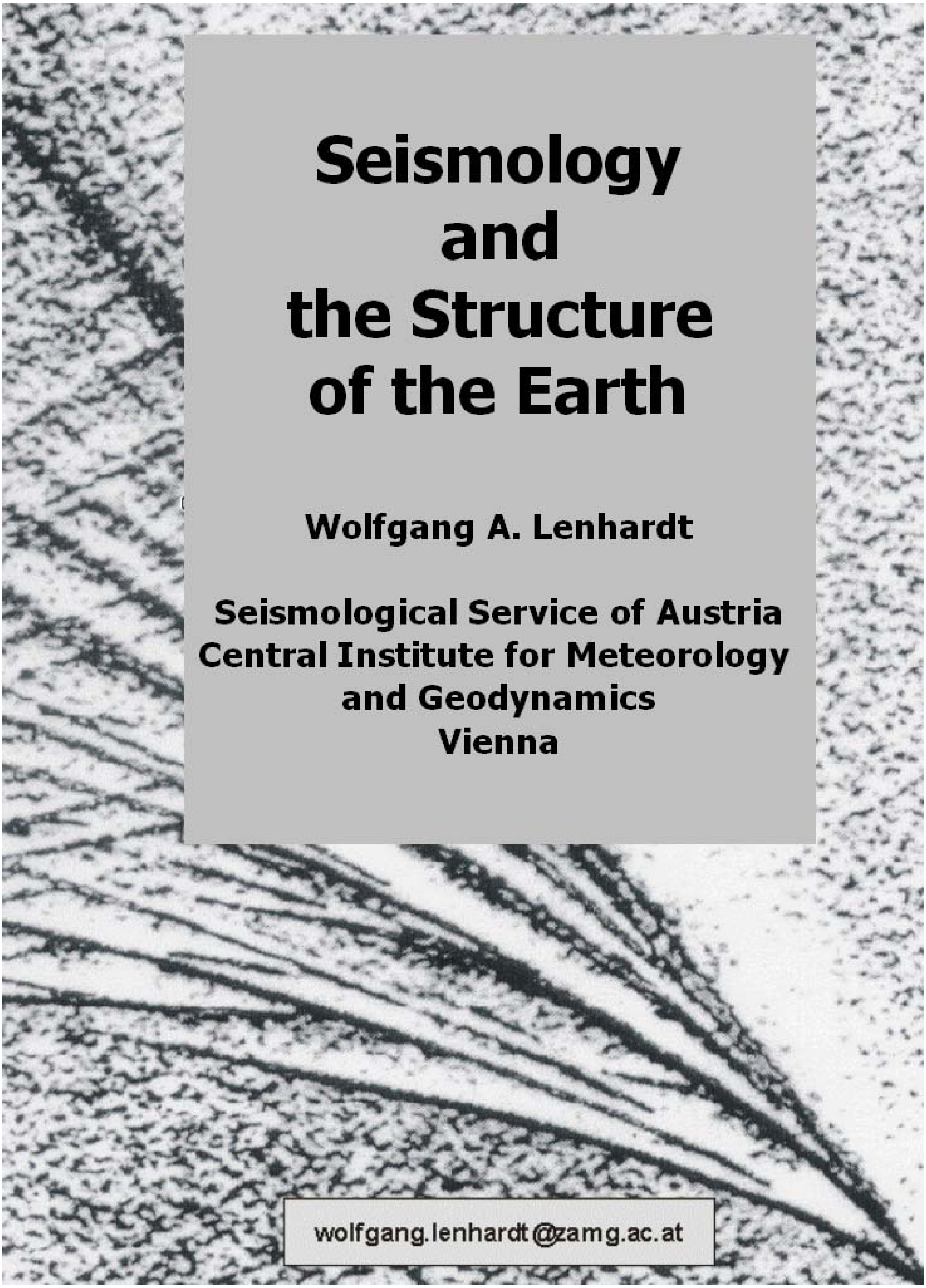

Seismology and the Structure of the Earth

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OVERVIEW

Literature

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Gibowicz, S.J. & Kijko, A. (1994). An Introduction to Mining Seismology. Academic Press, Inc., San Diego, California, 396 pages.

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Mendecki, A.J. (1997). Seismic Monitoring in Mines. Chapman & Hall, 262 pages.

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Software

Scherbaum, F. (1992). Programmable Interactive Toolbox for Seismological Analysis (PITSA). IASPEI Software Library Volume 5. Lee, W.H.K. (ed.). IASPEI Working Group on Personal Computers, P.O.Box 'I', Menlo Park, CA 94026, U.S.A.

