AFGL-TR-88-0334

Investigations on Local Seismic Phases and Evaluation of Body Waves Magnitude

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FIELD	GROUP	SUB-GROUP	Source function - synthetics seismogram - attenuation topographic effect - magnitude

19. ABSTRACT (*Continue on reverse if necessary and identify by block number*)

The scientific work done by RADIOMANA under DARPA Grant nr. AFOSR 87-0331 deals mostly with source studies.

For near events, we computed synthetics seismograms, using BOUCHON's method, for various heterogeneous structures. We put a special emphasis on topographic irregularities. This work was presented in the poster session at the 10th annual DARPA/AFGL SEISMIC RESEARCH SYMPOSIUM (2-5 may 1988). The programs used for this work are now implemented on our new SUN 3/280 system.

For teleseisms, ~~our~~ main effort was first to obtain attenuation models between Eastern Kazakh and several regions in France. The application of these results to source functions for a series of events recorded in France is currently being done. A first by-product from t study was a re-evaluation of the magnitude of all events and a determination of stations corrections.

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A) STUDIES IN PROGRESS

I) Poster

This study has been presented in the poster session at 10th Annual DARPA/AFGL SEISMIC RESEARCH (2-5 May 1988).

The effects of two-dimensional irregular structures in the vicinity of an explosive line source have been studied at short distances (less than 10 kilometers). The structures are made of a basin or of a ridge. Synthetic seismograms have been computed using the Discrete Wavenumber-Boundary integral equation method (Bouchon, M. and K. Aki - 1977, Bouchon, M., M. Campillo, and S. Gaffet - 1988, Gaffet S. and M. Bouchon - 1988). This seismic wave field representation is as precise as desired for all frequency ranges and type of structure studied.

The location of the source has a great importance on the shape of the seismic field diffracted by the nearby structure. Figure 1 shows surface waves generated by an irregular topography. The source is an explosive source made of two dipoles orthogonal to each other and is located under the ridge, at the basis and inside the ridge. The most important effect is an increasing of the amplitude of the diffracted Rayleigh wave when the source is located inside the ridge (See Figure 1c compare to Figure 1a and 1b). Figure 2 shows the effects of the position of an explosive source placed inside a basis. Three locations have been studied, (i) source located in the thin part of the basis (ii) source located between the thin and the thick parts of the basis (iii) source located straight above the thick part of the basis. The most important observed effect is the generation of a relatively higher frequency diffracted wave field when the source is located in the thick part of the basis (See Figure 2c and compare to Figure 2a). This effect had been experimentally showed by Vassiliou et al. (1987), for a source acting at the surface of a Yucca-type basis.

II) Present study

We are now considering the reciprocity principal at local distances and will extend it at teleseismic distances to study the importance of the source structure response in the determination of the energy of seismic or artificial event.

III) Other developments

An other part of the work had been the development of graphic software on the SUN-2 work station. This software permits graphics program written with a BENSON language to run. This software uses the SUN-CORE library to plot graphics on the screen and writes a POSTSCRIPT program which finally will be used to produce hard copy with the maximum resolution of the Appler Laser Writer.

B) SUN SYSTEM

We have received a SUN system configuration (One SUN 3/280 and two SUN 3/50 in Ethernet) at the beginning of July.

We are installing the "mgp" programs which was previously adapted to our seismic network for a SUN 2/170 configuration. These programs are able to:

- Make possible the acquisition of seismic data recorded on digital magnetic tapes (1600 bpi) which are composed of S.P. and L.P. signals from the French seismic network (30 S.P. stations and 6 L.P. 3 components stations).

- Demultiplex the channels

- Display on the screen selected channels or the whole set of channels

- Apply on them processing modules (filtering, correlations, spectra, delay and sum, etc)

- These first developments should be over at the beginning of October 1988.

