

Athens 1999 Earthquake Ground Motion Analysis

Dr. Serpetsidaki Anna

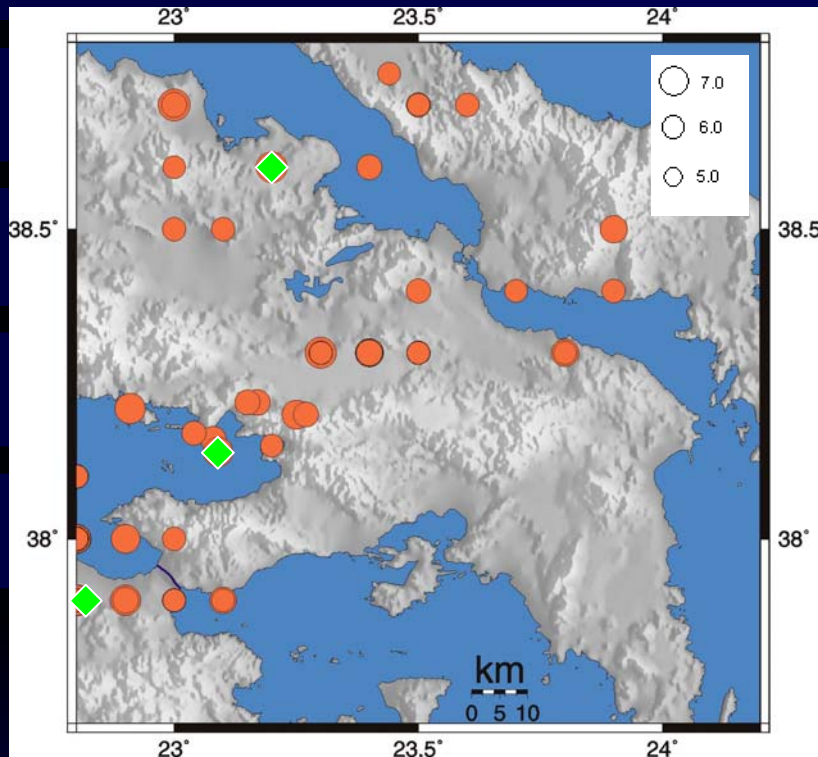
Patras University

Seismological Laboratory

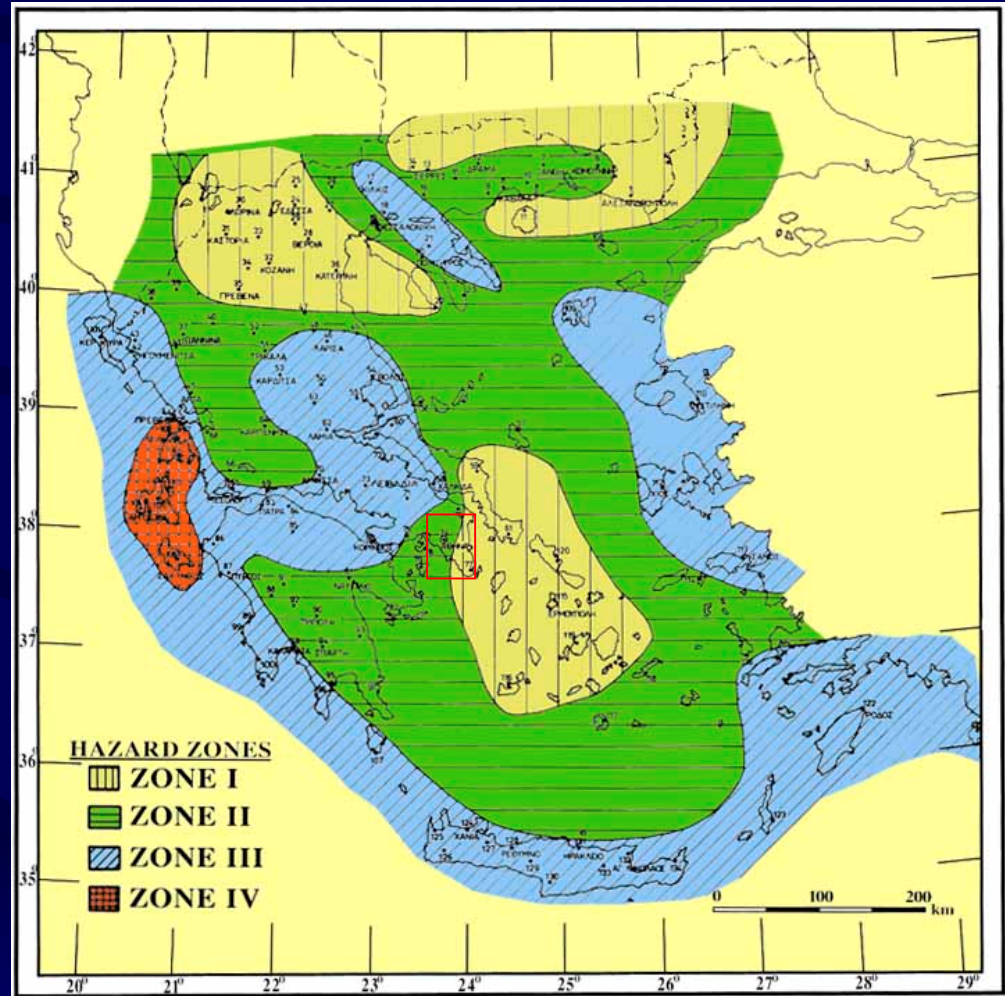
<http://seismo.geology.upatras.gr>

annaserp@geology.upatras.gr

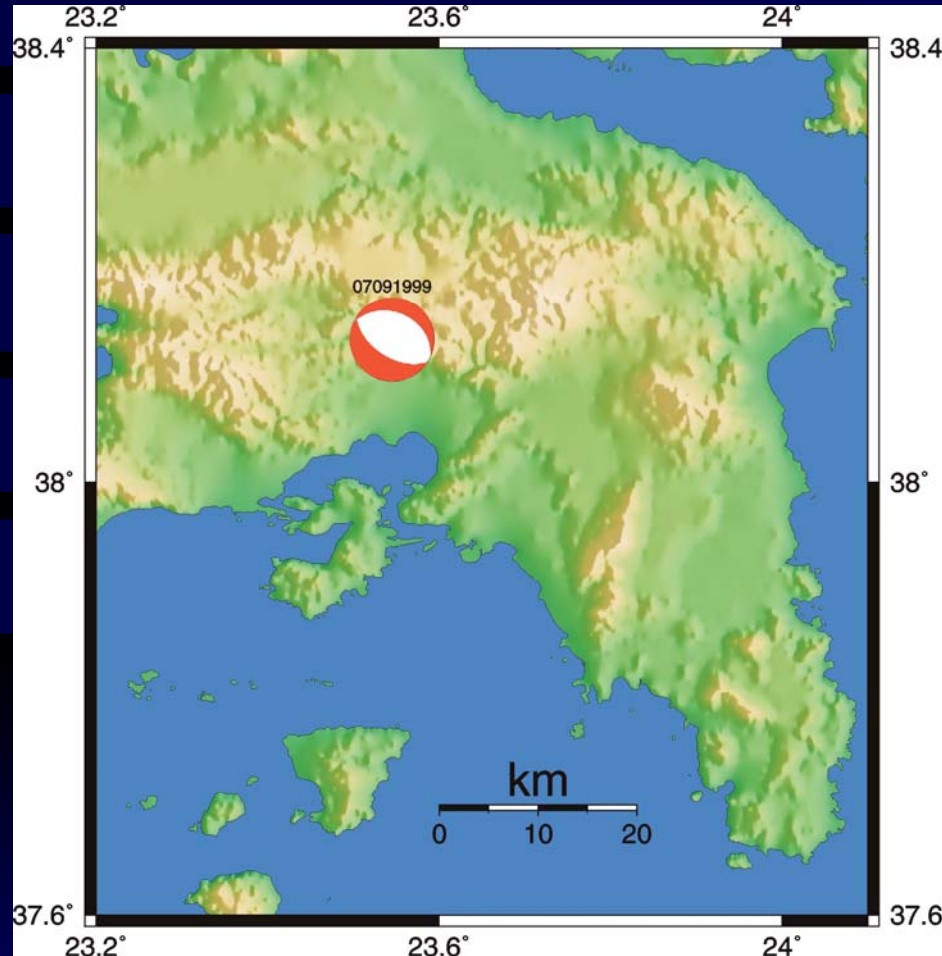
Athens : A Low Seismicity Region



489BC-1981 (Papazachos et al., 1997)



Athens 7th September 1999 Earthquake



- 7-9-1999 11:56:50 (GMT)
- $M_w=5.9$
- Lat: 38.132° Lon: 23.545° (USGS)
- Strike Dip Rake
123 $^\circ$ 55 $^\circ$ -84 $^\circ$

Most Destructive Earthquake during Greece Modern History



Ricomex Factory

Ano Liosia



Most Destructive Earthquake during Greece Modern History



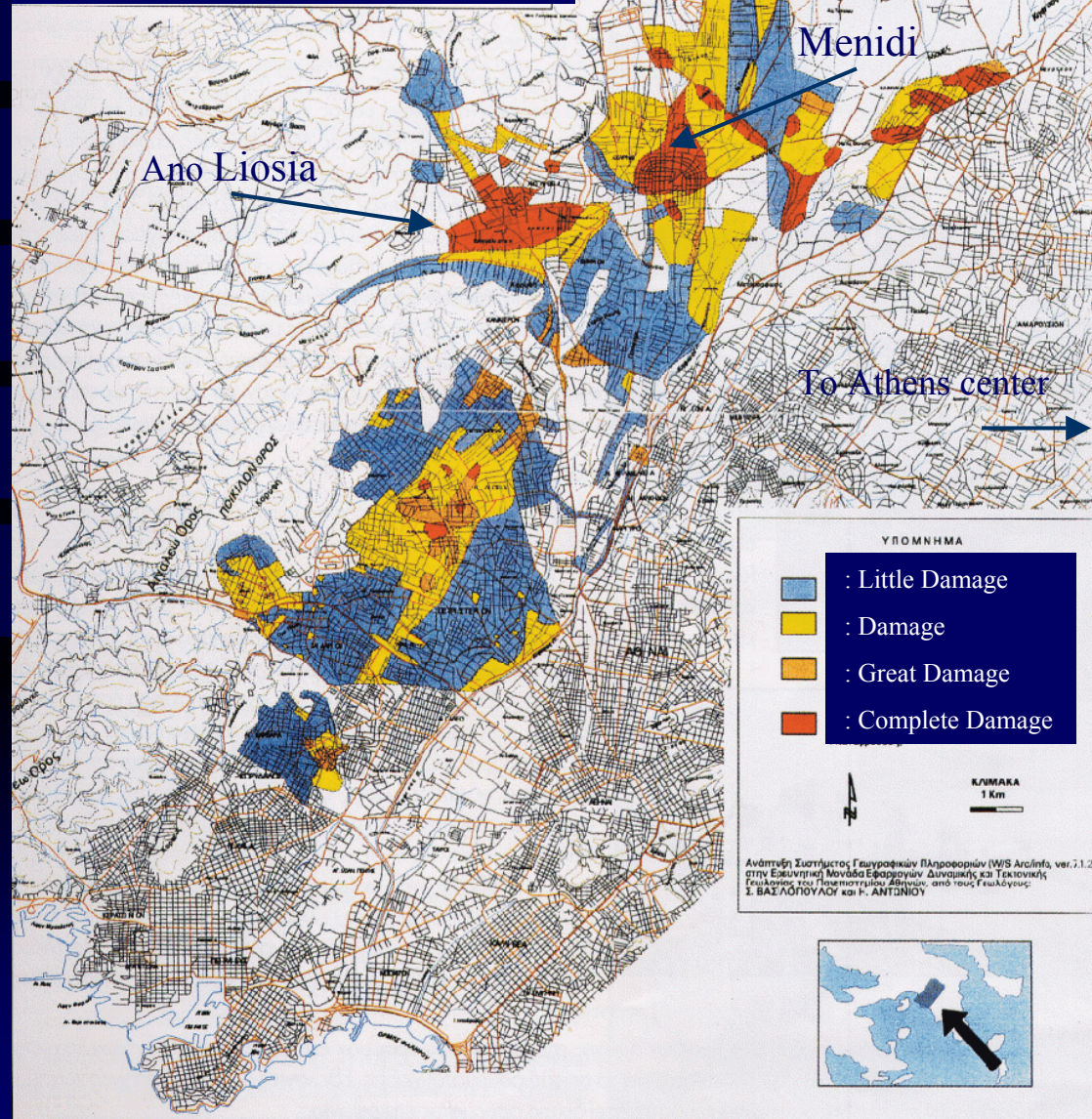
Faran Factory

Menidi



Intensity Distribution Map

www.oasp.gr



Irregularly
Distributed
Intensity
 I_0 :VII-IX



Ground Response Analysis

Aim: Understanding of Processes which Control the Strong Seismic Motion and Estimation of Ground Response

$$s(t) = i(t) * h_e(t) * h_g(t) * h_r(t)$$

- $s(t)$: Strong Ground Motion
- $i(t)$: Source
- $h_e(t)$: Path
- $h_g(t)$: Local Site Conditions
- $h_r(t)$: Instrument

Ideal Problem Approach:

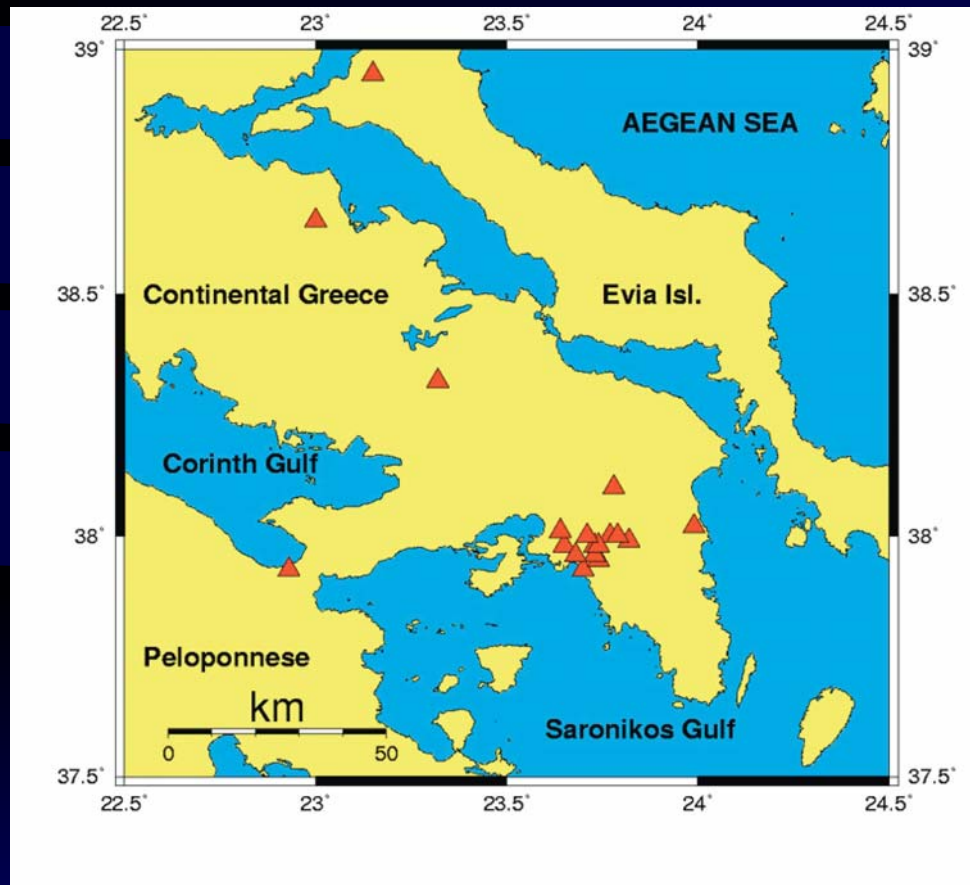
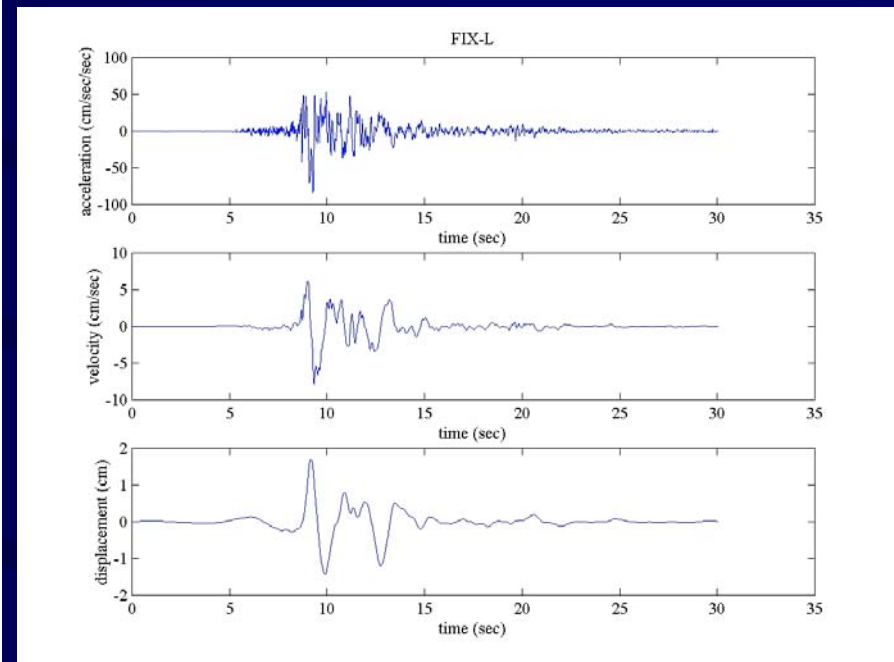
Rupture Process

Propagation up to Bedrock

Site Effects (Local Site Conditions)