INTRODUCTION

to

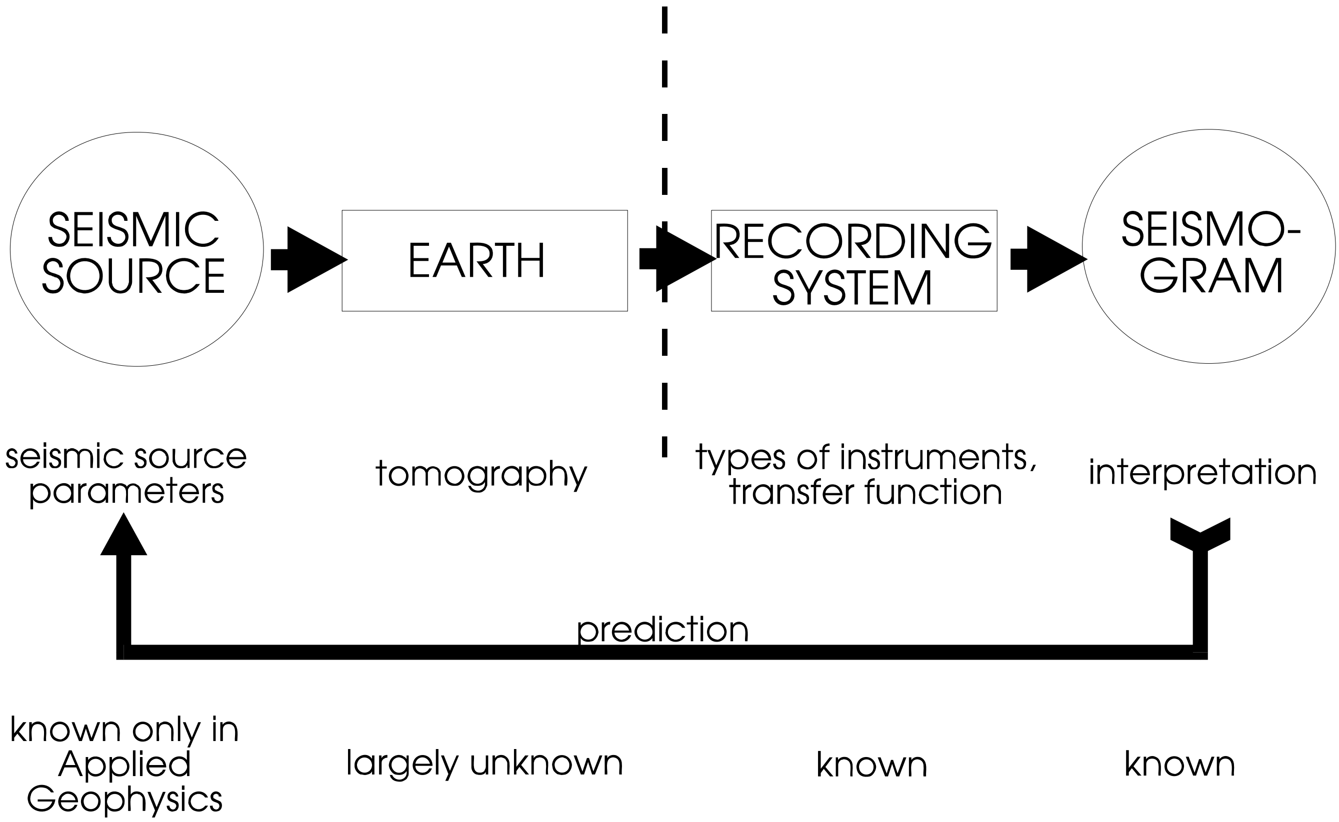
Seismometry

&

Restitution of Ground Motions

&

Interpretation of Seismograms



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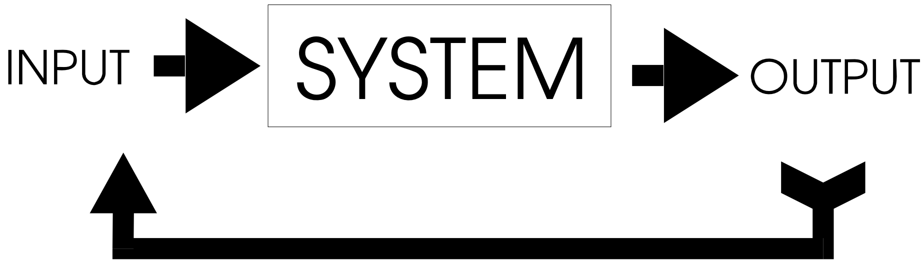
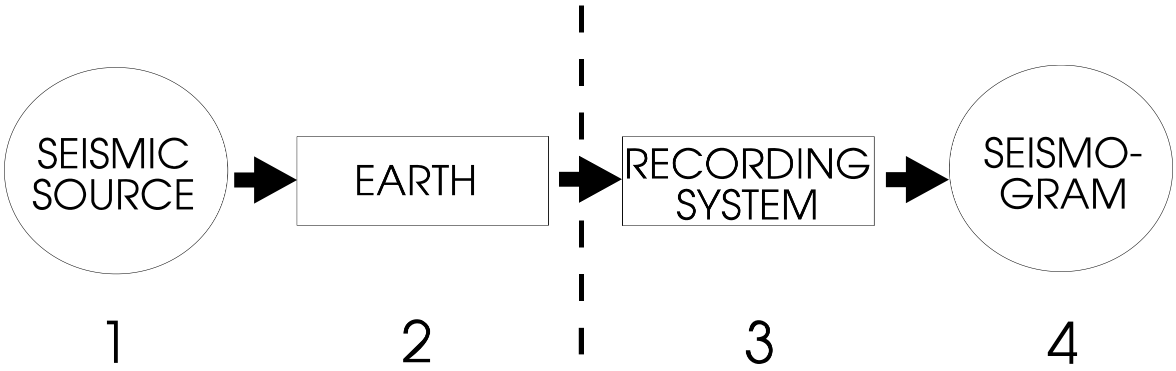


WHAT'S MISSING?



1. special seismic source models

2. site response
ray tracing
absorption
scattering
reflectivity
macroseismology

3. noise
coupling effects
simulating other instruments
world wide networks

4. archiving concepts
data formats
evaluation routines

OBJECTIVES

Major Topics of Global Seismology

Source topics	Earth structure topics
Classical objectives	
A. Source location	A. Basic layering (crust, mantle, core)
B. Energy release	B. Continent-ocean differences
C. Source type	C. Subduction zone geometry
D. Faulting geometry, area, displacement	D. Crustal layering, structure
E. Earthquake distribution	E. Physical state of layers
Current research objectives	
A. Slip distribution on faults	A. Lateral variations in crust, mantle, core
B. Stresses on faults and in Earth	B. Topography of internal boundaries
C. Faulting initiation/termination	C. Inelastic properties of the interior
D. Earthquake prediction	D. Compositional/thermal interpretations
E. Analysis of landslides, eruptions, etc.	E. Anisotropy