Bibliography:

Bouchon, M. and K. Aki (1977)
Discrete wave-number representation of seismic source wave fields
Bull. Seism. Soc. Am. 67, pp 259-277

Bouchon, M., M. Campillo, and S. Gaffet (1988)
A boundary integral equation-Discrete wavenumber representation method to study wave propagation in multilayered media having irregular interfaces
Geophysics in press

Gaffet, S. and M. Bouchon (1988)
Effects of two-dimensional topographies using the discrete wavenumber-boundary integral equation method in P-SV cases
Submitted to J. Acoust. Soc. Am.

Vassiliou, M.S., M. Abdel-Gawad, and B.R. Tittmann (1987)
Ultrasonic physical modeling of seismic wave propagation from graben-like structures
AFGL-TR-87-0256, pp 1-29 (ADA189066)

Figure captions:

Figure 1: The geometry of the topography profile is displayed with the locations of the receivers and sources. The left hand side of the figures 1a, 1b, and 1c represents the horizontal (U) and vertical (W) ground displacement. The right hand side shows the polarization plot which corresponds to a time extension of the particule motions.

Figure 2: The geometry of the structure is displayed in the left center of the figure with the locations of the receivers (1 through 31) and the three positions of the explosions (A,B, and C). The three other diagrams represent a time-space representation of the ground displacement.

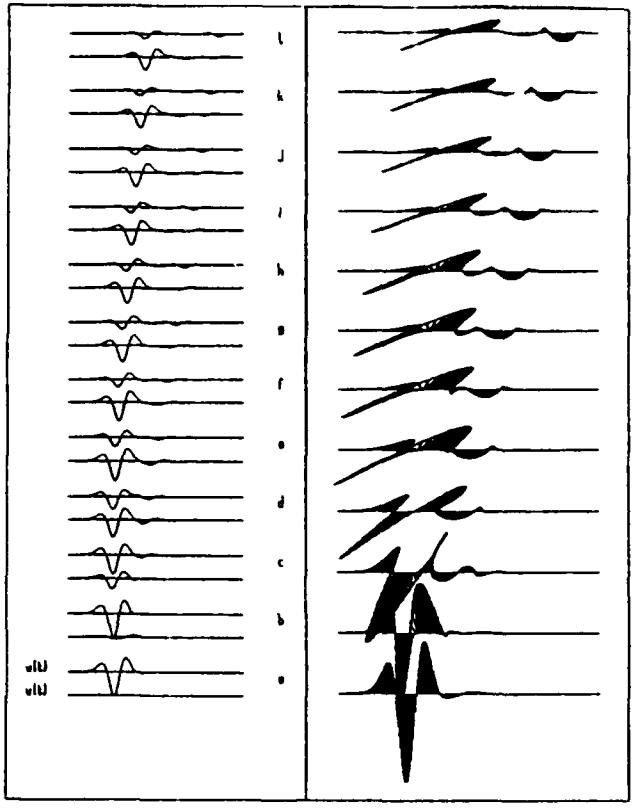
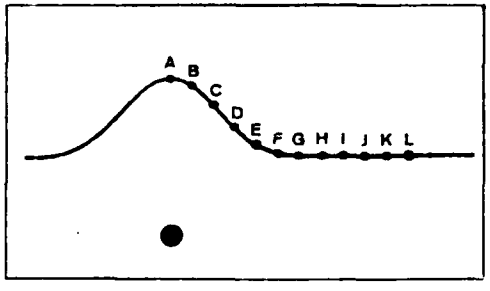