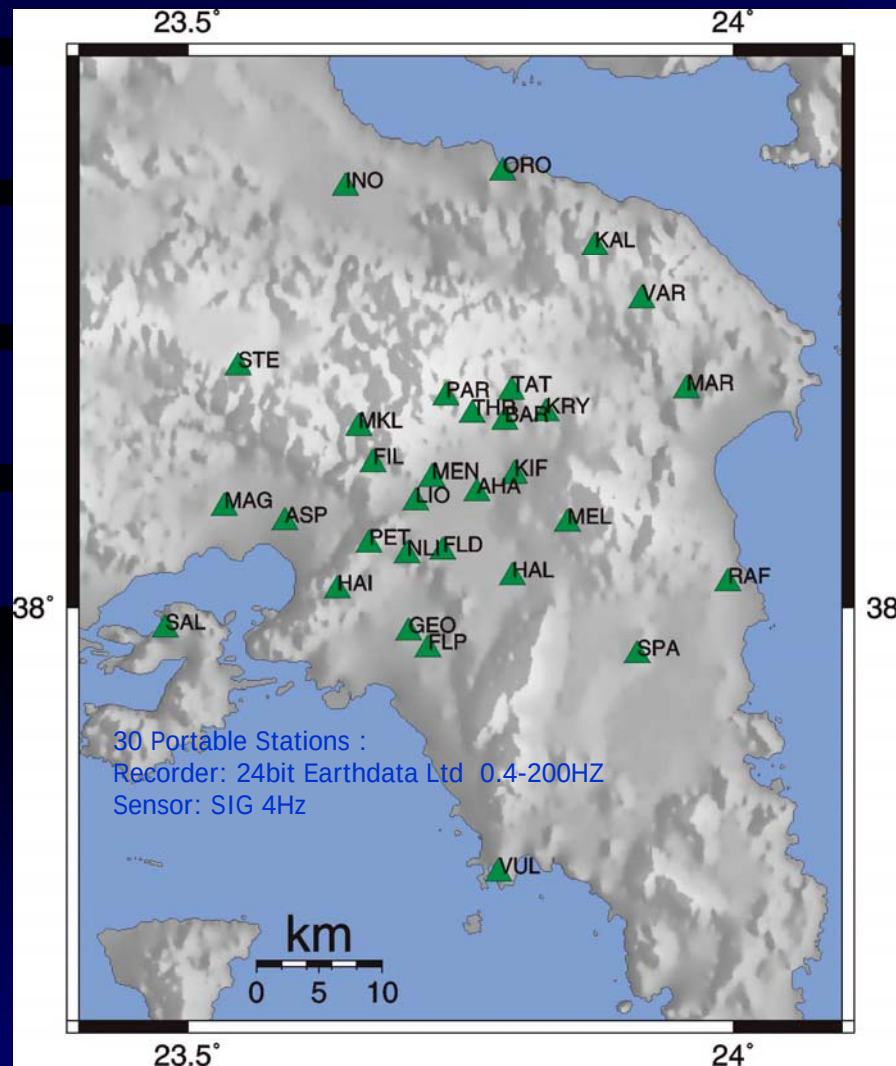
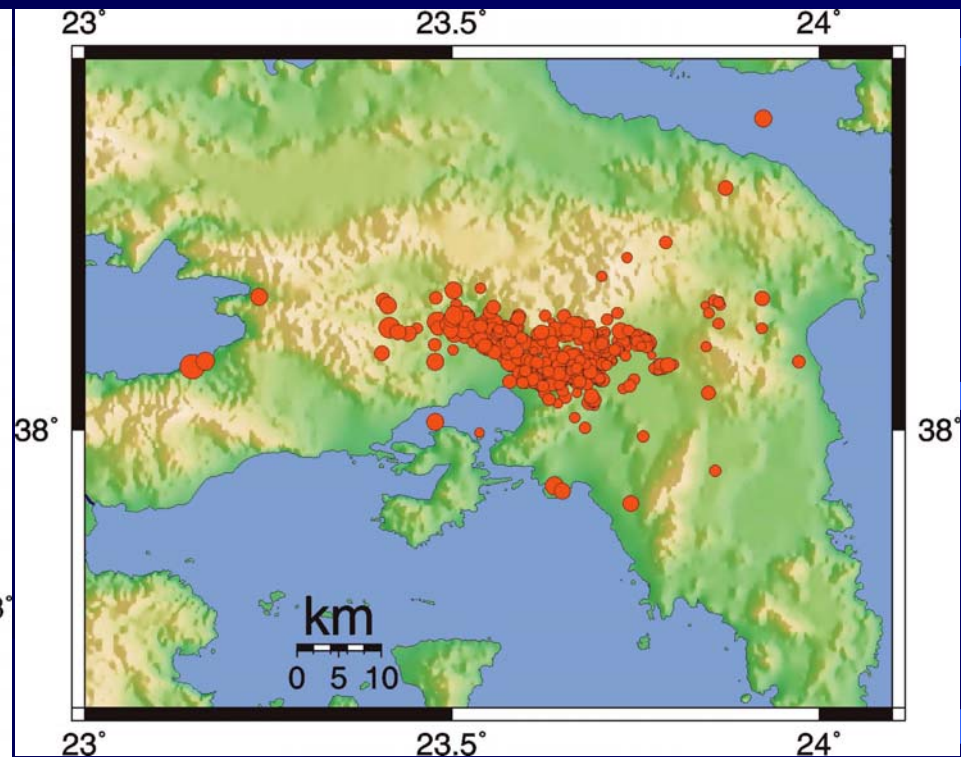
Seismological Data

Mainshock Strong Motion Recordings (NOA)



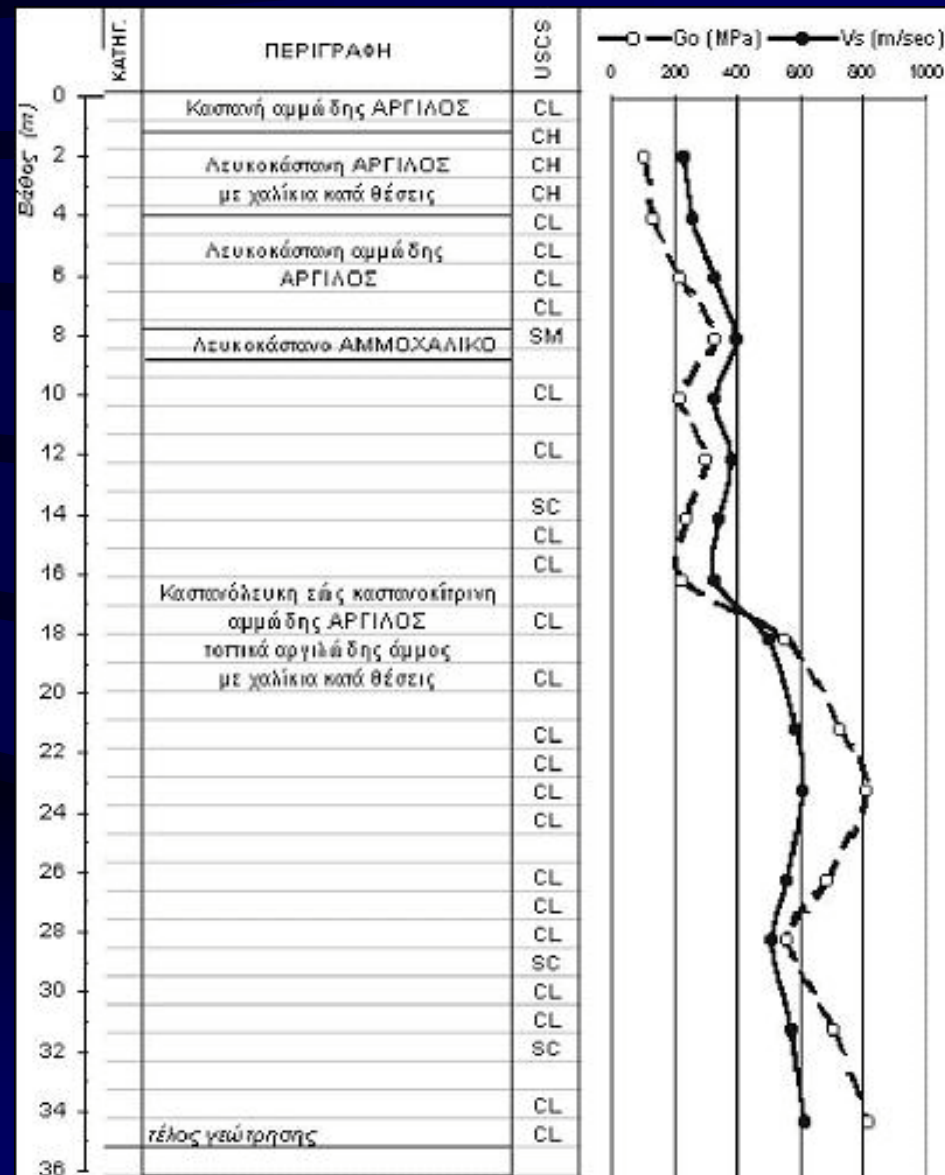
Seismological Data

Aftershock Sequence Recordings (UPSL)



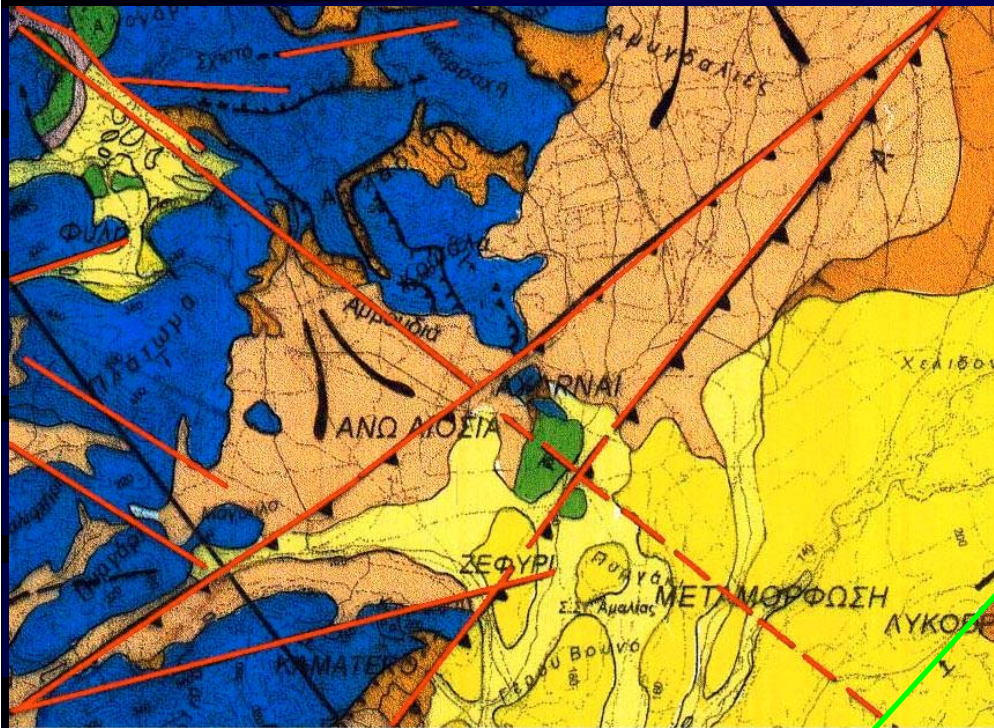
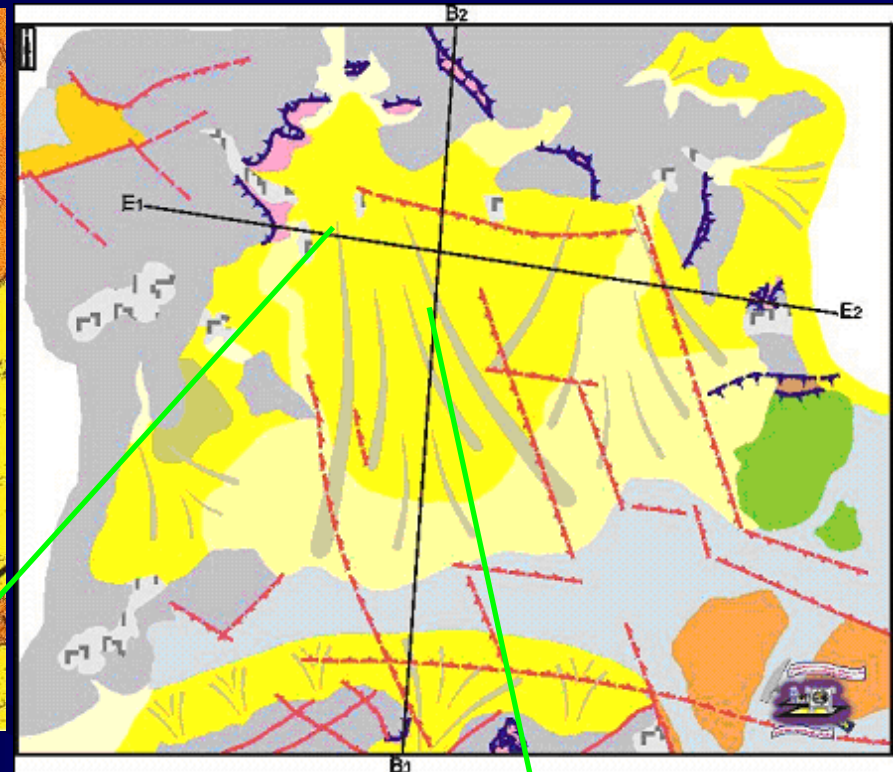
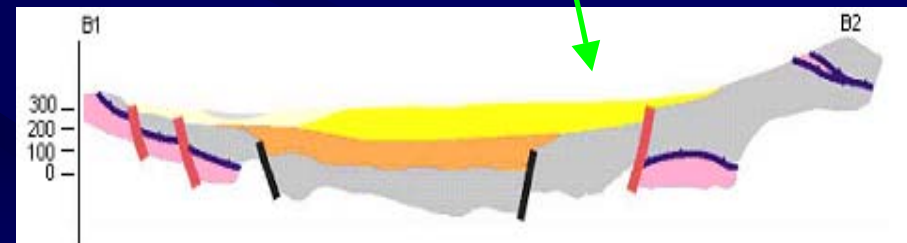
Geotechnical Data

Faran, Ricomex, Ano Liosia, Menidi



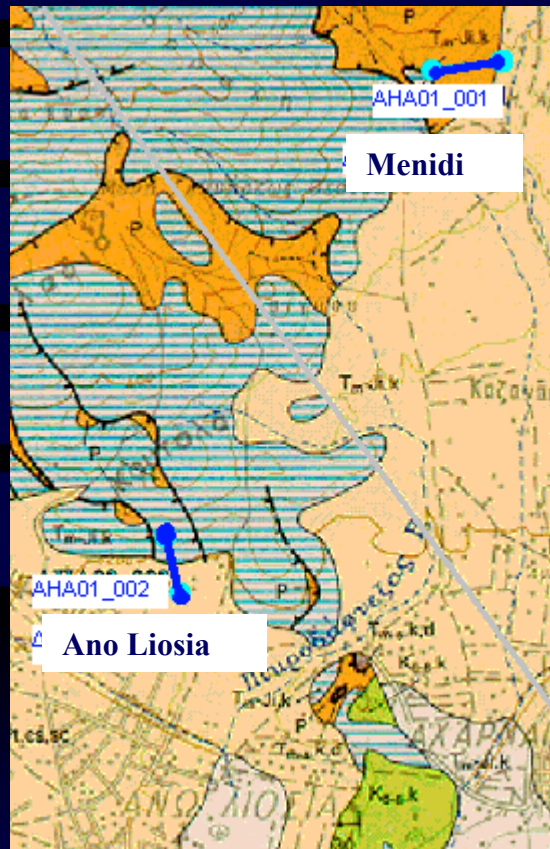
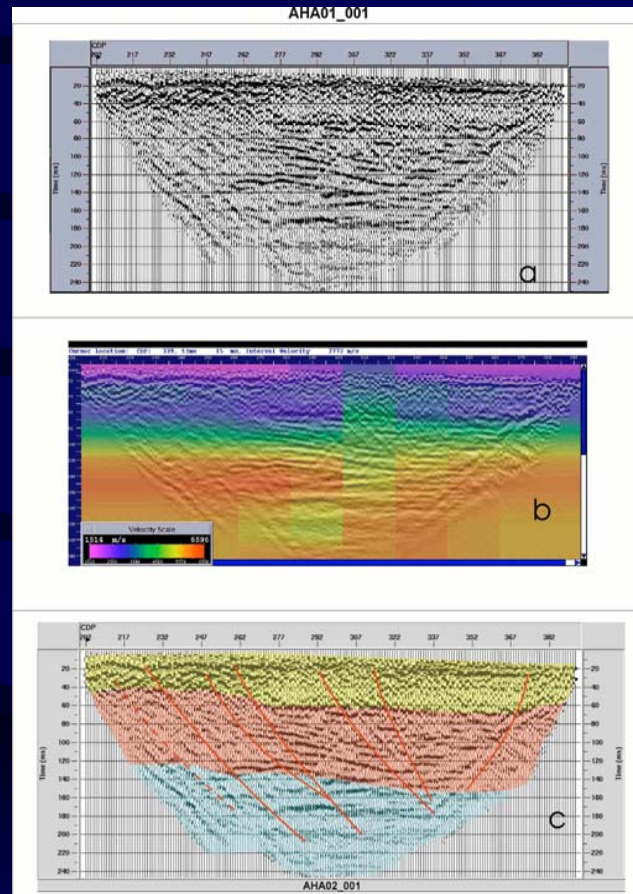
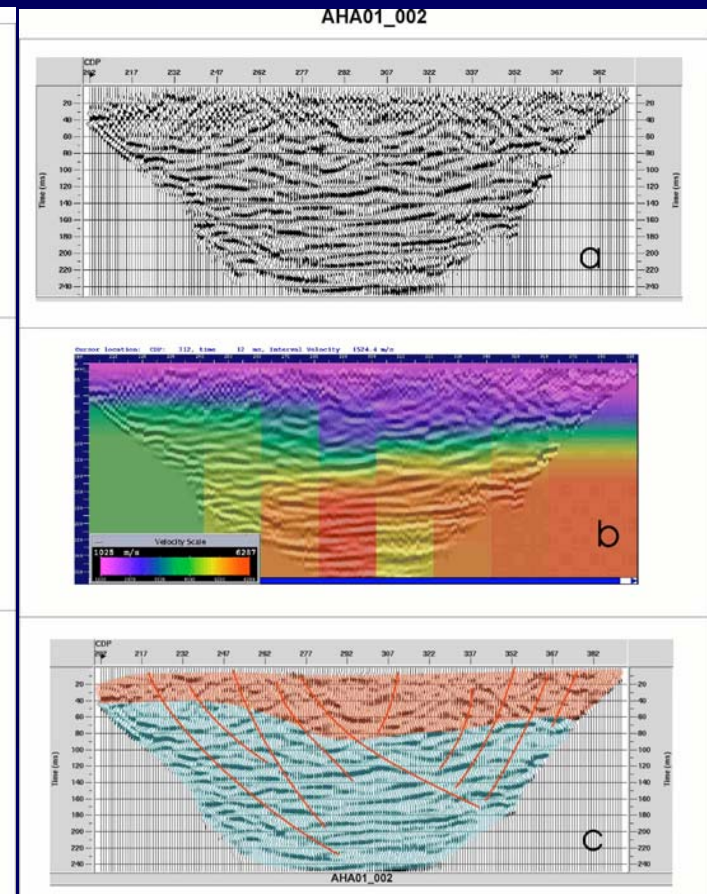
Geological Data