Primary Sources of Seismic Waves

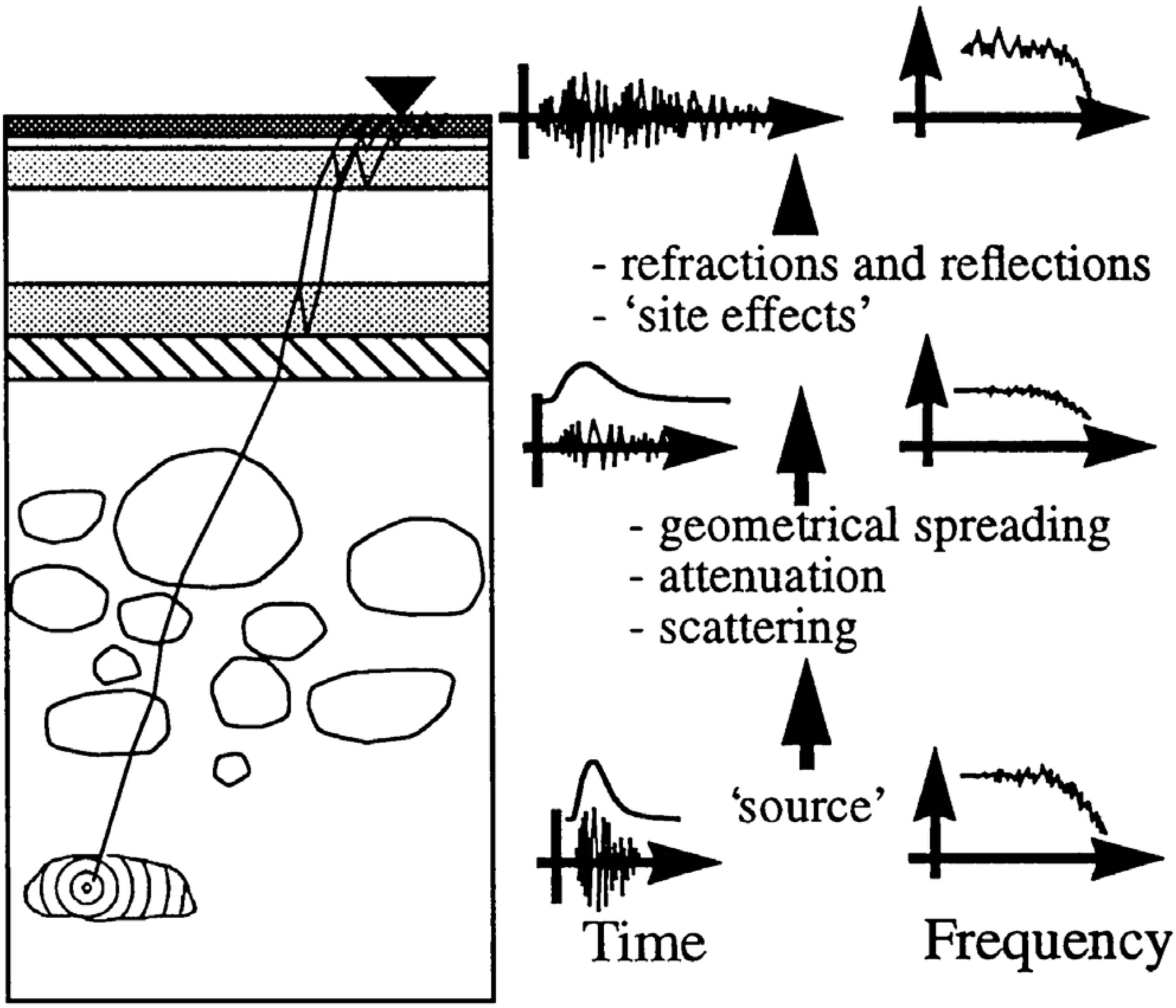
Internal	External	Mixed
Earthquake faulting	Wind, atmospheric pressure	Volcanic eruptions
Buried explosions	Waves and tides	Landslides
Hydrological circulation	Cultural noise	
Magma movements	Meteorite impacts	
Abrupt phase changes	Rocket launches, jet planes	
Mine bursts, rock spalliation		

Characteristic Seismic Wave Periods

Wave type	Period (s)
Body waves	0.01 - 50
Surface waves	10 - 350
Free oscillations	350 - 3600

To achieve these goals, different instruments need to be employed.