FIGURE 1A



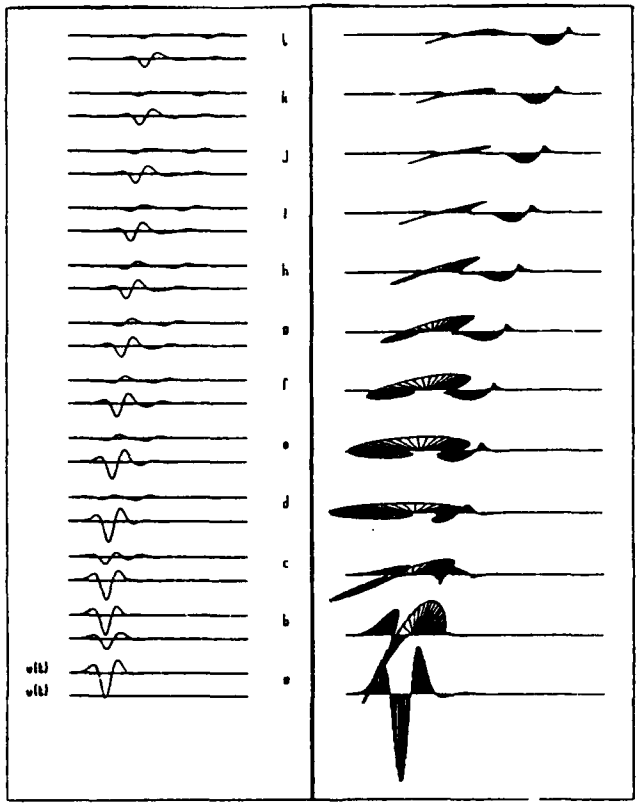
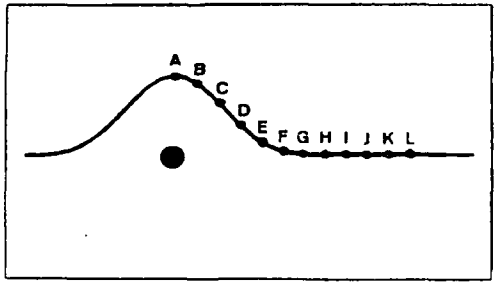