Western Attica Basin

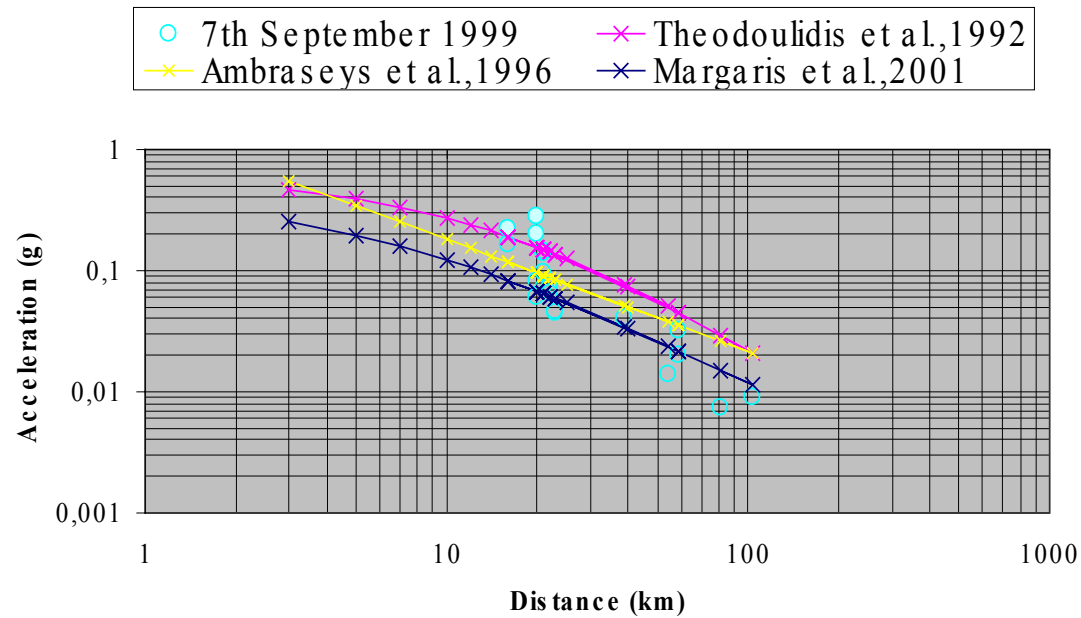


Geophysical Data

Menidi (Aharnai), Ano Liosia



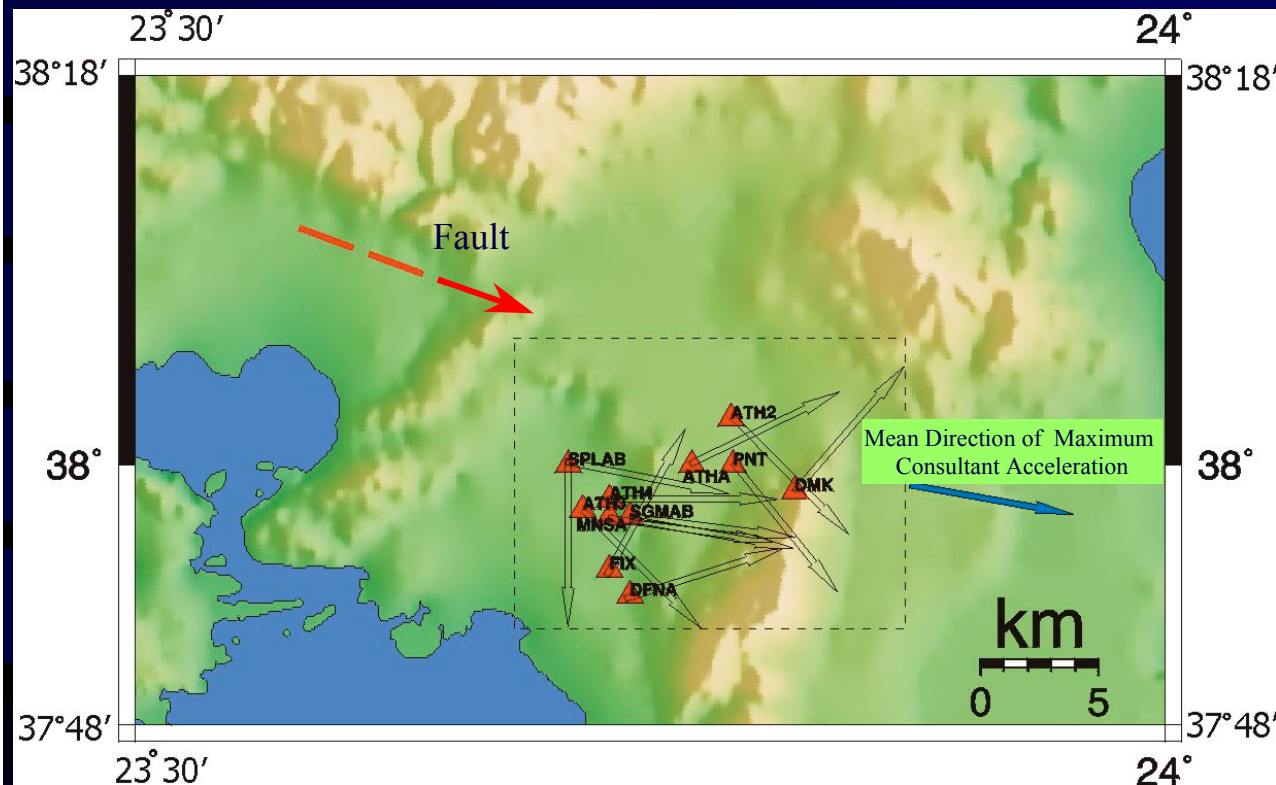
Peak Ground Acceleration , a_{RMS} , I_{ARIAS}



Station (Surface)	Geological Conditions	a_{RMS} (g)		I_{Arias} (m/sec)	
		L	T	L	T
ATHA	Rock	0.01192	0.01530	0.00057	0.00094
DMK	Rock	0.00799	0.00950	0.00020	0.00029
MNSA	Soil	0.02406	0.04490	0.00232	0.00809
RFN	Rock	0.01040	0.01089	0.00035	0.00038
SPLB	Soil	0.03970	0.04209	0.00617	0.00709
ATH02	Soil	0.01463	0.01917	0.00086	0.00147
KEAE	Soil	0.02871	0.03288	0.00330	0.00433
ATH04	Soil	0.01527	0.01272	0.00093	0.00065

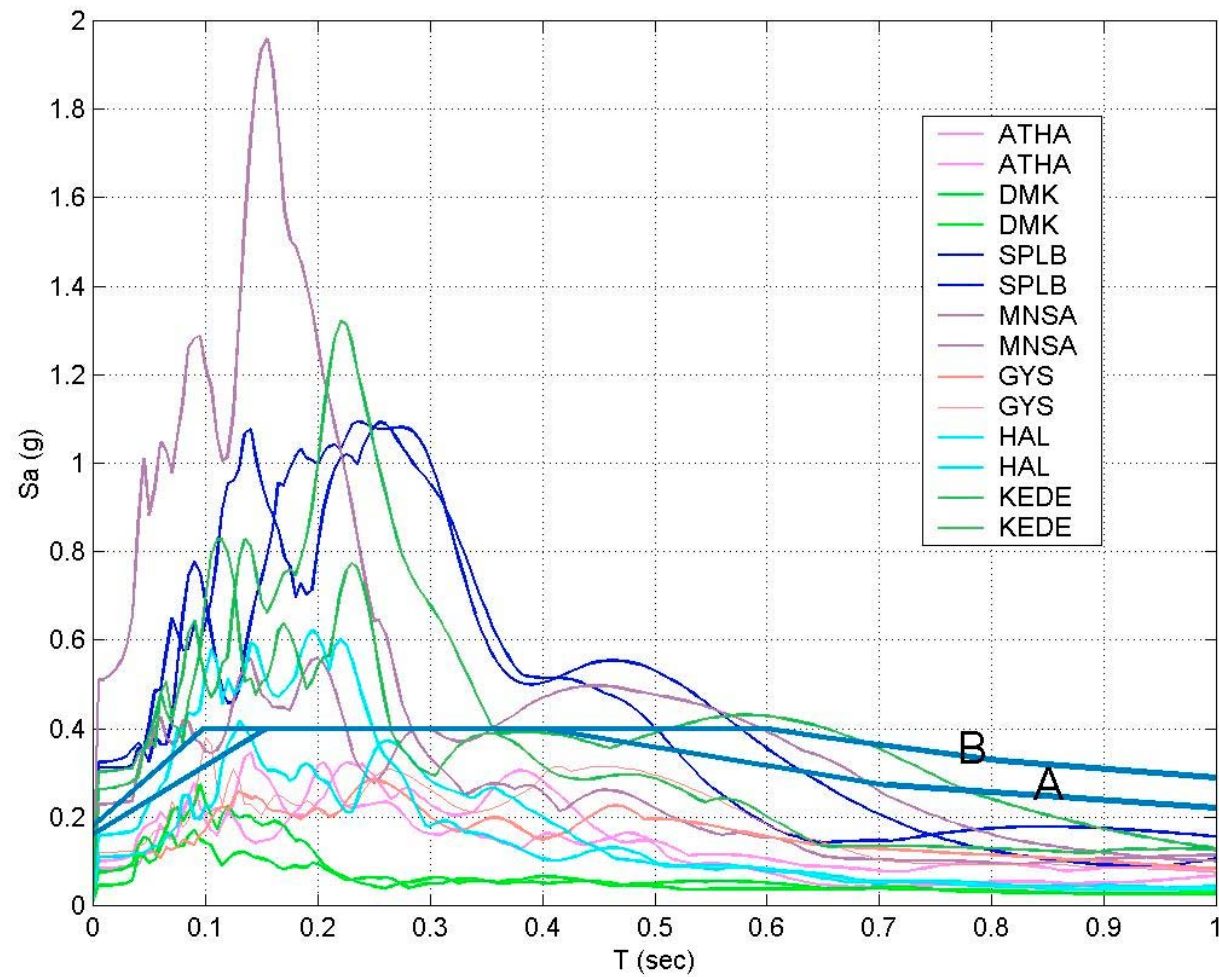
Maximum Consultant Acceleration

(N100°)

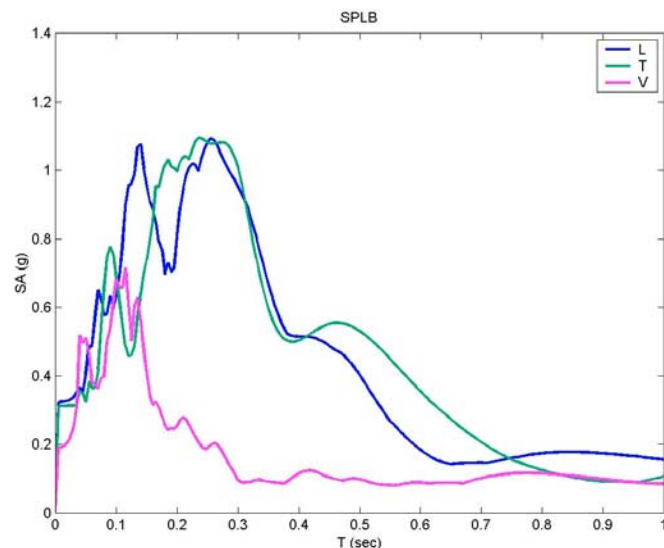
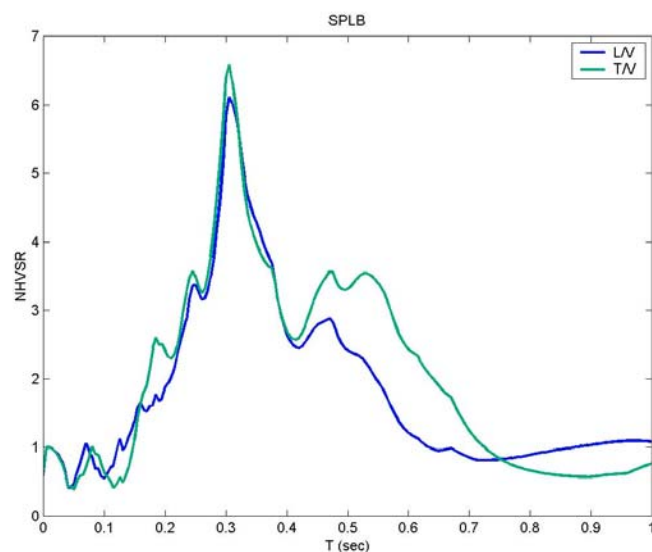


Station	Geological Conditions	Maximum Acceleration (g)	Orientation (°)
DMK	Rock	0.0808	72
FIX	Rock	0.1337	28
MNSA	Soil	0.5119	98
PNT	Soil	0.0886	141
ATHA	Rock	0.1054	64
DFNA	Rock	0.0808	72
SGMA	Rock	0.2395	97
SGMB	Rock	0.1351	170
SPLA	Rock	0.2876	101
SPLB	Soil	0.4130	180
RFN	Rock	0.0998	159
ATH-02	Soil	0.1616	135
ATH-03	Soil	0.1616	135
ATH-04	Soil	0.1306	90

Response Spectra



Normalized Spectral Ratio



Station Depth=0m	Geological Conditions	NHVSR max (L)	T (NHVSR max)	NHVSR max (T)	T (NHVSR max)
DMK	Rock	1.7265	0.390	1.5487	0.170
MNSA	Soil	6.2189	0.515	3.7892	0.190
ATHA	Rock	4.7907	0.255	4.6835	0.255
SPLB	Soil	6.1152	0.305	6.5833	0.305
RFN	Rock	2.1171	0.140	1.6590	0.295
ATH-02	Soil	3.7788	0.350	2.3497	0.145
ATH-03	Soil	2.8321	0.795	3.1972	0.235
ATH-04	Soil	2.7345	0.480	2.1123	0.475
Station Depth>0m	Geological Conditions	NHVSR max (L)	T (NHVSR max)	NHVSR max (T)	T (NHVSR max)
SGMA	Rock	1.8165	0.590	1.677	0.215
SGMB	Rock	4.2959	0.885	3.8484	0.330
SPLA	Rock	2.6059	0.275	1.9324	0.275
FIX	Rock	2.0833	0.595	2.1956	0.595
PNT	Soil	1.9755	0.505	2.8379	0.490
DFNA	Rock	2.1262	0.835	1.8033	0.205

SPL station - an interesting example
(SPLB-Surface, SPLA-13m)

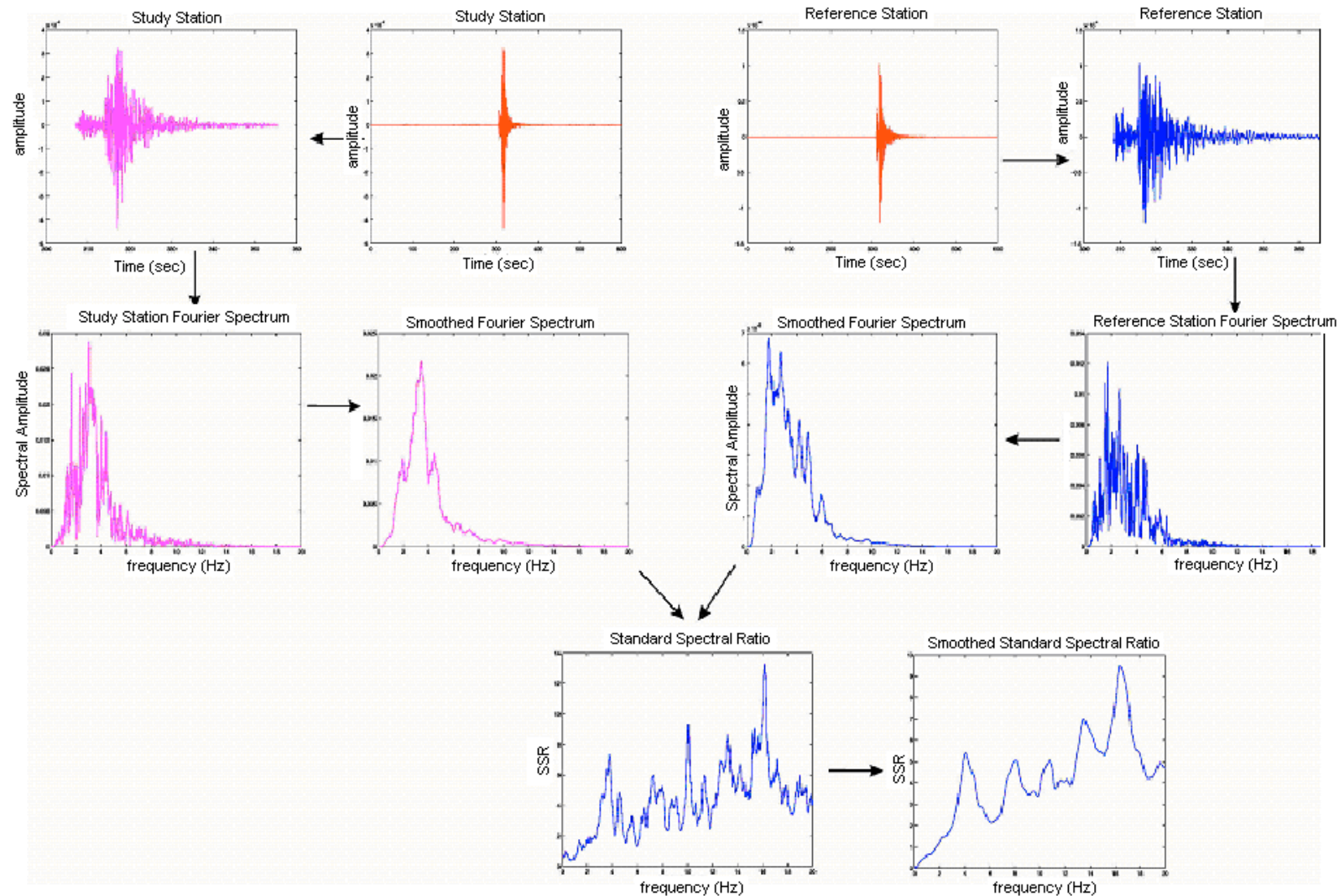
Weak Motion Recordings

(Temporary Network - UPSL)

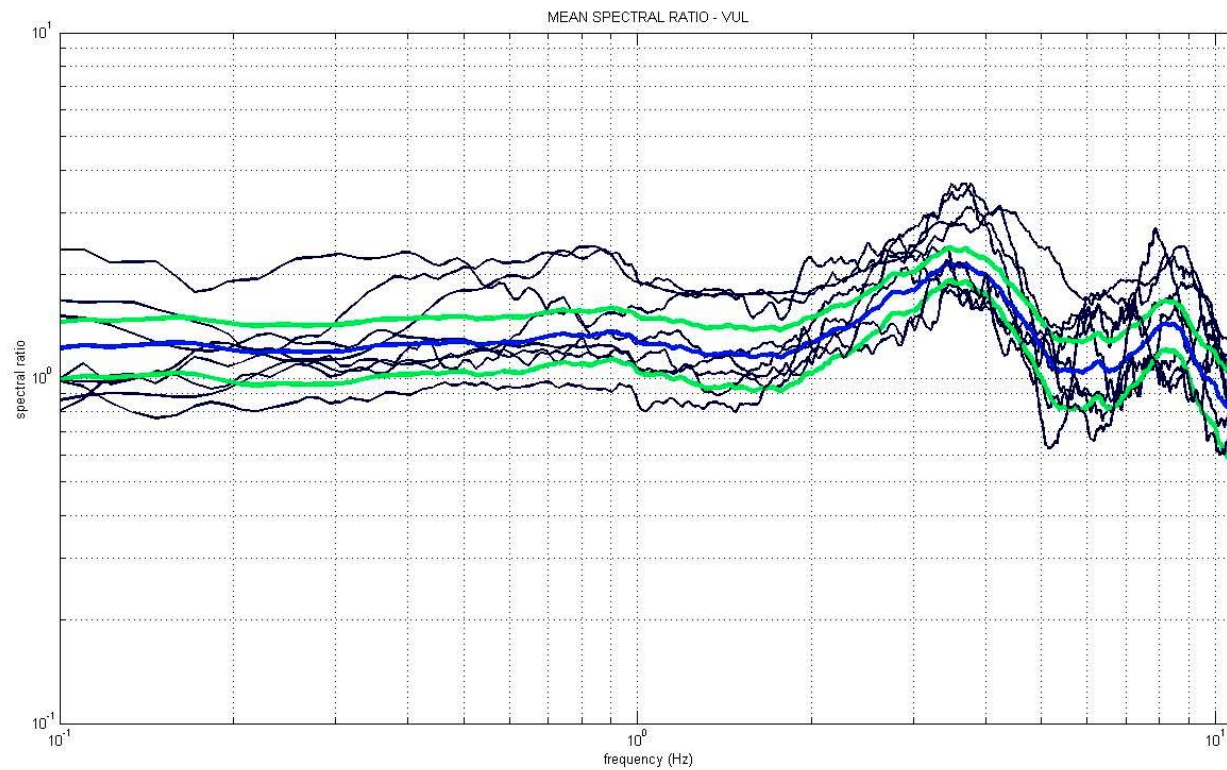
- Classic Spectral Ratio
(reference station-PAR)
- Horizontal to Vertical Spectral Ratio
(noise recordings)
- Horizontal to Vertical Spectral Ratio
(weak events recordings)