DISTORTION OF SEISMIC SOURCE SPECTRUM



s0101

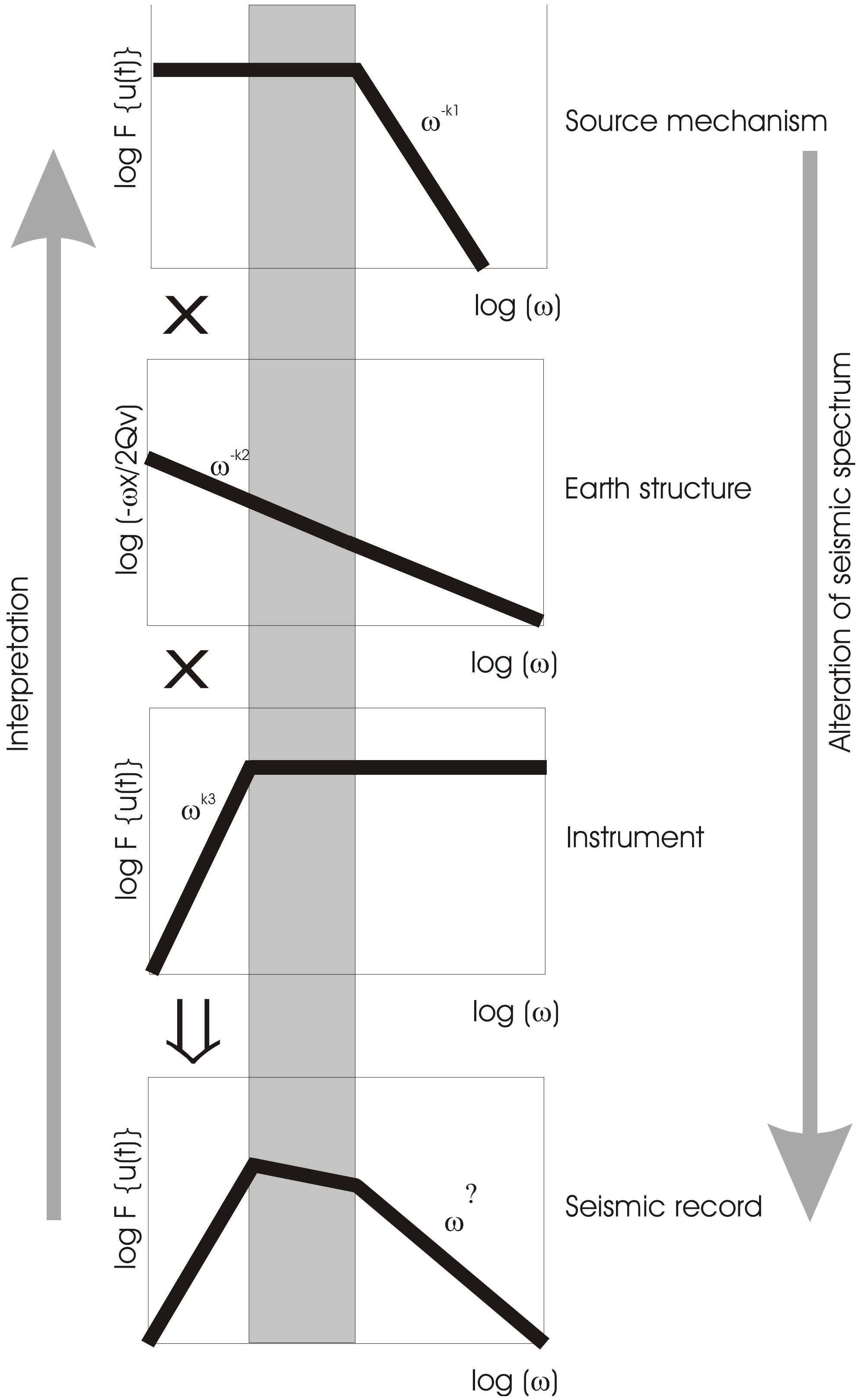
$$S(\omega) = A(\omega)\ I(\omega)\ R(\omega)\ B(\omega)\ G(\omega)$$

with

S (ω)... observed displacement spectrum
A (ω)... spectrum of actual source signal
I (ω)... instrument response
R (ω)... site response incl. the effect of the free surface
B (ω)... attenuation
G (ω)... geometrical decay

PRINCIPLE

OF DISTORTION OF THE SEISMIC SOURCE SPECTRUM



SEISMIC SOURCE SPECTRUM

Brune Model[1]

The Brune earthquake model consists of a circular fault of radius 'r' along which a constant shear stress drop '$\Delta\sigma$' takes place:

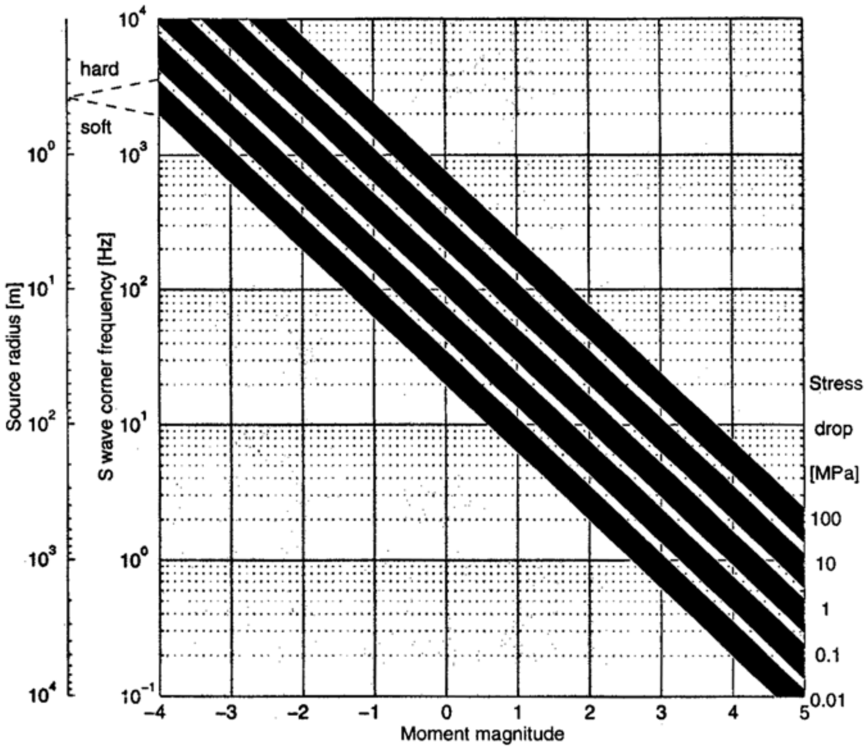
$$M_0 = c\int_{-\infty}^{\infty} u(t)dt = c\Omega(0)\ ,\ r^3 = \frac{7\,M_0}{16\Delta\sigma}\ ,\ f_0 = \frac{k\,V_S}{2\pi\ r}$$

with

- M_0... seismic moment (= G A D; G = modulus of rigidity, A = size of fault plane, D = average displacement)
- V_S... shear wave velocity
- f_0... corner frequency of s-wave
- k... constant, describes shape of source model (~ 2.34 for ‘Brune’ model)