FIGURE 1B



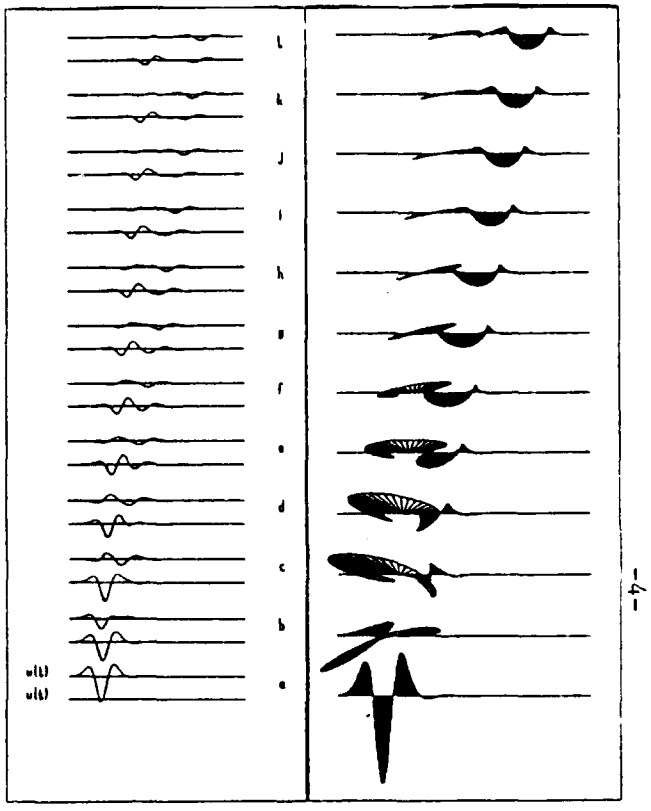


FIGURE 1C

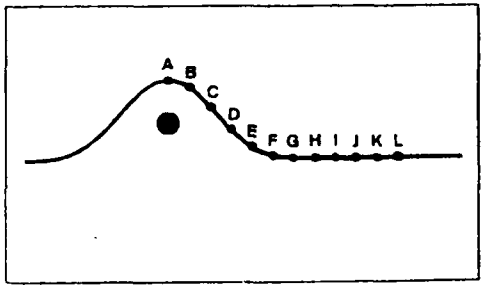


FIGURE 2A

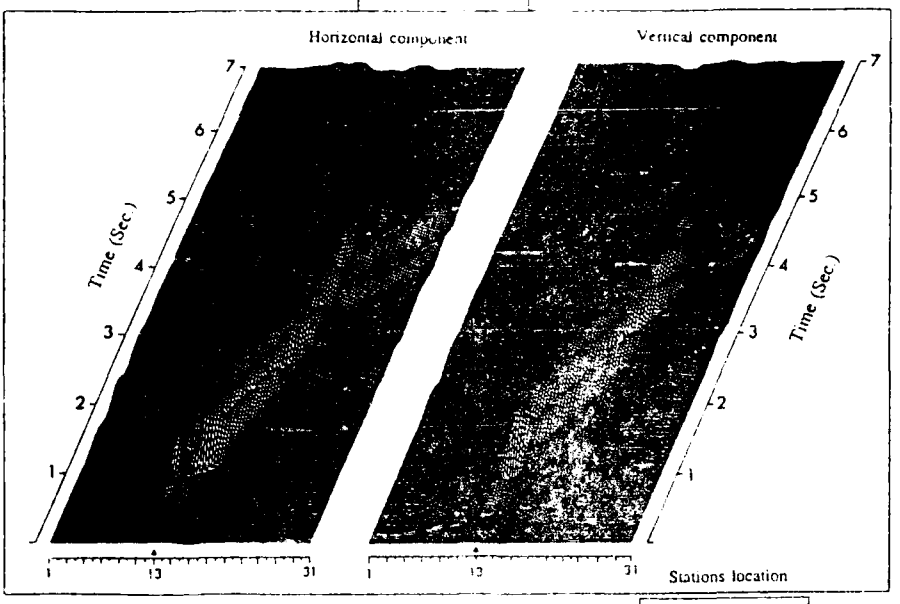


FIGURE 2B

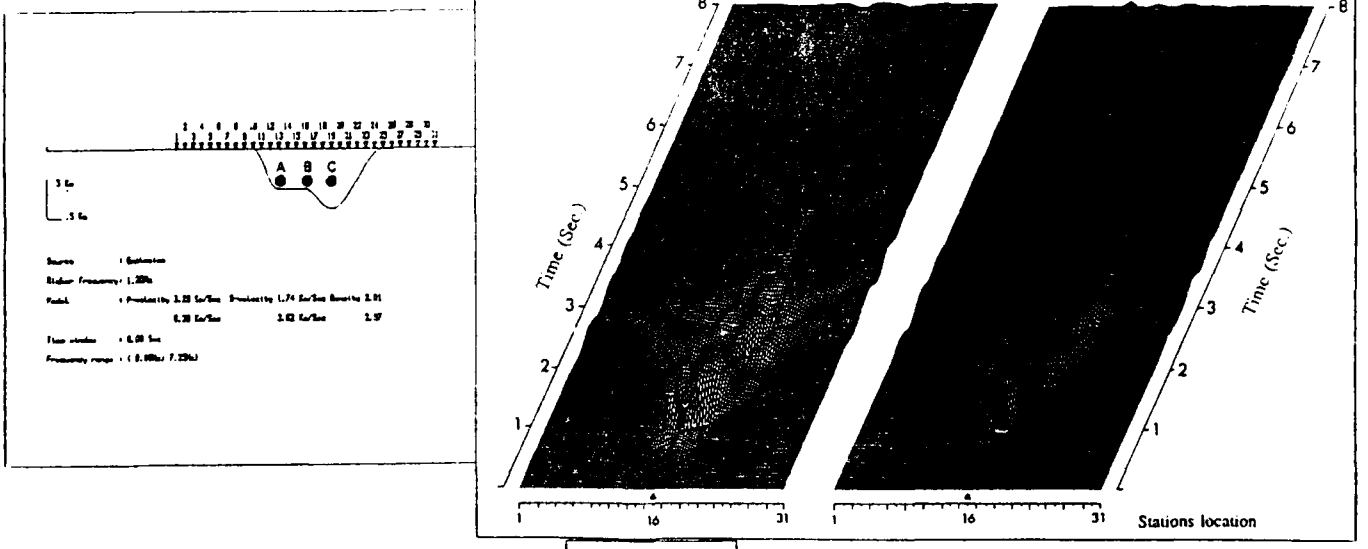
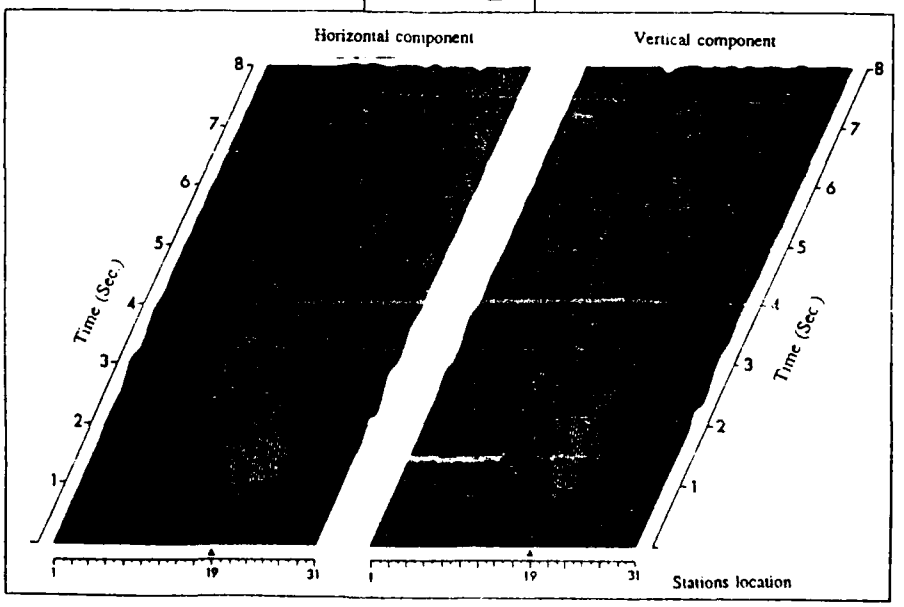