Station	Geological Conditions
AHA	Soil
MEN	Soil
KIF	Rock
THR	Rock
BAR	Soil
LIO	Soil
PAR	Rock
KRY	Rock
HAL	Soil
MEL	Soil
MKL	Rock
HAI	Rock
GEO	Soil
MAR	Soil
VAR	Rock
SPT	Rock
MAG	Soil
STE	Rock
KAL	Rock
RAF	Soil
FLD	Soil
FLP	Rock
VUL	Rock

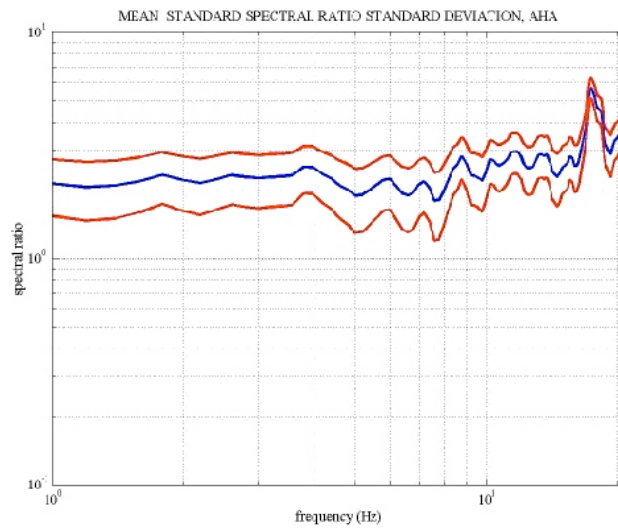
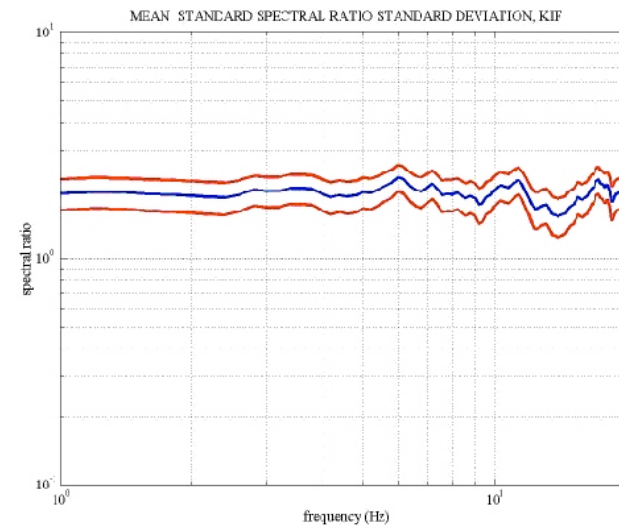
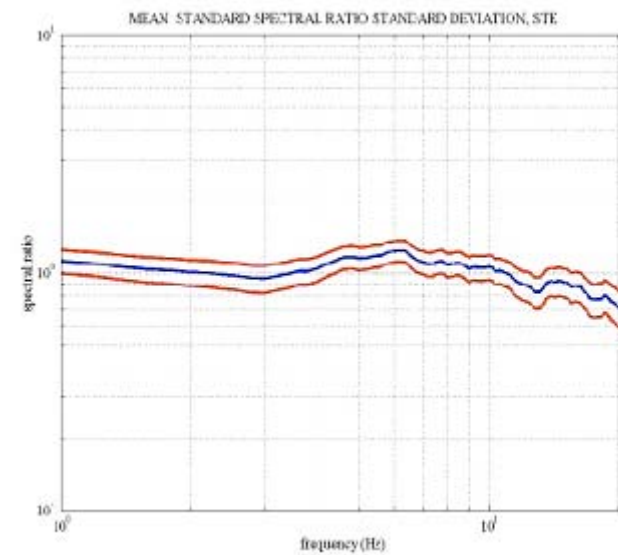
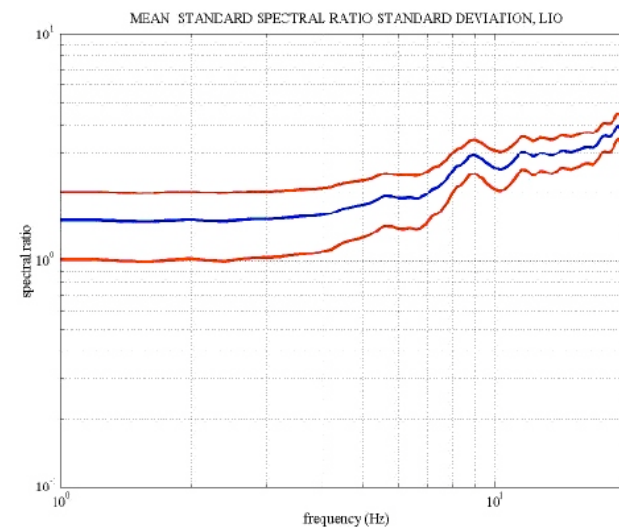
Spectral Ratios



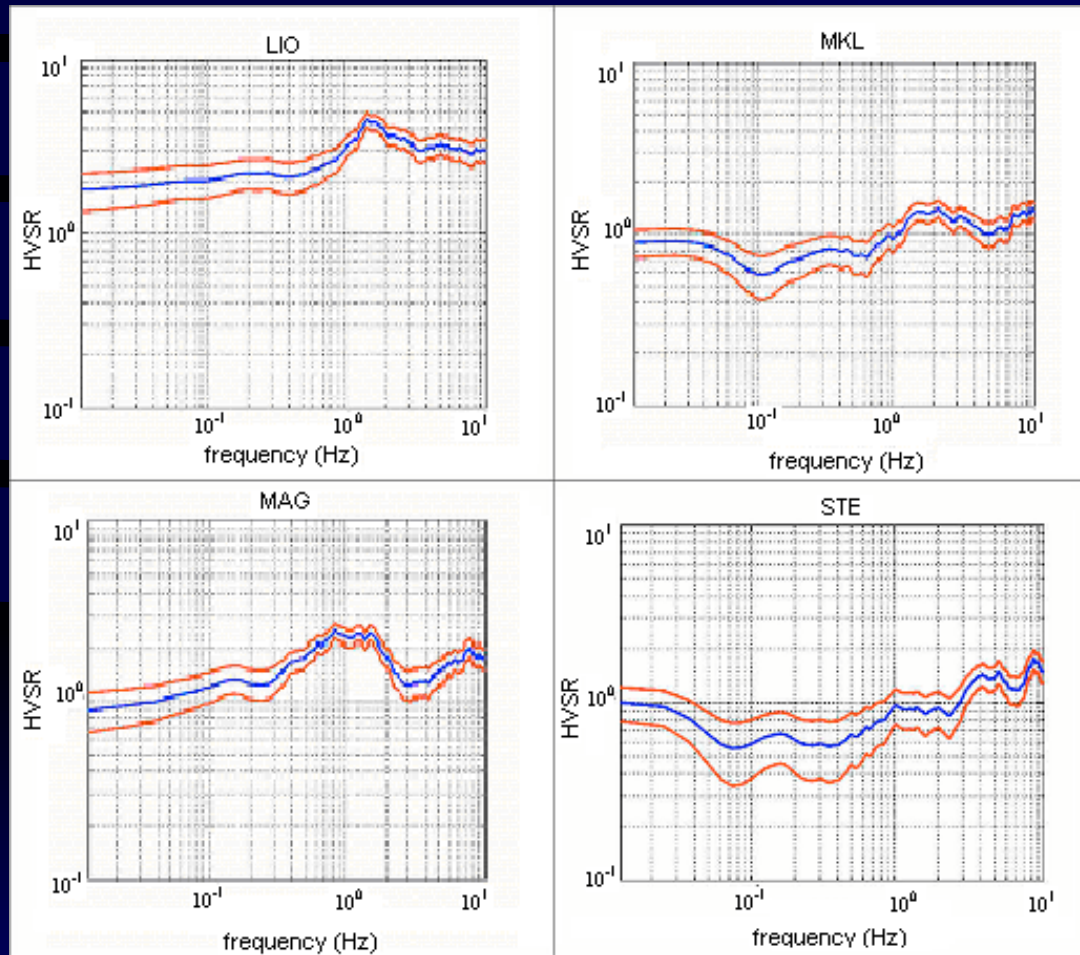
Mean Spectral Ratio



SSR

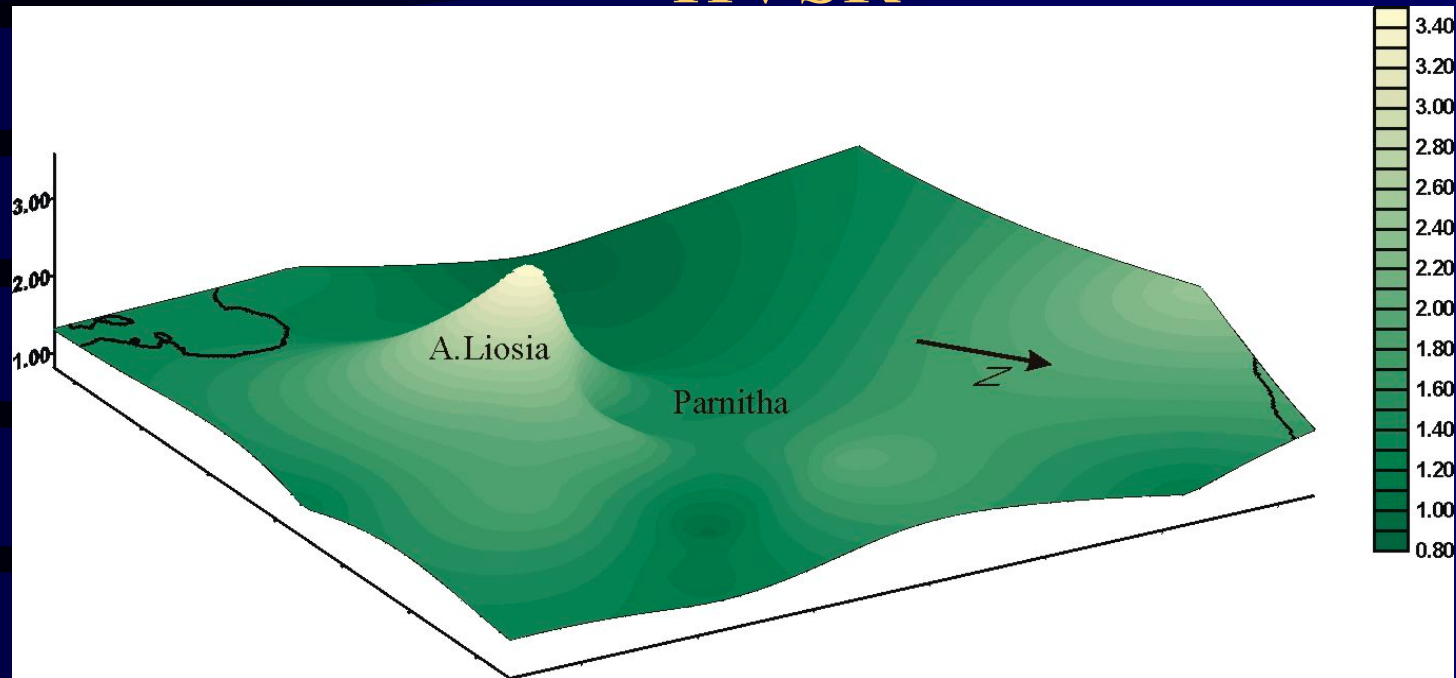


Horizontal to Vertical Spectral Ratio noise, weak motion

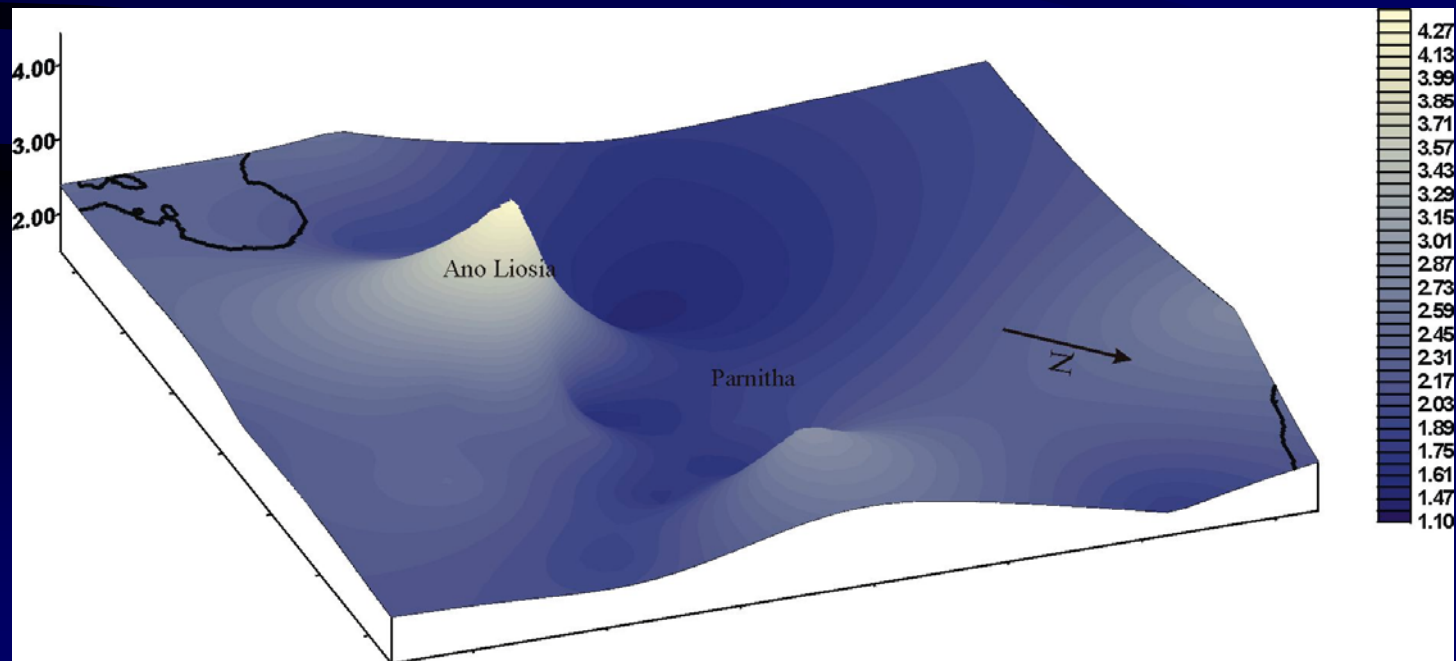


Station	Max HVSr (noise)	Frequency (Hz)	Max HVSr (weak motion)	Frequency (Hz)
AHA	2.0	2.5	2.2	1.1
ASP	1.2	1.0	1.9	0.7
BAR	1.6	1.0	1.7	9.0
FLD	2.1	10	2.4	4.0
FLP	1.2	1.0	2.2	3.1
HAL	1.9	3.0	2.4	2.0
KAL	1.2	2.2	1.8	8.1
KIF	0.9	1.0	1.7	0.3
KRY	2.0	1.7	3.0	5.0
LIO	3.7	3.0	4.6	1.5
MAG	1.4	1.5	2.5	0.8
MAR	1.5	1.5	2.1	7.5
MEL	1.1	1.8	1.9	7.8
MEN	1.4	7.0	1.6	4.8
MKL	1.1	10	1.5	2.3
ORP	2.5	10	2.8	2.6
PAR	1.6	6.0	1.9	4.0
RAF	1.3	10	4.7	5.3
SPT	1.5	1.0	2.4	0.1
STE	0.8	7.1	1.7	8.2
THR	1.5	1.1	1.9	9.5
VUL	1.0	1.1	2.3	3.5

HVSR



noise



weak
motion

Hybrid Method PEXT

finite-source modeling

*stochastic PErurbation and EXtrapolation of the
low-frequency deterministic wavefield*

- Simulation of Extended Source (Divide Main Asperity of the Fault into Sub-Faults)
- Sub-faults , Discrete Wavenumber $\rightarrow$ *Sub-events*
- Sub-events, Summation (like EGF) $\rightarrow$ Low Frequency (LF) Waveform- $I(t)$, *spectrum* $L(f)$
- LF $\rightarrow$ Shaping Window $w(t)$ (moving average of 101 points $|I(t)|$)
- $w(t) \times$ Gaussian Noise $\rightarrow$ Windowed Gaussian Noise (WGN) $\rightarrow$ spectrum $G(f)$
- $|L(f)| \cdot G(f) = A(f) \rightarrow$ Calculation of Complex High Frequency Spectrum , $A(f)$
- IFFT $[A(f)] \rightarrow$ Calculation of Synthetic Accelerogram, $a(t)$

1D Simulation - PEXT

10x8 km, Zahradnik and Tselentis, (2000)

Empirical relationships, Somerville et al., 1999

Seismic Moment M_0	8e17
Magnitude M_w	5.9
Moment M_0 (asperity)	0.5* M_0
L x W (asperity)	4.5 (km)x4.5 (km)
Number of sub-events	4 x 4
Total number of sub-events	16
L x W (sub-event)	1.125 (km) x 1.125 (km)
Stress drop ratio -C	1
S-wave velocity- V_s	3.48 (km/sec)
Ruprure velocity- V_r	3.2 (km/sec)
Sub-event duration	0.375 (sec)
Critical frequency Brune	2.67 (Hz)
Slip (sub-event)	0.153 (m)
Slip (asperity)	0.610 (m)
Stress drop (sub-event)	1.069362E+07 (Pa)
Stress drop (asperity)	1.069362E+07 (Pa)
Mean slip velocity =sub-event slip / sub-event duration	0.41 (m/sec)

Source Model

Hypocenter: 38.08°B, 23.58°A,
depth=10km Zahradnik and Tselentis, (2000)
strike=123°, dip=55°, rake=-84°