The moment magnitude 'M_w' is given by[2]:

$$M_W = \frac{2}{3}log(\,M_0\,) - 6.1 \quad \text{; } M_0 \text{ given in Nm}$$



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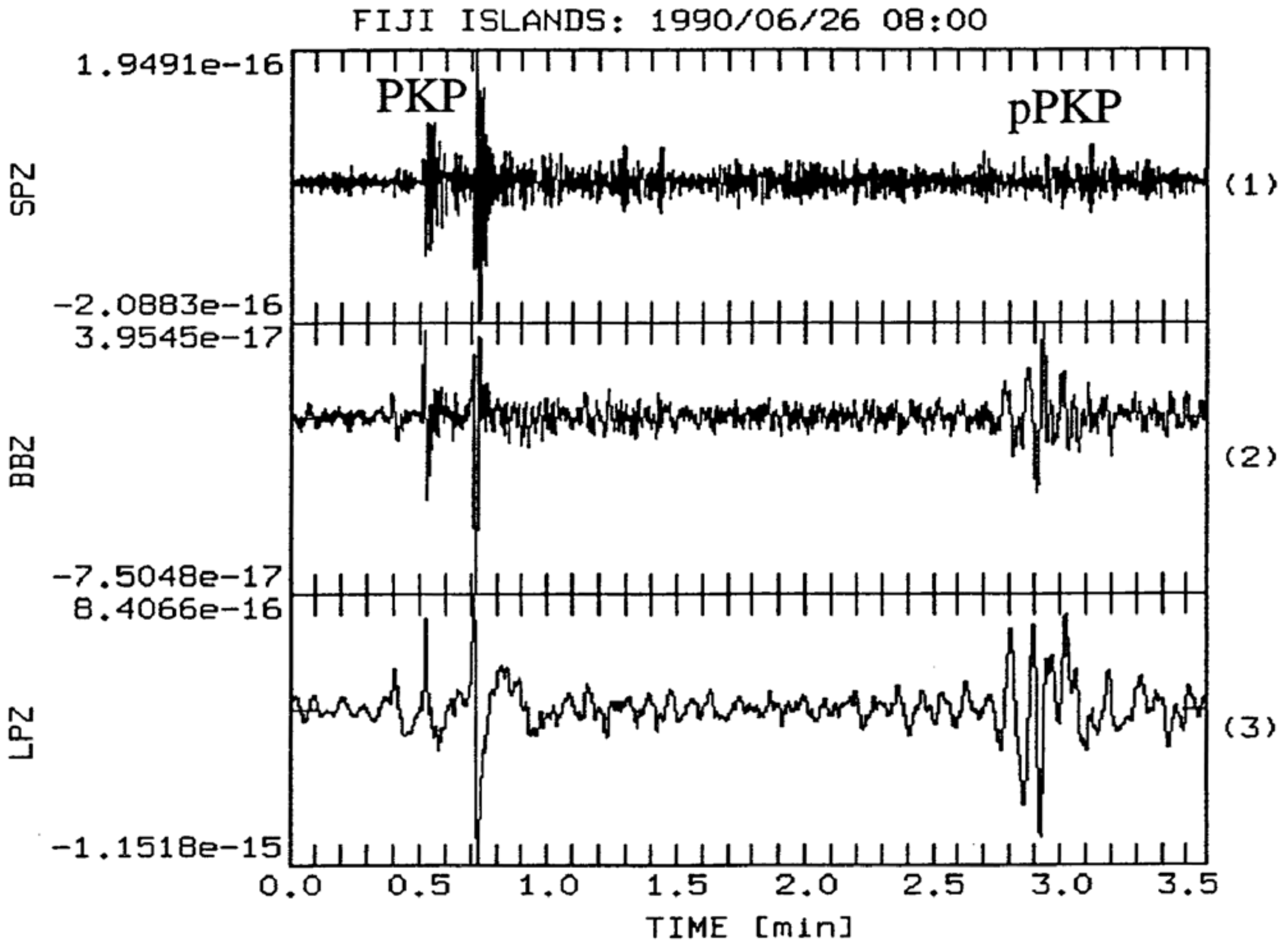
Expected source radius and corner frequency as function of moment and stress drop. Frequencies between $f_0/2$ and $5f_0$ must be recorded for seismic moment and energy determinations (from Mendecki, A.J. 1997).

[1]see also Brune, J. 1970, 1971. Tectonic stress and the spectra of seismic shear waves from earthquakes. J.Geophys.Res., Vol.75, 4997-5009 (correction1971 in J.Geophys.Res., Vol.76, 5002).

[2] Hanks, T.C. & Kanamori, H. 1979. A moment-magnitude scale. J.Geoph.Res. 84, 2348-2350

EFFECT OF RECORDING INSTRUMENTS
SEISMOMETERS

Depending on the instrument deployed, recorded waveforms appear different. Short-period instruments allow the detection of high frequent seismic signals (e.g. PKP phases of remote earthquakes), whereas long-period instruments permit the detection of signals with lower frequencies (e.g. pPKP phases). Broad-band instruments are a compromise and combine both advantages.