FIGURE 2C



C) STUDY OF TELESEISM FROM EASTERN KAZAKH

1) *Magnitude estimation*

We studied a set of events originating in Eastern Kazakh, all with very similar source functions and recorded by the French Seimic Network. An averaged (weighted) signal was computed from the 27 stations of the network and defines the *averaged event* recorded in France.

For each station *s* and each event *e*, the signal X_s^e is represented as :

$$X_s^e = K_s^e \overline{X} + \text{noise}$$

but also

$$X^e = K^e \overline{X} + \text{noise}$$

X^e being the averaged (weighted) signal in France for the event *e*.

The K^e and K_s^e factors have to be a function of magnitude :

$$m_b = a \log(K) + b$$

We compute **a** and **b** from the magnitudes defined by the classical way. The expected value for **a** is 1. , **b** is a scaling factor including epicentral distance and station's corrections.

a coefficient determination allowed us to point out important variations of the value depending on the studied station. The comparison was made with several determination of magnitude, including the magnitude published by the French Seimic Network and by ISC. **a** coefficients computed from those various data give the same *anomalies*.

The origin of **a** value variations is certainly related to the spectral content of the signals. The band pass of the used seismometer has an influence on the measure of $\log\left(\frac{A}{T}\right)$, it is also not obvious that the ratio of two $\log\left(\frac{A}{T}\right)$ from 2 events remains constant with distance, even measured by similar seismometers.

The conclusion of our study is that the magnitudes computed from K factors seem more precise than those obtained in the classical way because of their independence from the instrumental response. But the mean disadvantage is that this method could only be applied for the comparison of events with very close sources.

2) *Source functions*

We tried to obtain the studied event characteristics: yield **W** and depth of burial **h**. All the events originating in the same region, we'll tried to define a relation like:

$$h = c\ W^d$$

as Mueller and Murphy did for NTS events.