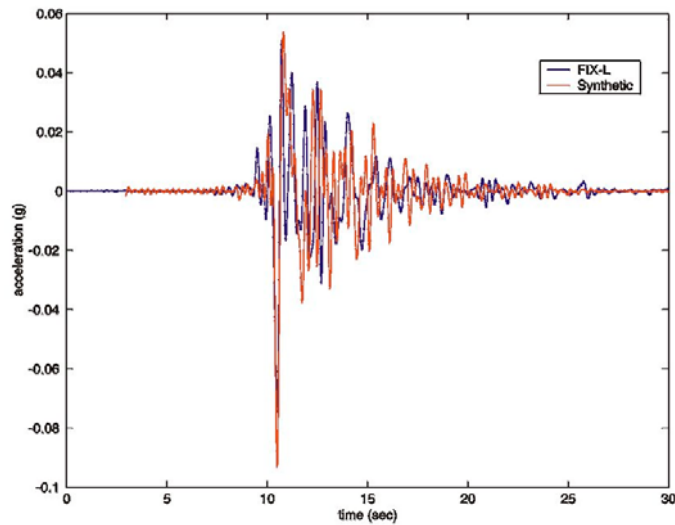
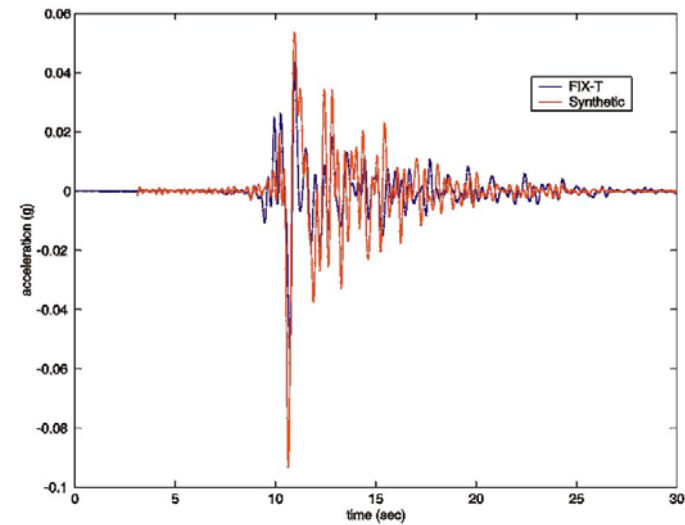
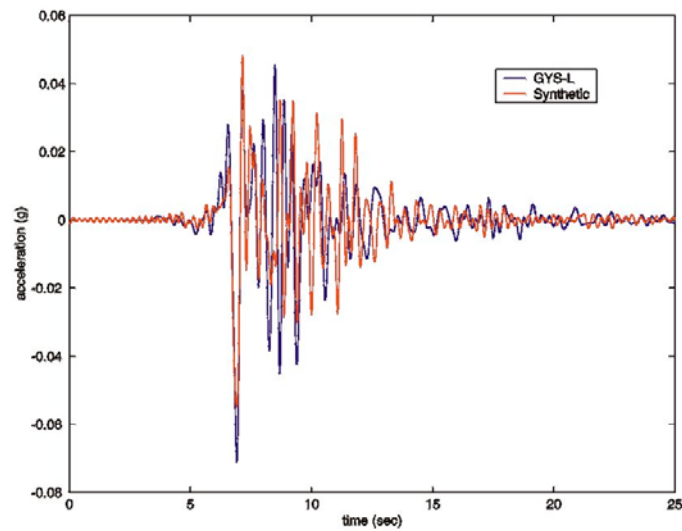
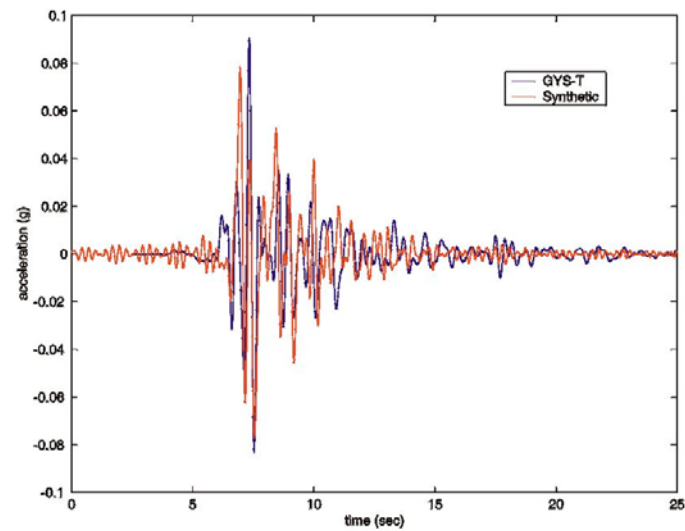
Layer	Width (km)	V_p (km/sec)	V_s (km/sec)	ρ (kg/m ³)	Q_p	Q_s
1	0.2	1.25	0.7	2.1	150	150
2	1	2.67	1.5	2.5	300	300
3	1	4.45	2.5	2.5	300	300
4	3	5.7	3.2	2.84	300	300
5	13	6	3.37	2.9	300	300
6	21	6.4	3.6	2.98	300	300
7	99	7.9	4.44	3.28	1000	1000

1D Model

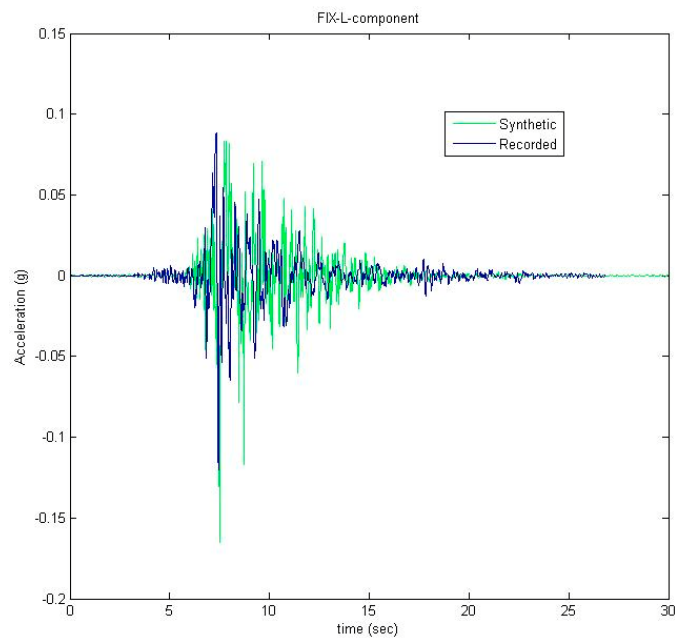
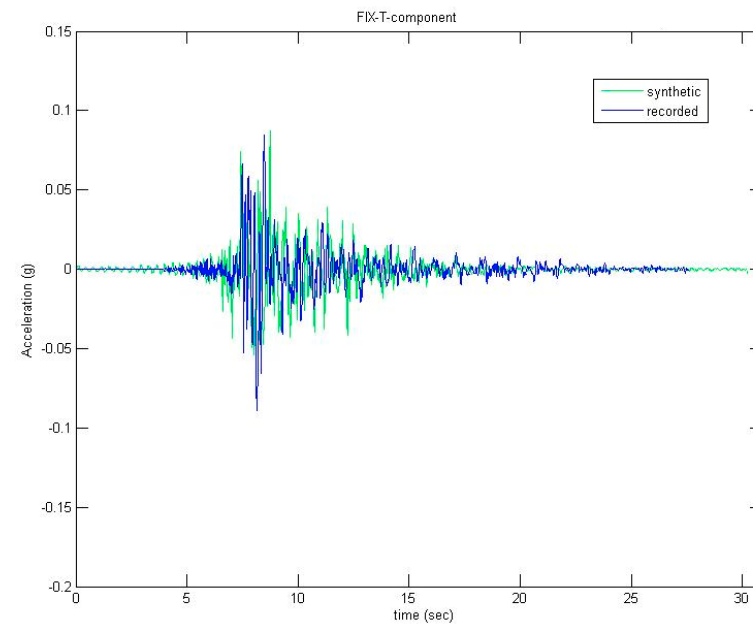
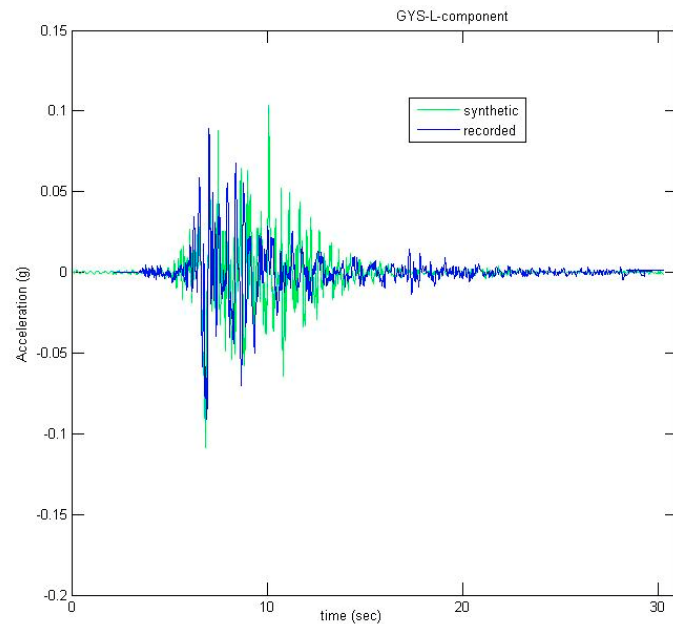
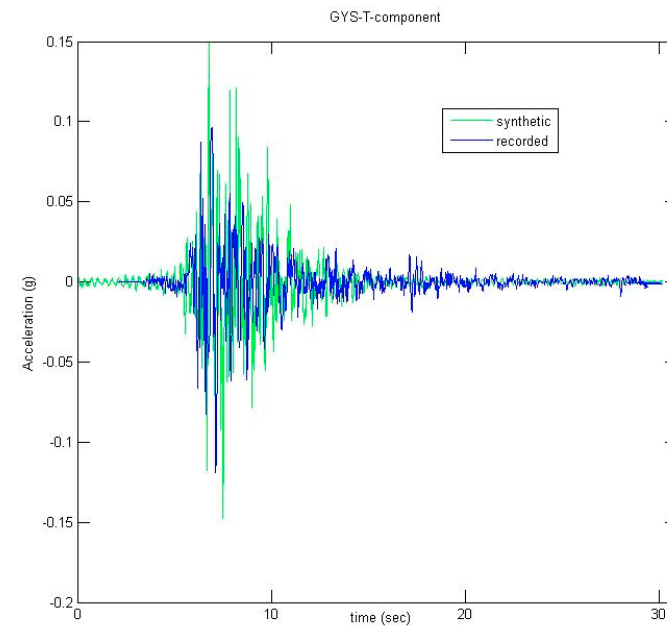
tests

- $f_c = \underline{2.8\text{Hz}}$ (deterministic part)
- 3×3 , $\underline{4 \times 4}$, 5×5
- $k = \underline{0.03}$, $k = 0.06$ (high horizontal pga)
 $\exp(-\pi.k.f) = \exp(-\pi.R.f / V_s / Q(f))$
- 1st layer (amplitudes, duration)

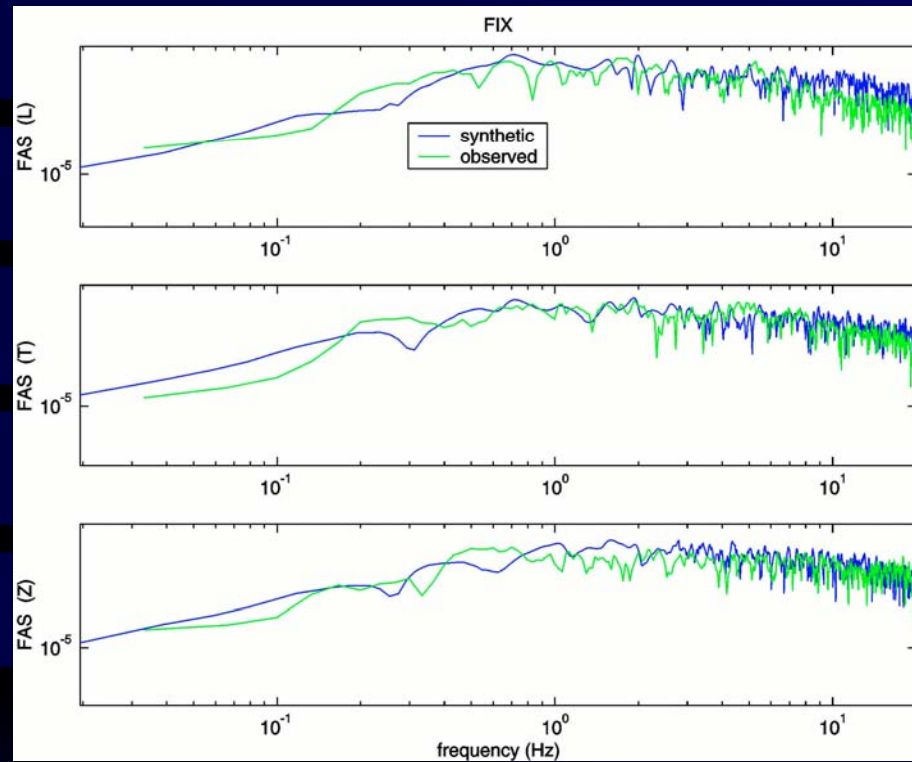
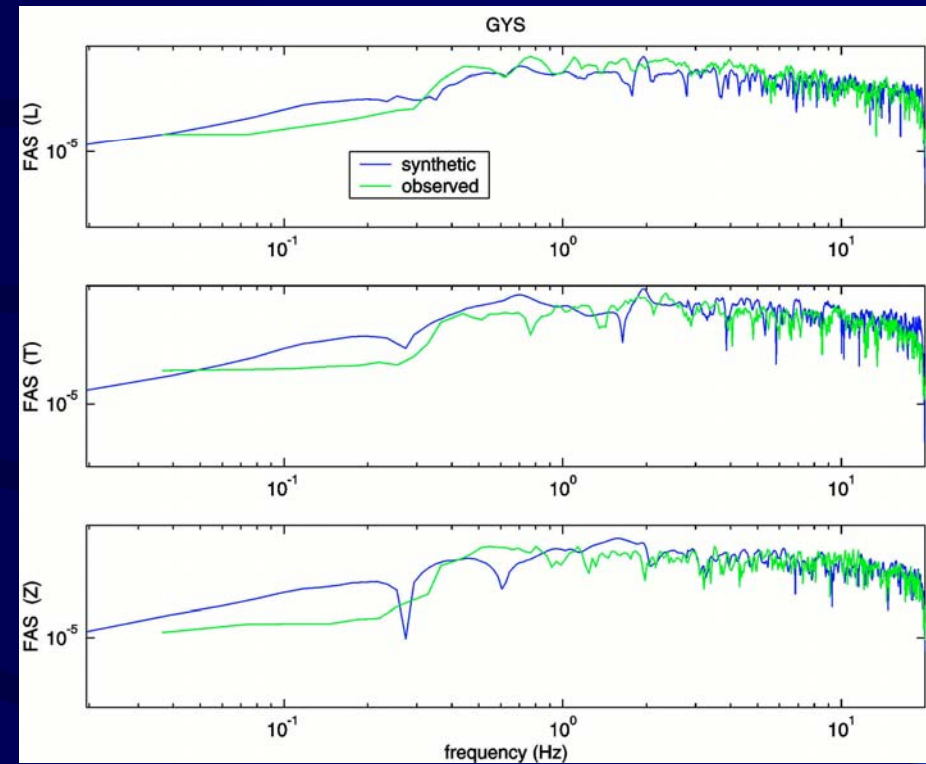
4Hz, waveform comparison



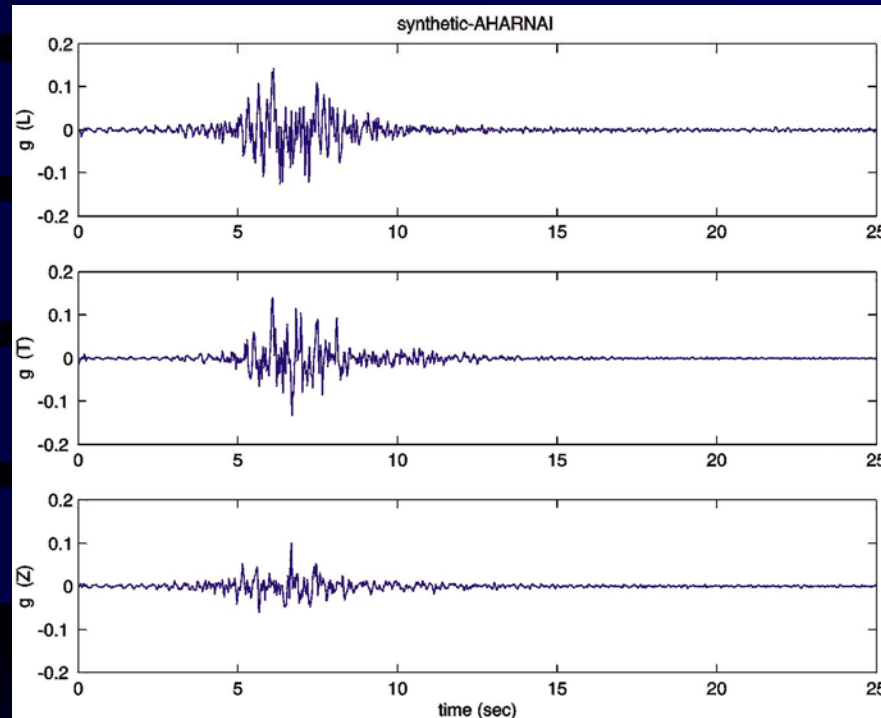
20Hz, waveform comparison



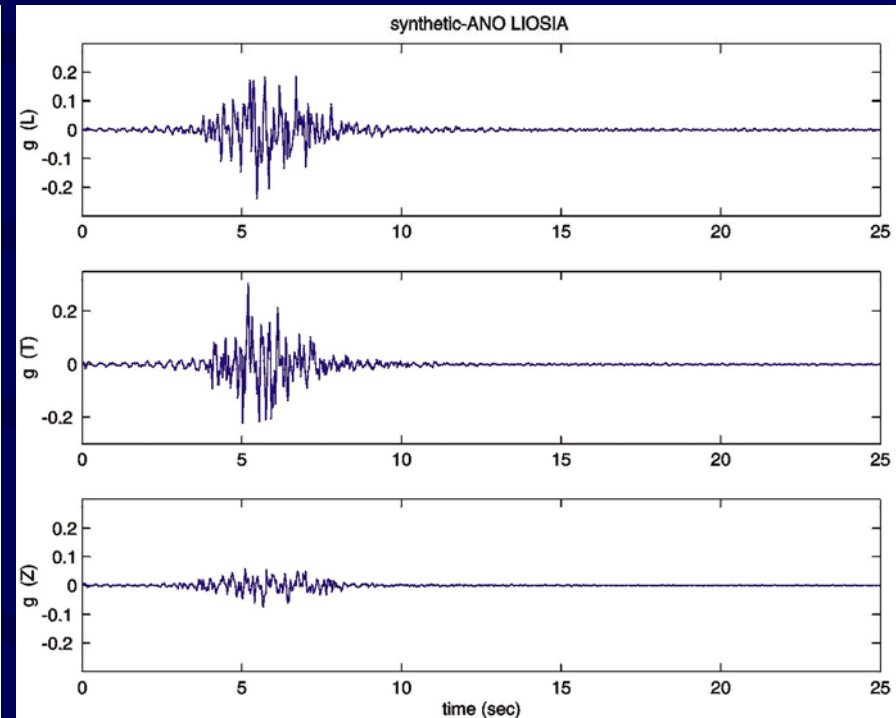
20Hz, Spectra comparison



Simulation - *bedrock*

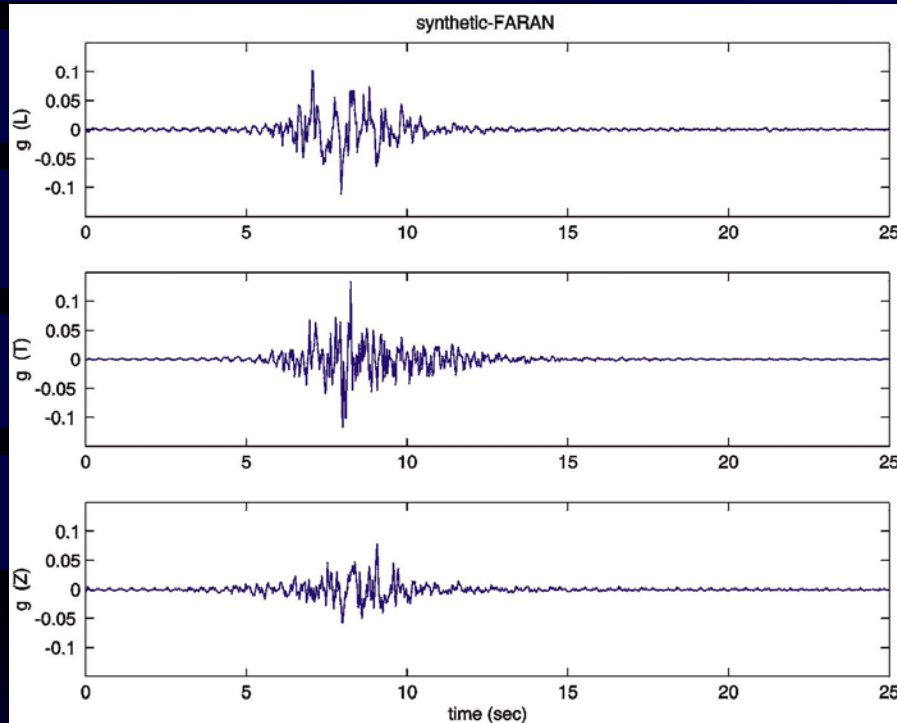


$PHA_L = 0.142g$
 $PHA_T = 0.139g$
(D=14.1km)