s0102

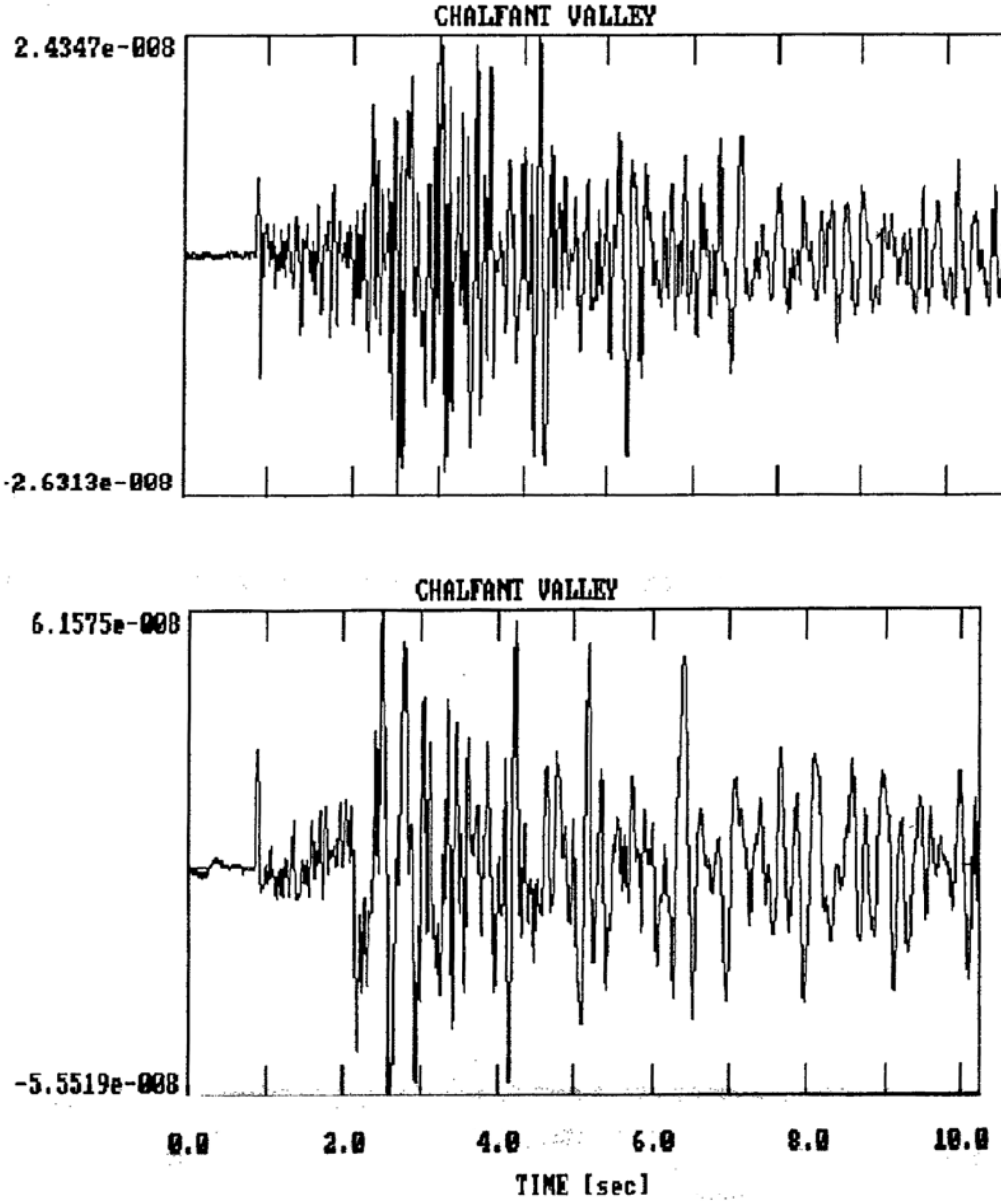
top: 'SPZ' short period instrument (WWSSN)
centre: 'BBZ' broad band instrument (KIRNOS)
bottom: 'LPZ' long period seismometer (WWSSN)

remark: PKP = core phase of P-wave from distant earthquake (Fiji Islands, distance ~ 151°)
pPKP = surface reflection of PKP (can be used for focal depth determination)

(see also Scherbaum, F. 1996)

EFFECT OF RECORDING INSTRUMENTS
CORRECTION FOR FREQUENCY RESPONSE

Converting seismic traces from e.g. velocity to displacement traces often leads to distinct onsets, which would have been difficult to detect on the original trace.



s01050107

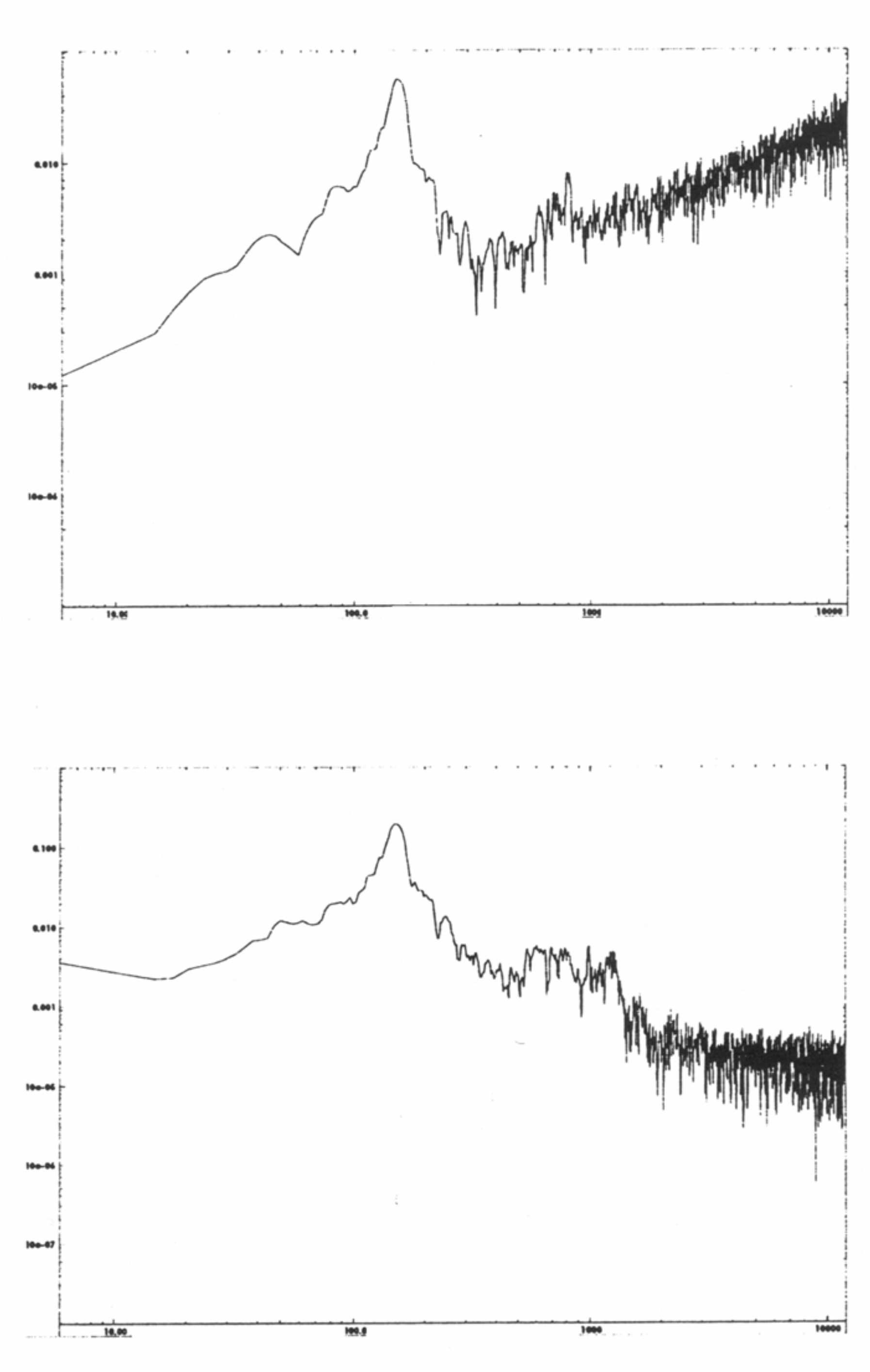
top: velocity record
bottom: corresponding displacement record reconstructed from velocity record