a) *Attenuation modeling*

In order to obtain source function spectra we had to define attenuation models. The followed method is decribed by T. Bache and al. (1986). The french array is too wide with regard to the arrays used by T. Bache so we defined 6 subarrays by using geological features.
We determined 6 attenuation models from a mean spectrum computed for each subarray. The figure 1 shows how we fitted the spectra with the theorical models. The results obtained for the region 5 surely are in relation with the very complicated structure of this region.
The obtained parameters are presented in the following table:

reg	t_0	τ_m	t_1
1	0.55	0.04	
2	0.75	0.05	0.02
3	0.80	0.05	
4	0.75	0.05	
5	0.75	0.05	0.04
6	0.75	0.05	

b) *Source function parameters modeling*

We used the Mueller-Murphy model (1971) for the source function spectrum modeling. We used an inversion method by least-squares fit to define the parameters **h** and **W**. The relation to minimize is:

$$f_o(\omega) = f_t(\omega) + \Delta h \frac{\delta f_t(\omega)}{\delta h} + \Delta W \frac{\delta f_t(\omega)}{\delta W}$$

where f_o is the observed spectrum and f_t the theorical spectrum. Δh and ΔW are the parameters which added respectively to **h** et W allow to find the "true" values for **h** and **W** by iteration.
This method didn't provide good results because the theorical curves of the source function spectra are really characteristic between 0.5 and 2 Hz, frequency range where we find the frequency corner. But the usual band recorded by the network is between 1 and 15 Hz (flat in velocity for a 1 Hz seismometer).

c) *Low frequency spectra contents improvement*

Our present work is devoted to the re-processing of our data after an extension of the spectral contents from 1 Hz to 0.25 Hz.
After extension of the band width, we'll try to follow the same method than described previously to obtain the source function parameters.

References

Bache T.C., Bratt S.R., Bungum H. (1986):
"High frequency P wave attenuation along five teleseismic paths from Central Asia"
Geophys. J.R. astr. Soc., 85, 505-522.

Bache T.C. and al. (1985):
"Q for teleseismic P waves from Central Asia"
J. Geophys. R., 90, B5, 3575-3587.

Mueller R.A. and Murphy J.R. (1971):
"Seismic characteristics of underground nuclear detonations"
Bull. Seism. Soc. Am., 65, 1675-1692.

Von Seggern D. and Blandford R. (1972):
"Source time functions and spectra for underground nuclear explosions"
Geophys. J.R. astr. Soc., 31, 83-97.

Figure captions:

Figure 1: Attenuation models for the 6 regions of France.
region 1: Armorican massif
region 2: Central massif
region 3: Aquitain bassin
region 4: South east of France
region 5: Morvan (North of Central massif)
region 6: Vosges (East of France)

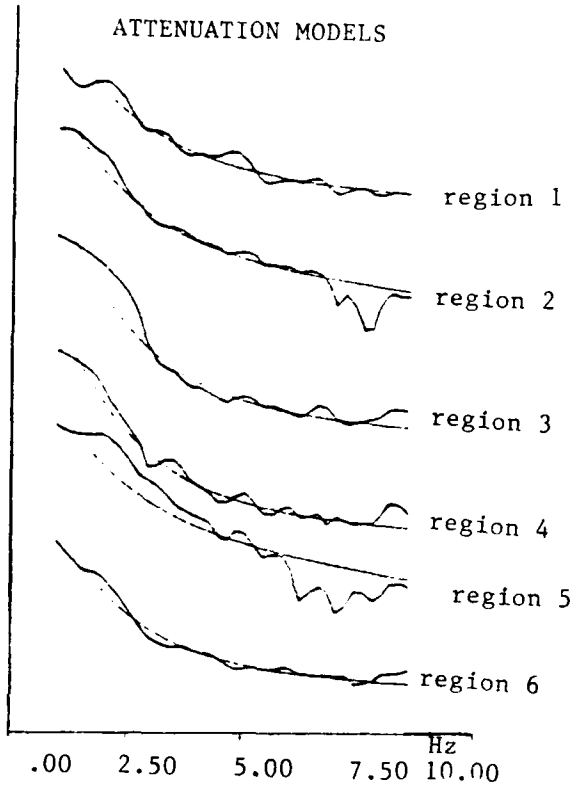

ATTENUATION MODELS
region 1
region 2
region 3
region 4
region 5
region 6
Hz
.00
2.50
5.00
7.50
10.00

FIGURE 1

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