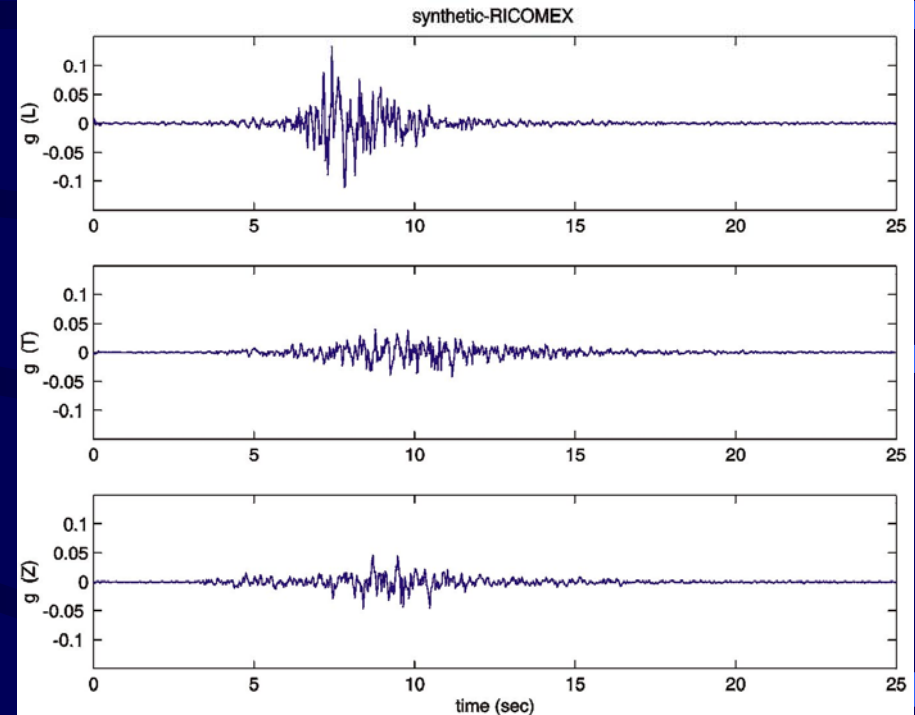


$PHA_L = 0.237g$
 $PHA_T = 0.305g$
(D=10.7km)

Simulation - *bedrock*



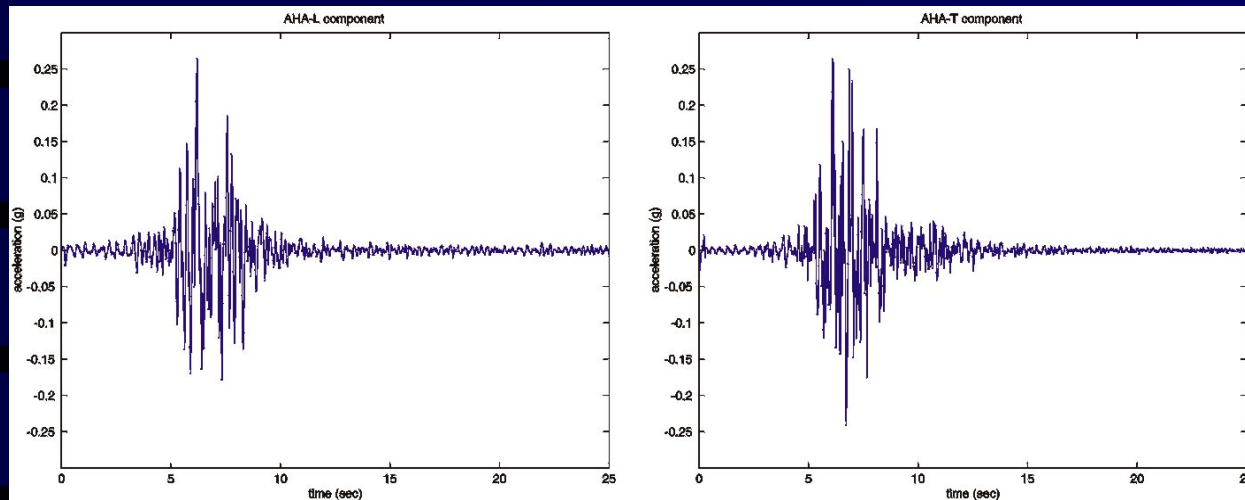
$PHA_L = 0.111g$
 $PHA_T = 0.134g$
(D=17.9km)



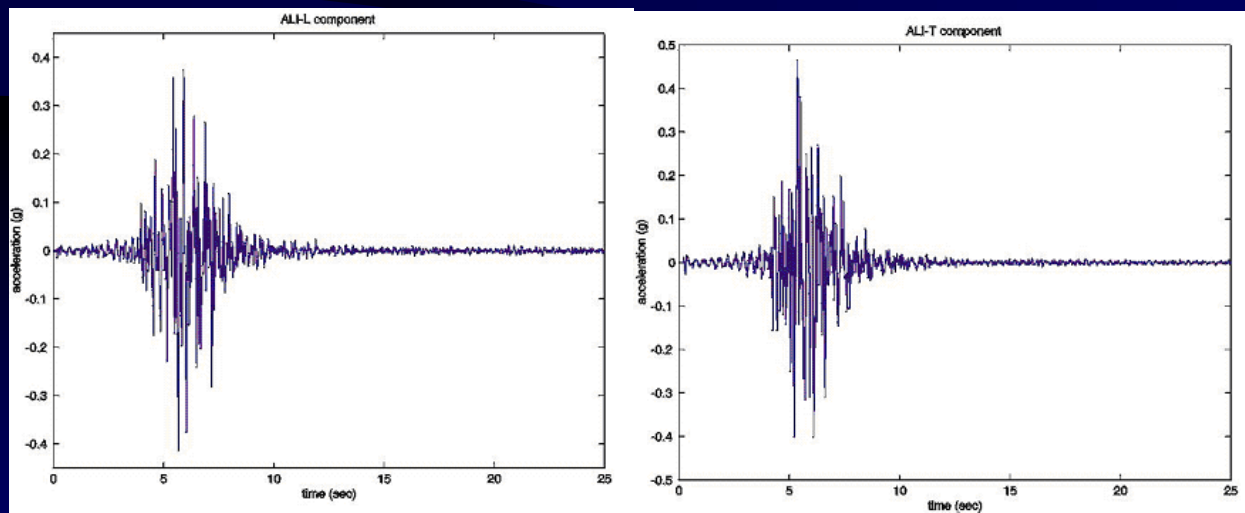
$PHA_L = 0.133g$
 $PHA_T = 0.041g$
(D=18.0km)

Simulation – *Surface*

(Matrix method – Crosshole Data)



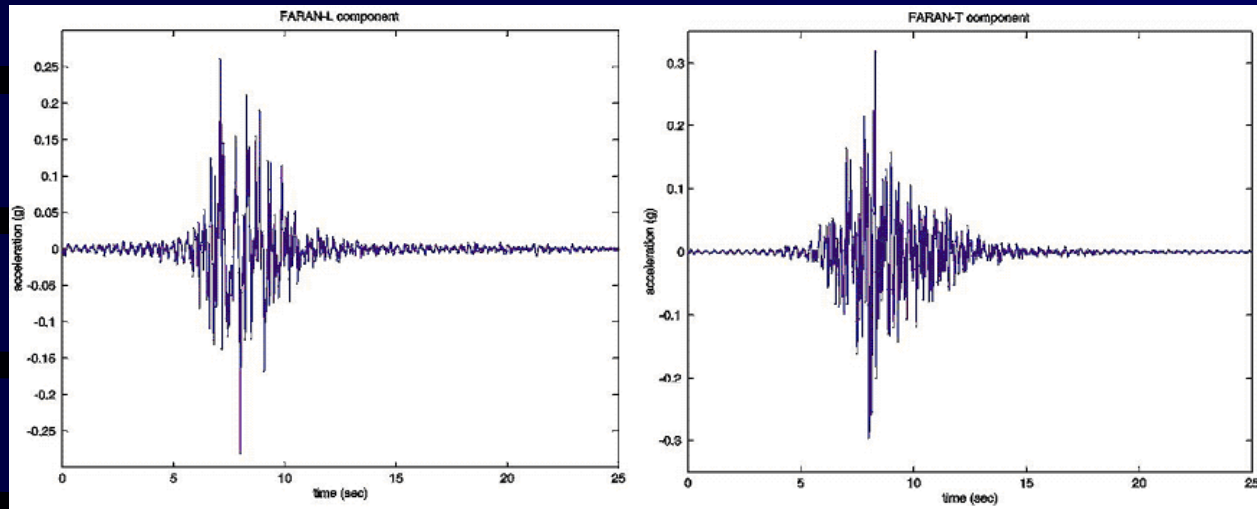
Menidi
 $PHA_L = 0.265g$
 $PHA_T = 0.265g$
(D=14.1km)



Ano Lioisia
 $PHA_L = 0.414g$
 $PHA_T = 0.466g$
(D=10.7km)

Simulation – *Surface*

(Matrix method - Crosshole Data)

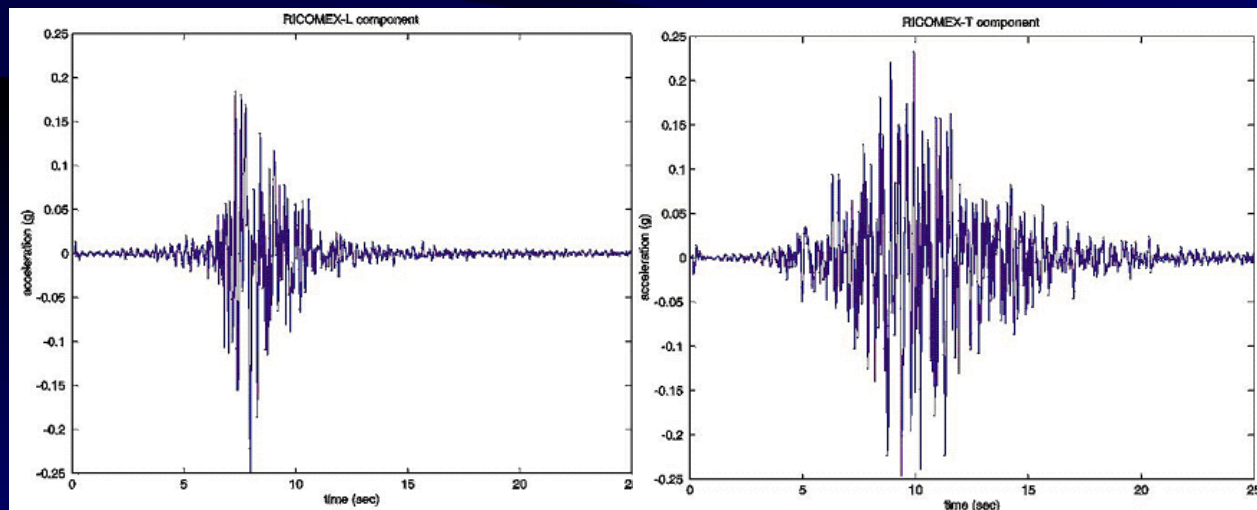


Faran

$PHA_L = 0.281g$

$PHA_T = 0.319g$

(D=17.9km)



Ricomex

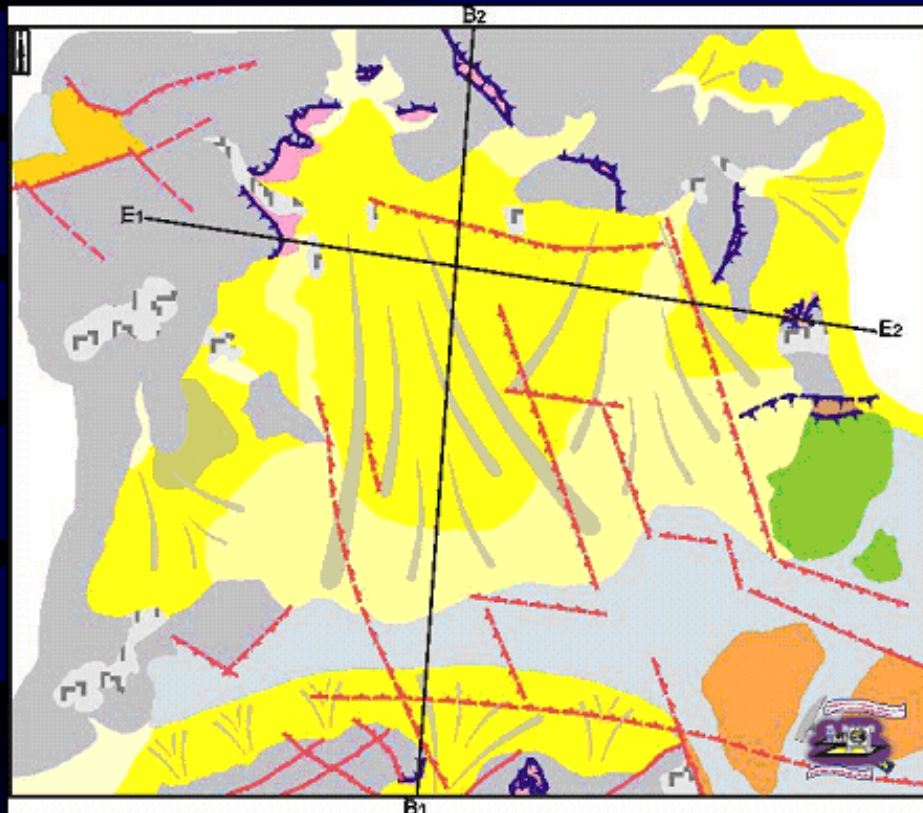
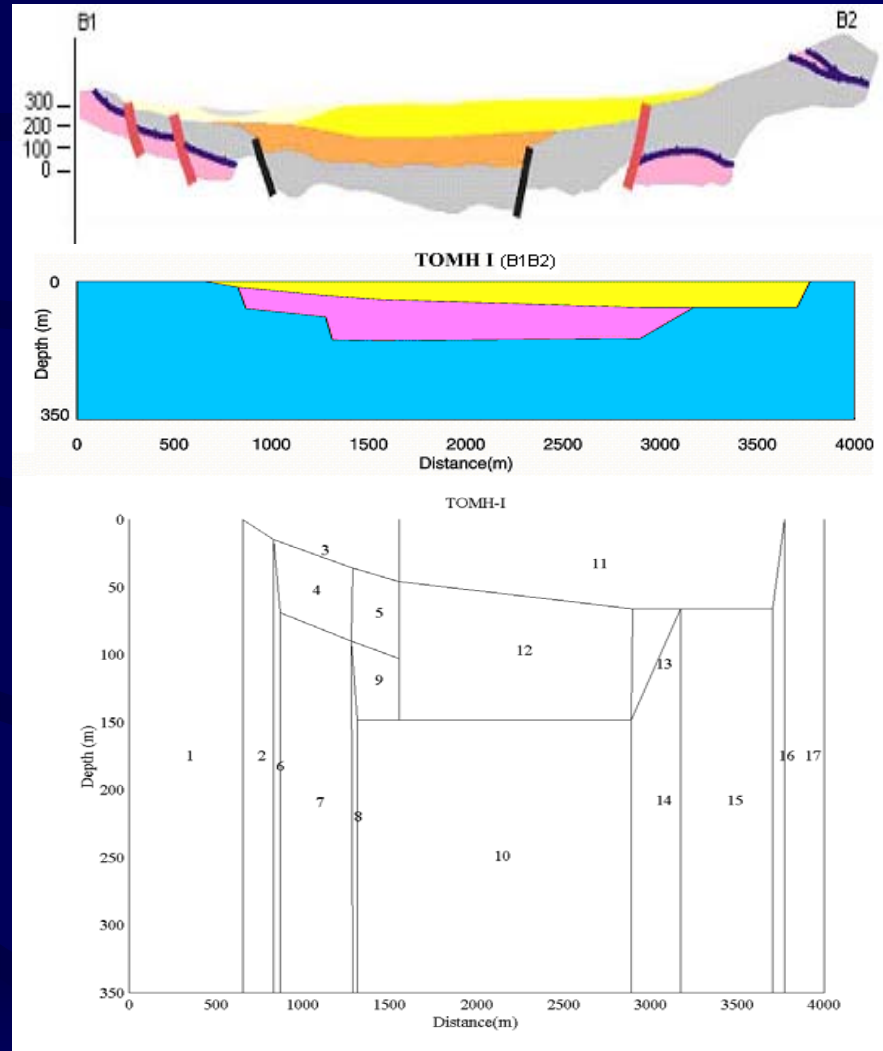
$PHA_L = 0.247g$