(see also Scherbaum, F. 1996)

EFFECT OF NOISE ON DETERMINING SPECTRA

Geophone versus Accelerometer

To create acceleration-seismograms from velocity records, differentiating velocity records may enhance unwanted high frequent noise, thus obscuring the seismic spectrum.



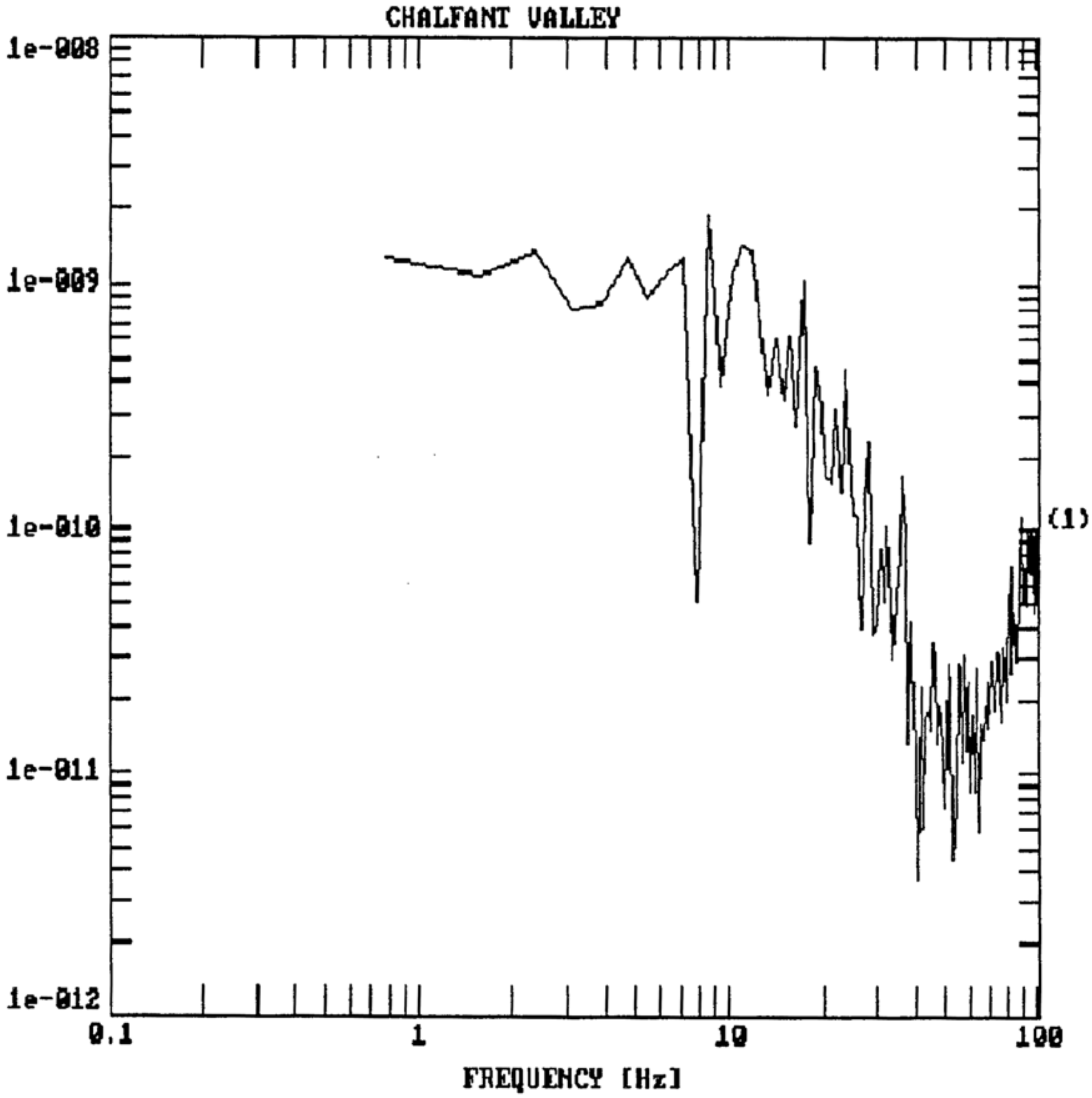
m0109

x-axis: frequency (Hz), y-axis: amplitude

top: pseudo-acceleration spectra (differentiated velocity record of geophone)
bottom: acceleration spectra from accelerometer
(see also Mendecki, A.J. 1997)

EVALUATION OF SEISMOGRAMS

FREQUENCY DOMAIN



s0108

Displacement spectrum for P-wave after instrument correction (from Scherbaum, F. 1996).

The seismic moment is given by the flat portion of the spectrum '$\Omega(0)$', with 'c' being a factor taking account of distance, attenuation and radiation:

$$M_o = c\int_{-\infty}^{\infty} u(t)dt = c\Omega(0)$$

FOURIER ANALYSIS – A BRIEF REVIEW

Every periodic and non-harmonic process can be represented by a sum of harmonic time-series. The frequency-dependent amplitude of each harmonic time-series depends on the shape of the non-harmonic process.

A time-series f(t) can be approximated by the sum of 1st and higher harmonics 'a' and 'b'.

$$f(t) = a_0 + a_1 \cos \omega t + a_2 \cos 2\omega t + ... + b_1 \sin \omega t + b_2 \sin 2\omega t + ...$$

The latter parameters constitute the frequency dependent amplitudes "$(a^2+b^2)^{1/2}$" and phases "arctan(a/b)" of the desired 'Fourier' spectrum.

The Fourier-transform for a time series f(t) is [3]

$$f(t) = \frac{1}{\sqrt{2\pi}} \int_{-\infty}^{\infty} F(\omega) e^{i\omega t} d\omega =$$

$$a_0 + a_1 \cos \omega t + a_2 \cos 2\omega t + ... + b_1 \sin \omega t + b_2 \sin 2\omega t + ...$$

$$F(\omega) = \frac{1}{\sqrt{2\pi}} \int_{-\infty}^{\infty} f(t) e^{-i\omega t} dt = \frac{1}{\sqrt{2\pi}} \int_{-\infty}^{\infty} f(t)(\cos \omega t - i \sin \omega t) dt$$

Consider effects of limited bandwith, clipping and/ or dynamic range and the sampling rate!

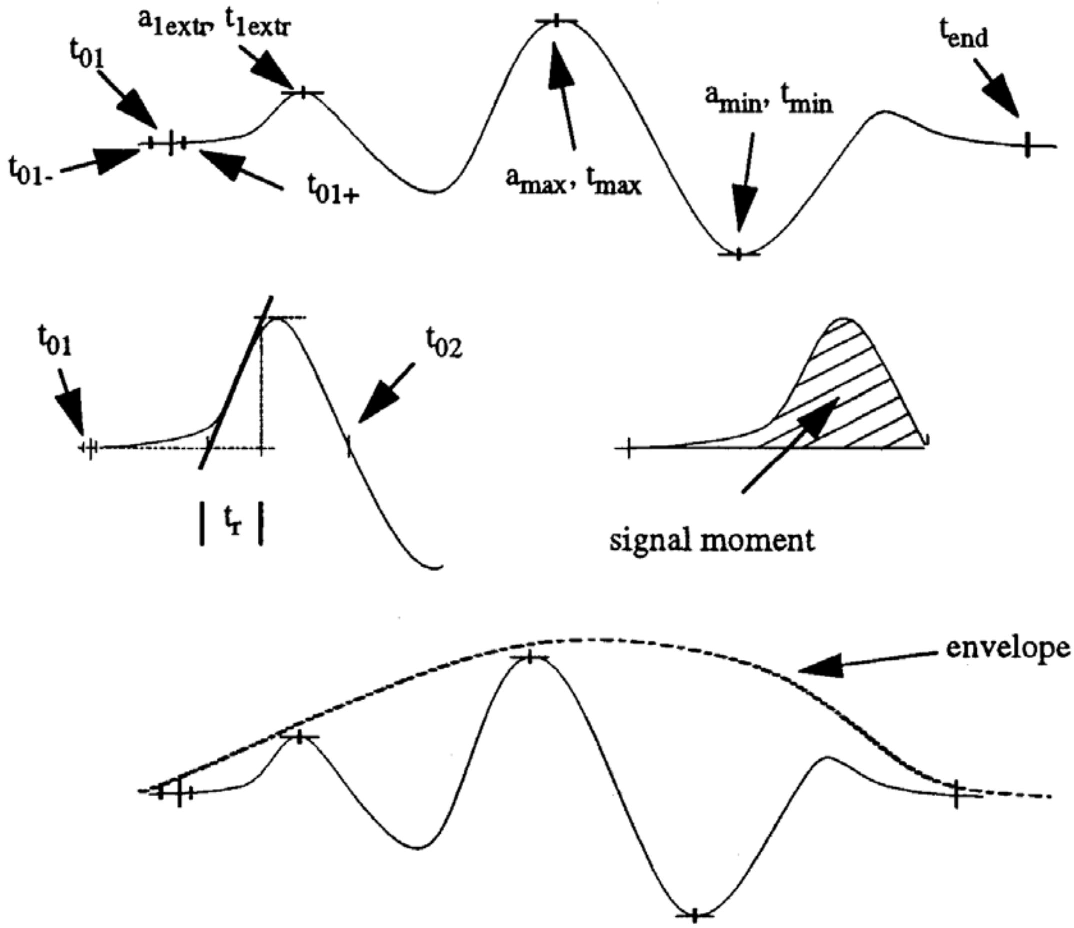
Which influence would they have on spectral analysis?

Which wrong conclusions could be drawn?

---

[3] remember that $e^{i\omega t} = \cos(\omega t) + i*\sin(\omega t)$ and $e^{-i\omega t} = \cos(\omega t) - i*\sin(\omega t)$, $i = \sqrt{-1}$.

TIME DOMAIN



s0109

Various parameters are necessary to describe and evaluate seismic onsets (from Scherbaum, F. 1996).

The seismic moment of the signal is given by integration of the displacement pulse 'u(t)', with 'c' being a factor taking account of distance, attenuation and radiation:

$$M_o = c \int_{-\infty}^{\infty} u(t)dt = c\Omega(0)$$

Other parameters in the time domain are:

1. t_{01-}, t_{01}, t_{01+}... arrival time with error margin (depending on noise level!)
2. a_{1extr}, t_{1ext}r... amplitude and time of first extremum
3. a_{max}, t_{max}... amplitude and time of maximum amplitude
4. a_{min}, t_{min}... amplitude and time of minimum amplitude
5. t_{end}... end of signal (depending on noise level!)
6. t_{01}, t_{02}, t_r start and end-time of signal used to determine the signal moment, rise time
7. envelope affected by attenuation
8. & other onsets and extremes with different periods.