$PHA_T = 0.246g$

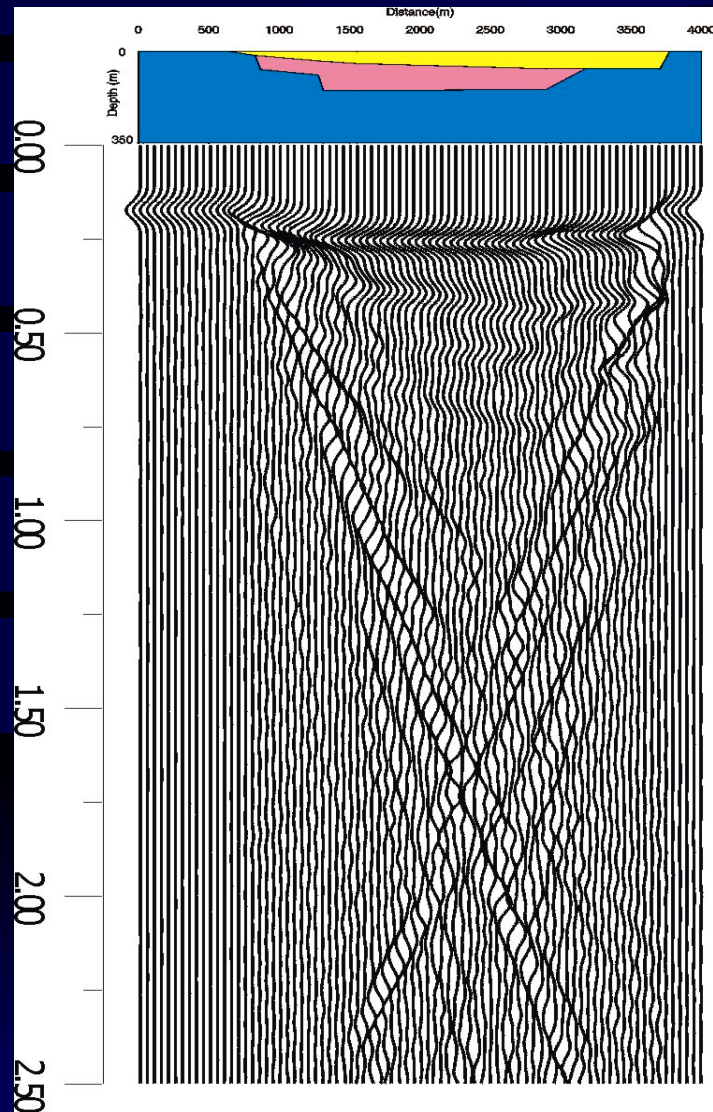
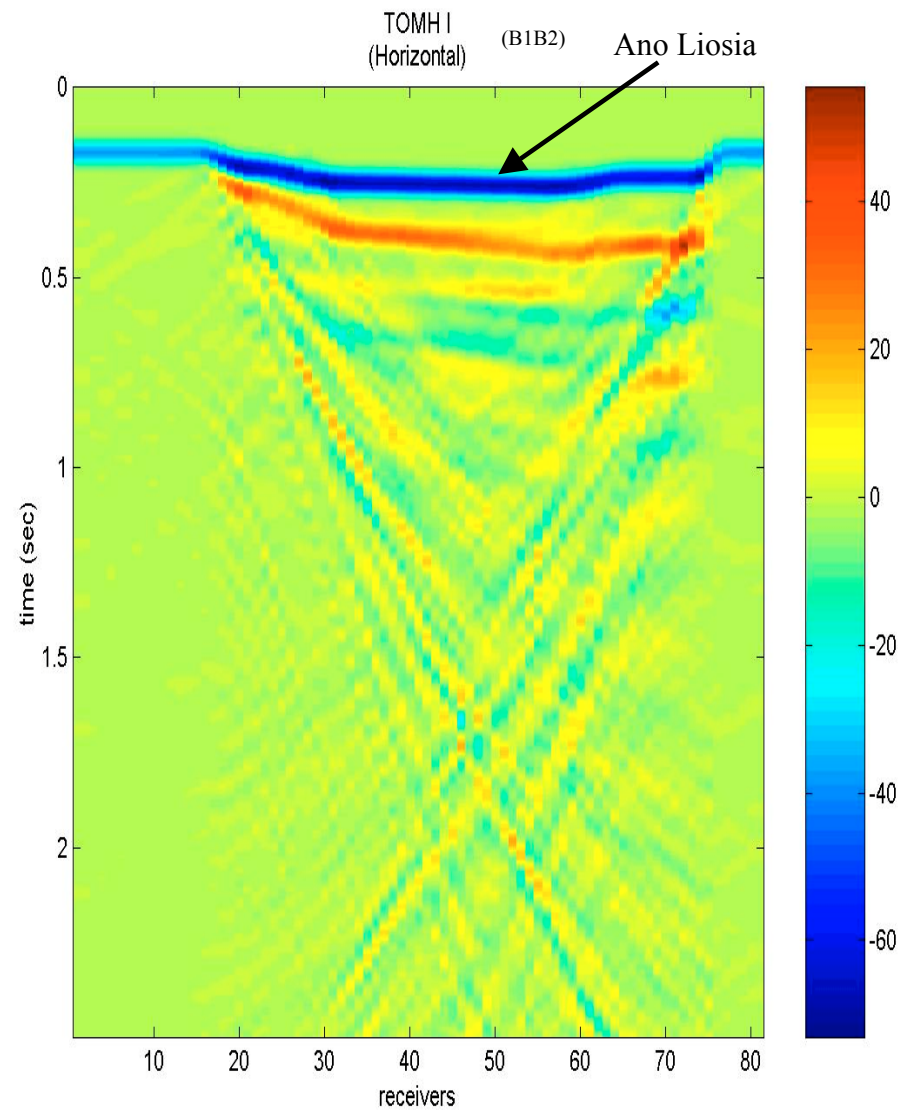
(D=18.0km)

Western Attica Basin Response Simulation

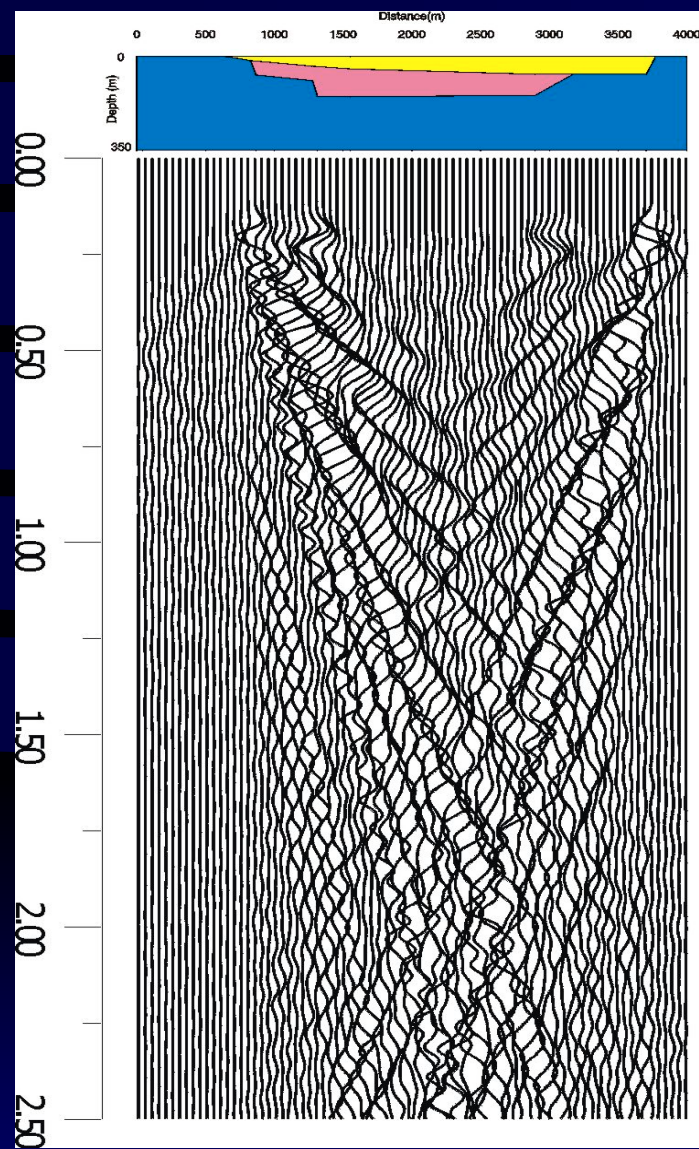
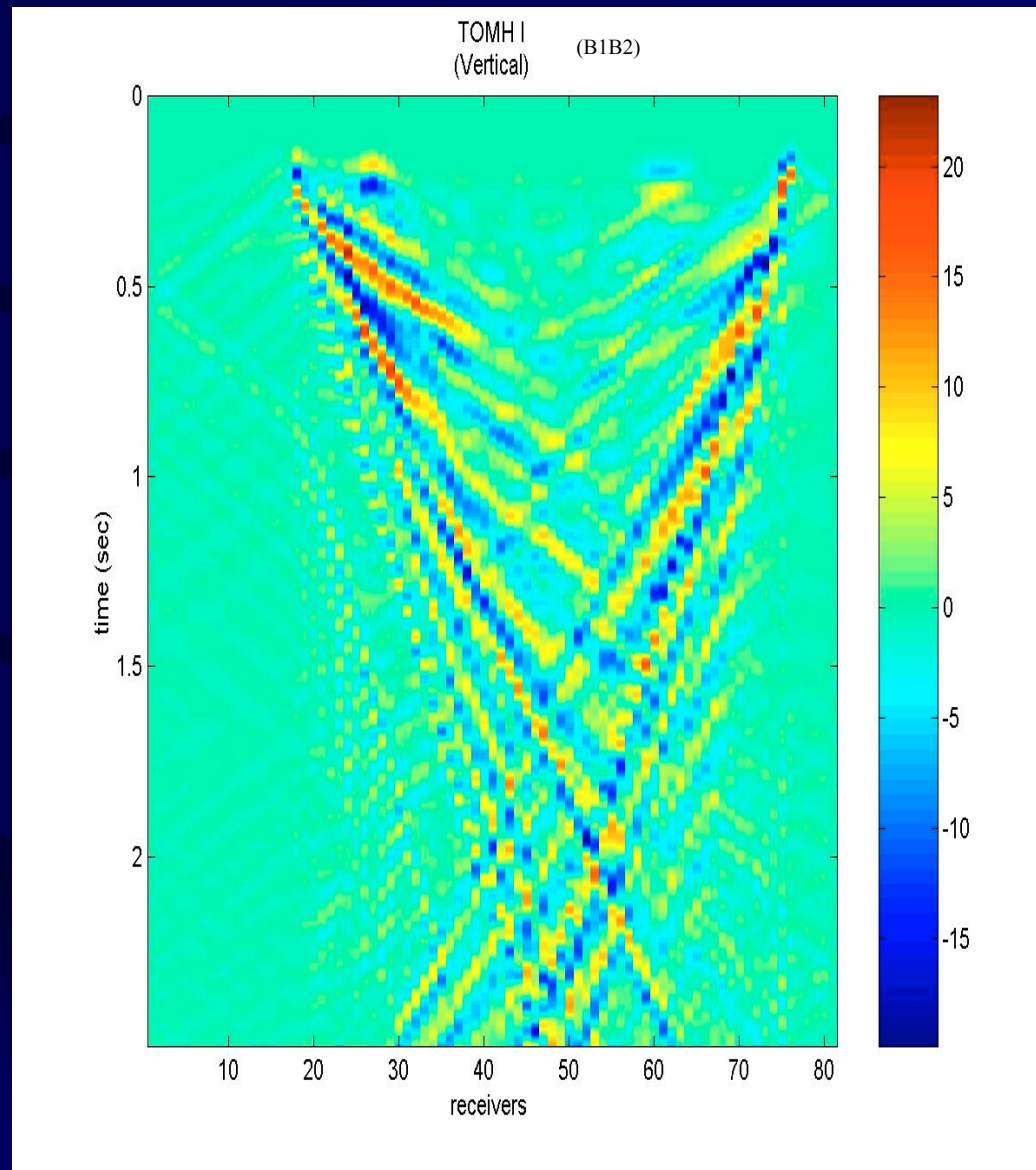
Finite Differences



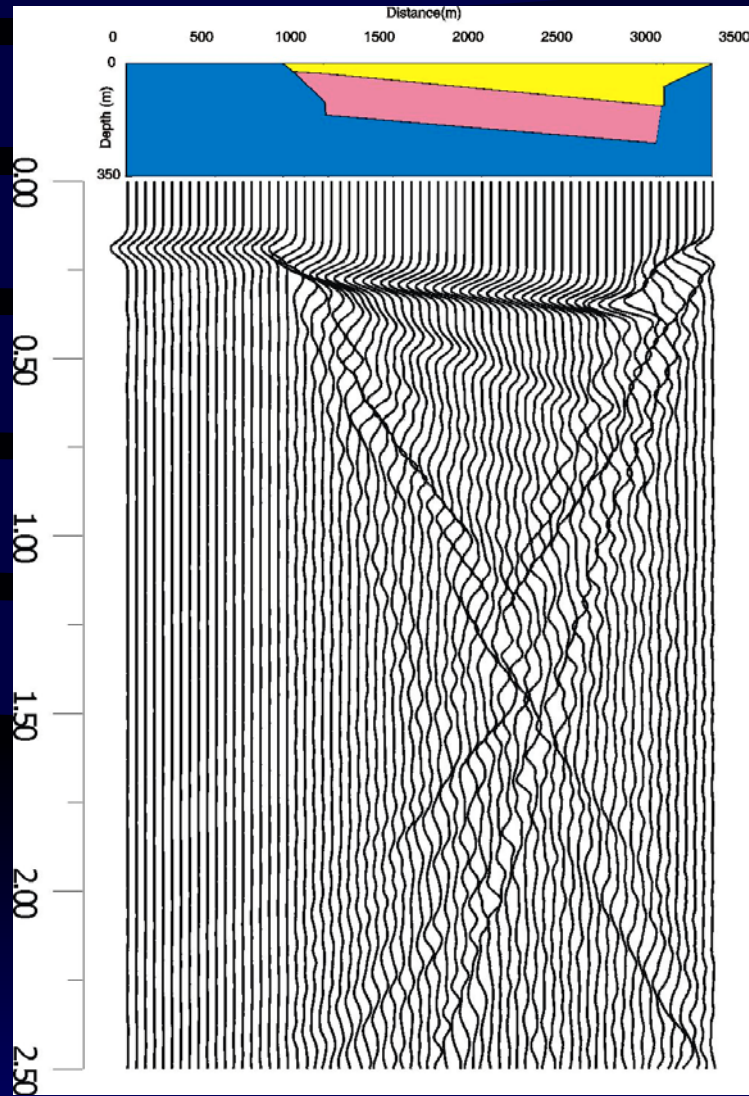
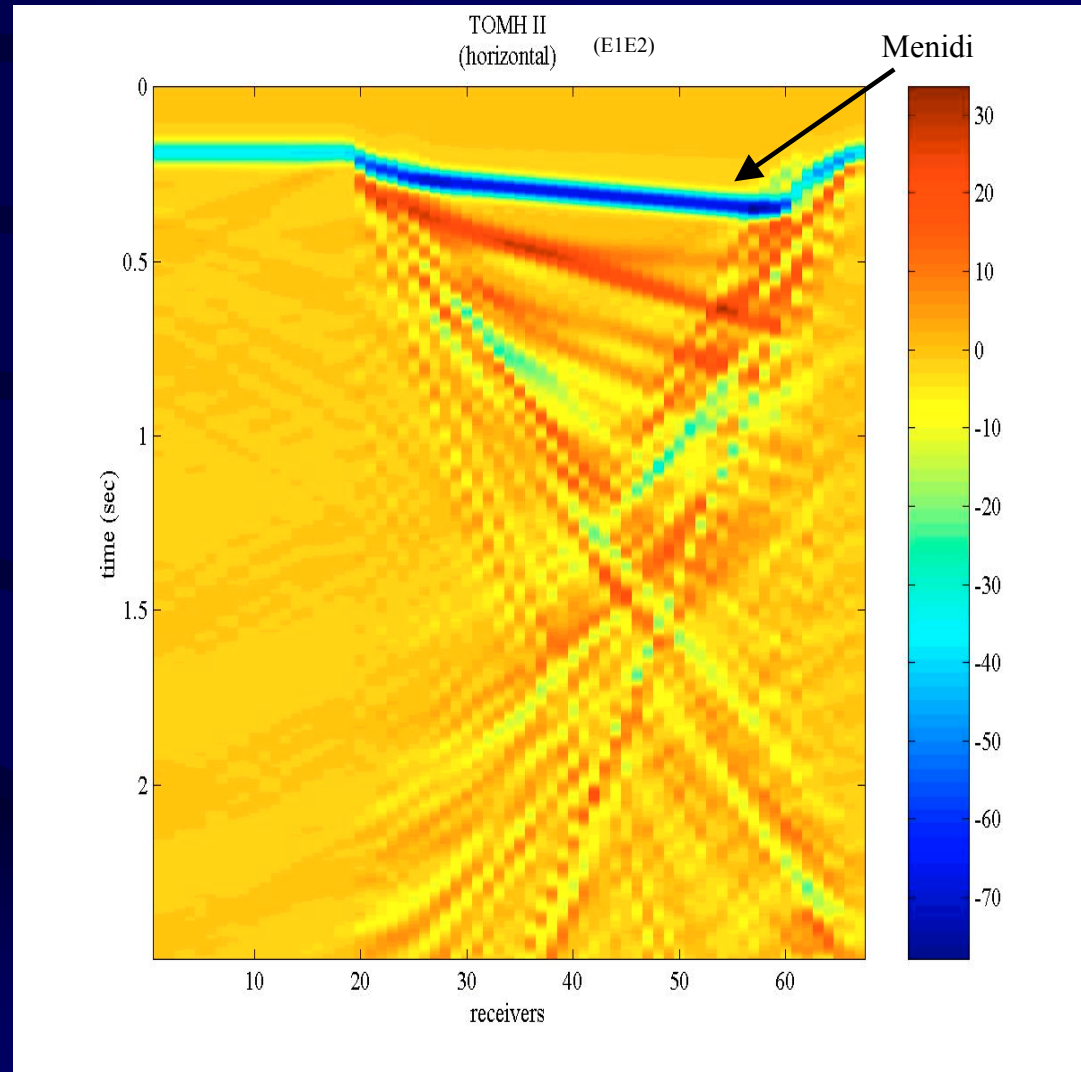
B1B2, SSW-NNE



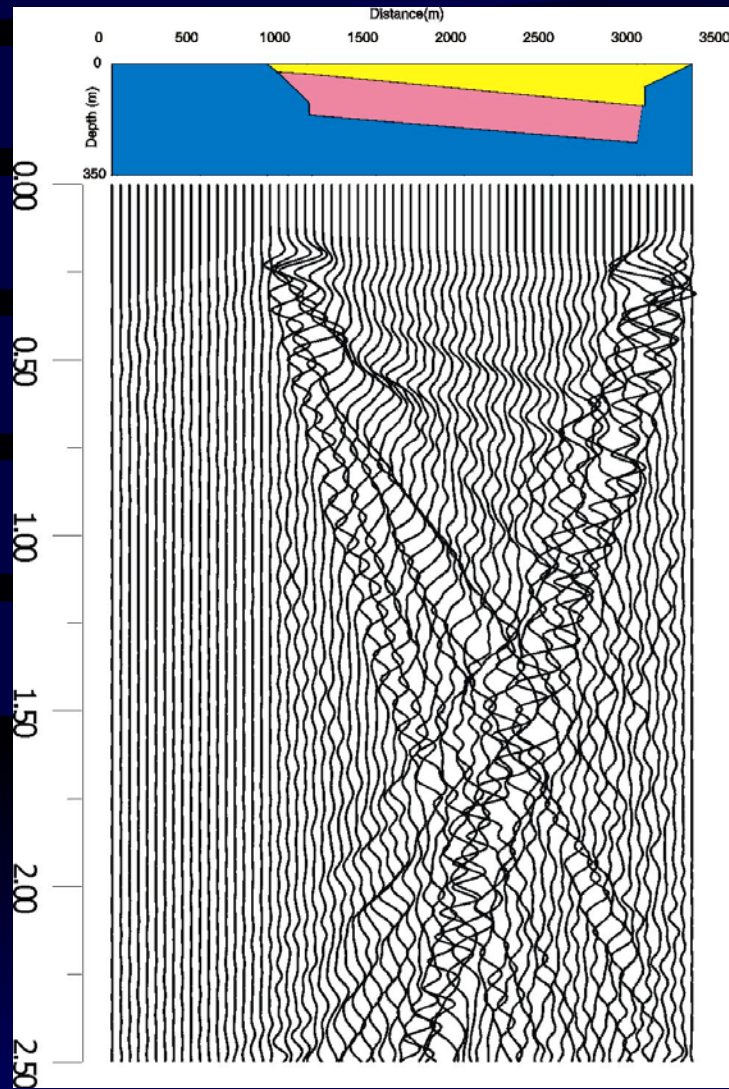
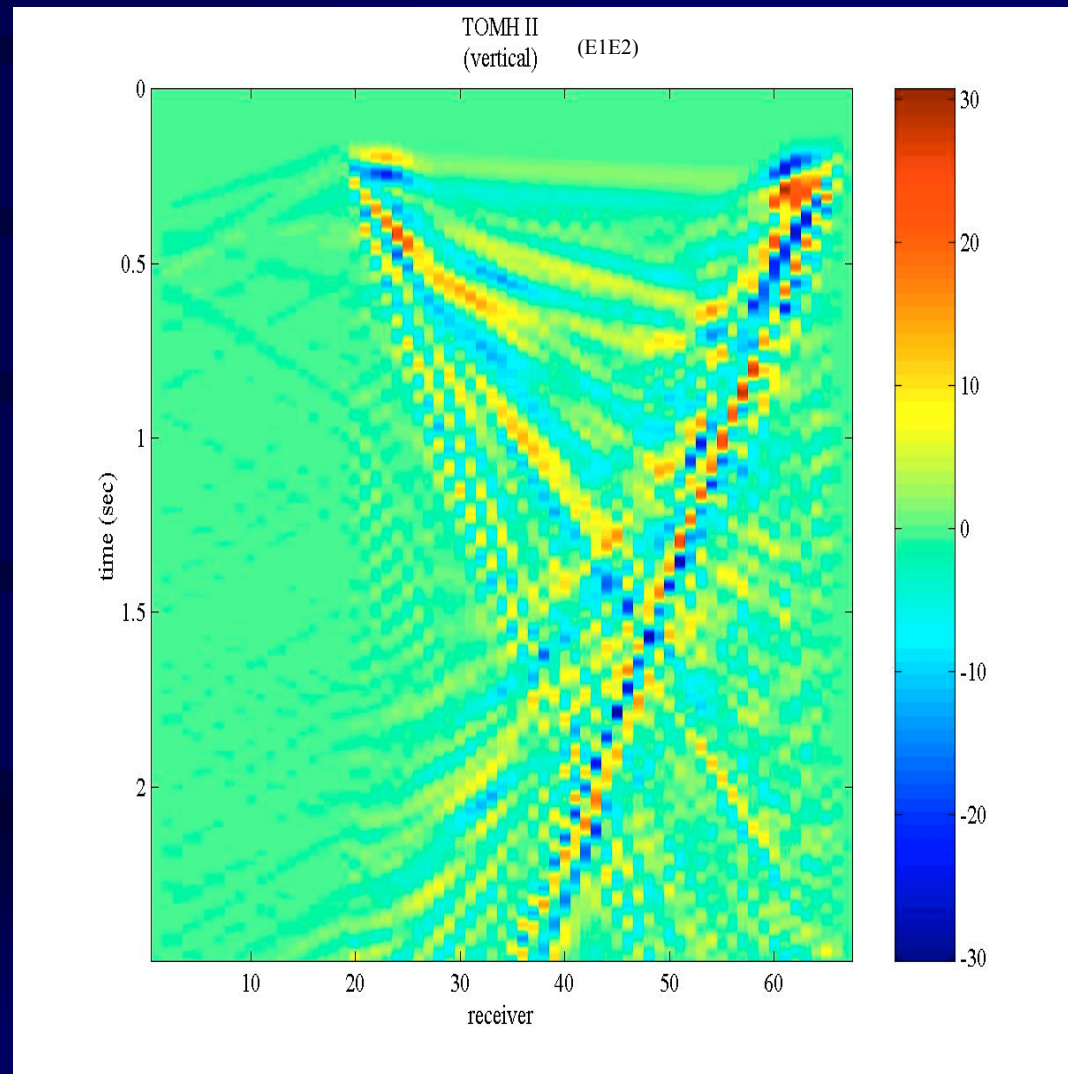
B1B2, SSW-NNE



E1E2, WNW-ESE



E1E2, WNW-ESE



Conclusions

1) Strong Motion Recordings:

- Peak Ground Acceleration values are well described by attenuation relationships except MNSA, SPLB, KEDE
- SPL (A,B) station in a nice example concerning site effects
- Mean Direction of Maximum Acceleration Resultant (N100°) suggests (not proves) Source Directivity
- Spectral Ratios, I_{Arias} , RMS acceleration indicate effect of local geological conditions

2) Temporary Network Recordings, SSR- HVSR

- Amplification in sites like Menidi, Liosia, Thracomacedones, Halandri (soil conditions)
- Unaffected motion in Moni Kleiston, Parnitha, Kalamos, Stefani (bedrock conditions)

Conclusions

3) 1D Modeling

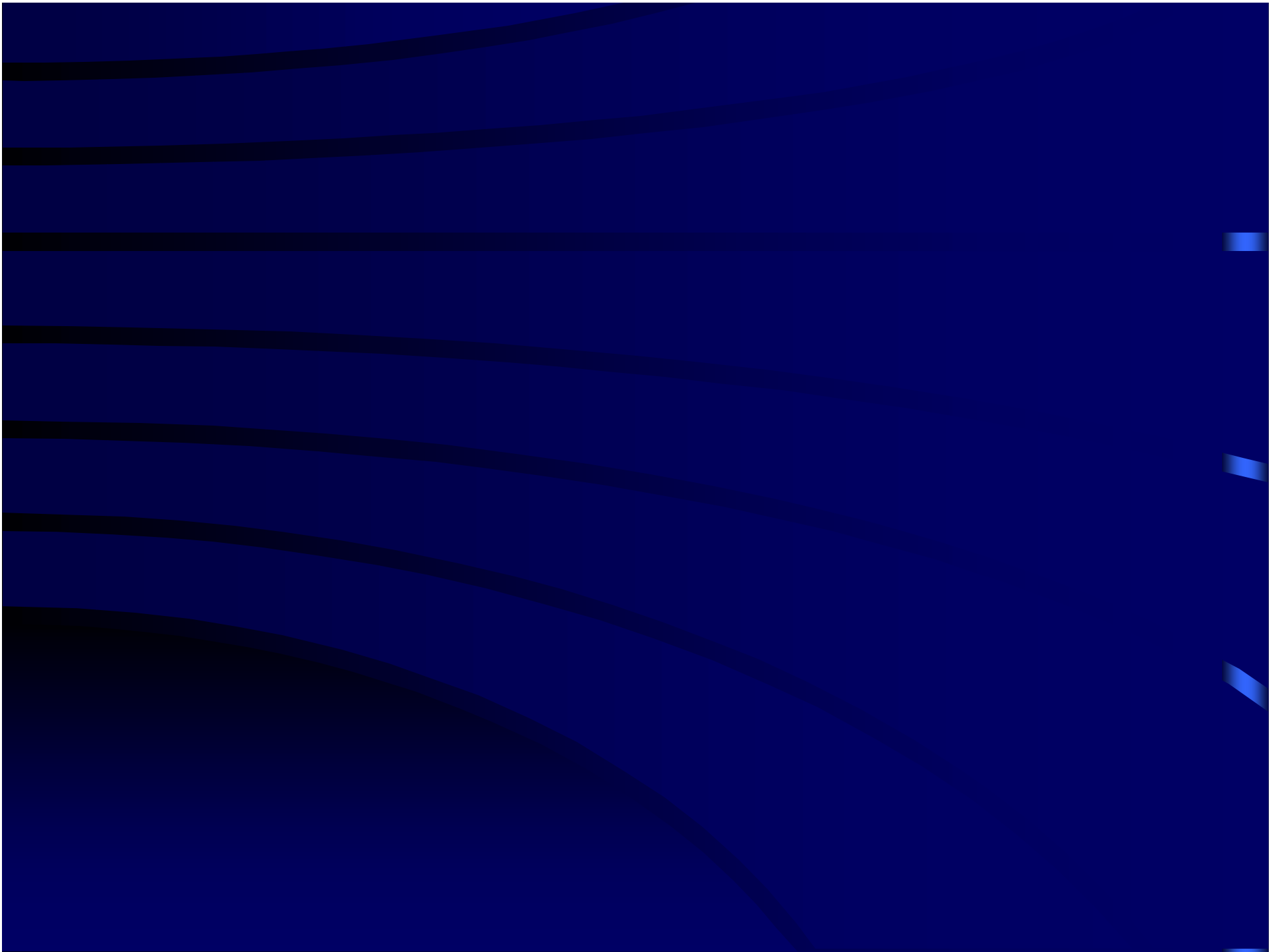
- Source Directivity
- Local Geological Conditions Effect

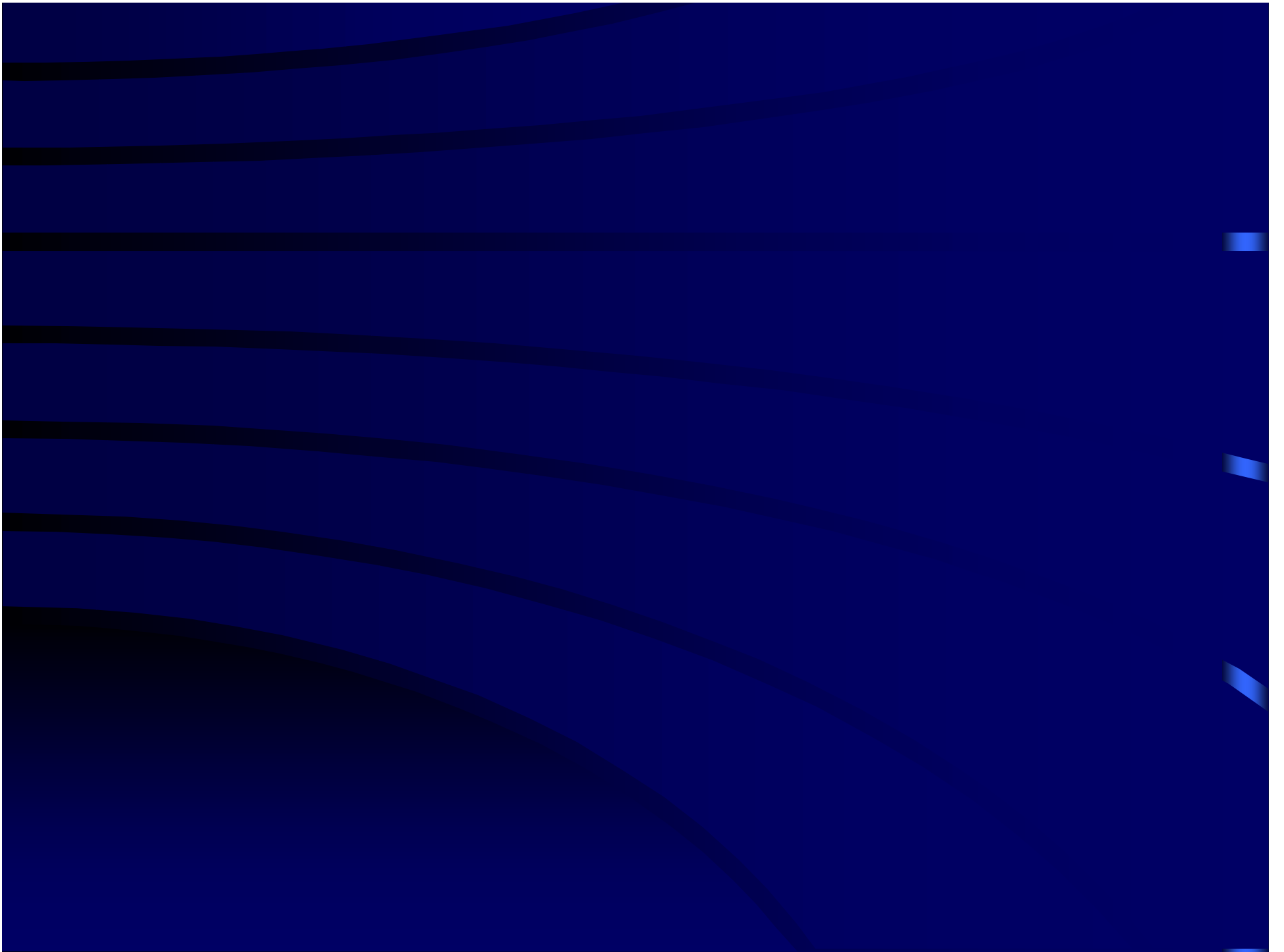
4) 2D Modeling

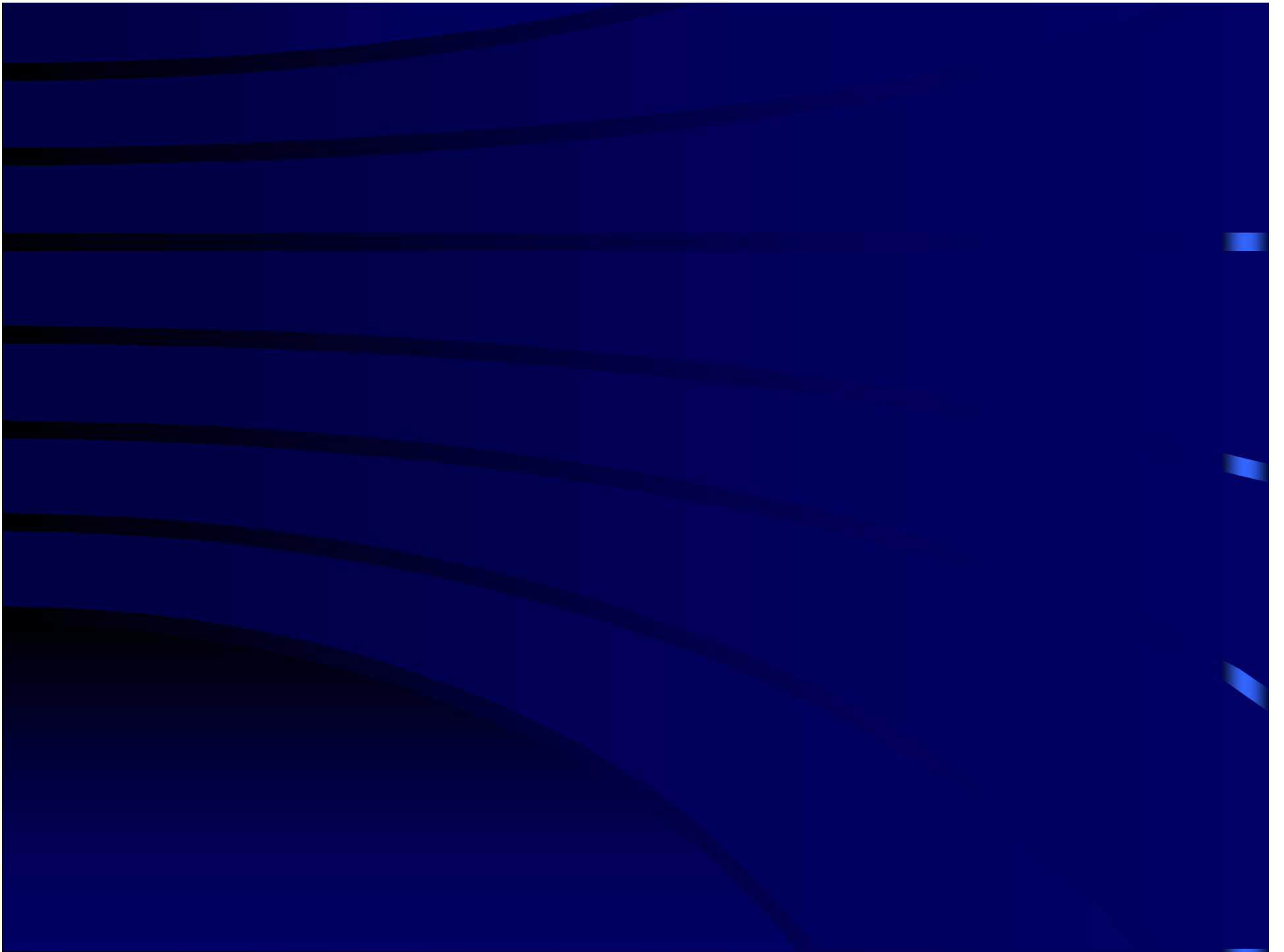
- Geological Conditions
- Basin Morphology

amplification of the motion in sites in the center and at the edges of the basin (Liosia 0.47g, Menidi 0.34g)

Thank You







Comparison

Site	Epicentral Distance (km)	Maximum Acceleration (g) L-component Bedrock	Maximum Acceleration (g) T- component Bedrock	Maximum Acceleration (g) Z- component	Maximum Acceleration (g) L-component Surface	Maximum Acceleration (g) T- component Surface
Menidi	14.1	0.142	0.139	0.101	0,265	0,265
Ano Liosia	10.7	0.237	0.305	0.073	0,414	0,466
FARAN	17.9	0.111	0.134	0.079	0,281	0,319
RICOMEX	18.0	0.133	0.041	0.046	0,247	0,246

tests

- $f_c = \underline{2.8\text{Hz}}$
- $3 \times 3, \underline{4 \times 4}, 5 \times 5$
- $\exp(-\pi \cdot k \cdot f) = \exp(-\pi \cdot R \cdot f / V_s / Q(f))$
 $k = \underline{0.03} \quad k = 0.06 \text{ (high pha)}$
- 1st layer (amplitudes, duration)

- Calculation of Synthetic Green Functions
- Discrete Wavenumber
- Stochastic Simulation

Aim: Constraint of Stochastic Character in a “Natural Way”