the
abdus salam
international
centre
for theoretical
physics

united nations educational, scientific and cultural organization

international atomic energy agency

ATTENUATION OF VRANCEA EVENTS REVISITED

M. Radulian

G.F. Panza

M. Popa

and

B. Grecu

preprint

Available at: http://www.ictp.trieste.it/~pub_off IC/2003/153

United Nations Educational Scientific and Cultural Organization
and
International Atomic Energy Agency

THE ABDUS SALAM INTERNATIONAL CENTRE FOR THEORETICAL PHYSICS

ATTENUATION OF VRANCEA EVENTS REVISITED

M. Radulian
National Institute for Earth Physics, Bucharest-Magurele, Romania

G.F. Panza
Department of Earth Sciences, University of Trieste, Trieste, Italy
and
The Abdus Salam International Centre for Theoretical Physics, SAND Group, Trieste, Italy

M. Popa and B. Grecu
National Institute for Earth Physics, Bucharest-Magurele, Romania.

Abstract

New aspects of the frequency-dependent attenuation of the seismic waves traveling from Vrancea subcrustal sources toward NW (Transylvanian Basin) and SE (Romanian Plain) are evidenced by the recent experimental data made available by the CALIXTO'99 tomography experiment. The observations validate the previous theoretical computations performed for the assessment, by means of a deterministic approach, of the seismic hazard in Romania. They reveal an essential aspect of the seismic ground motion attenuation, that has important implications on the probabilistic assessment of seismic hazard from Vrancea intermediate-depth earthquakes. The attenuation toward NW is shown to be a much stronger frequency-dependent effect than the attenuation toward SE and the seismic hazard computed by the deterministic approach fits satisfactorily well the observed ground motion distribution in the low-frequency band (< 1 Hz). The apparent contradiction with the historically-based intensity maps arises mainly from a systematic difference in the vulnerability (buildings eigenperiod) of the buildings in the intra- and extra-Carpathians regions.

MIRAMARE – TRIESTE

November 2003

Introduction

The Vrancea zone, located at the most tightly curved portion of the mountain belt (45.5°N, 25.5°E), presents the most unusual and intriguing aspects related to seismic activity, volcanism, and surface deformation all along the Carpathians arc (Fig. 1). The earthquakes, reaching magnitudes as high as M_w 7.7, are generated in a well-defined and isolated nest situated at intermediate depths (60 – 220 km). The damage, as reported by macroseismic data, is strongly laterally asymmetric, sharply decreasing towards the inner side (Transylvanian Basin) as compared with the outer side (Romanian Plain) of the Carpathians arc (SR 11100, 1993).

The deterministic hazard estimation made by Radulian et al. (2000) for Vrancea earthquakes, based on the computation of complete synthetic seismograms for frequencies below 1 Hz, leads to hazard distribution reproducing well the observations in the southeastern part of Romania, with an excellent agreement between the computed ground motion values and the available instrumental data (e.g., Moldoveanu and Panza, 1999; Kouteva et al., 2000; Moldoveanu et al., 2000; Kouteva et al., 2001). At the same time the deterministic estimate predicts much higher values in the Transylvanian Basin and north Moldova relative to what the macroseismic information indicates. Although the historically- and empirically-based information for these regions is scarce and poor, this discrepancy could raise serious doubts about the suitability of the deterministic approach.

We show here that this difference is limited to the high frequencies (> 1 Hz) and that the apparent contradiction can be naturally explained by an attenuation process strongly dependent on frequency along the path from Vrancea subcrustal domain to the NW.

Attenuation of seismic waves from Vrancea subcrustal foci

In 1999 a large international tomography experiment, CALIXTO'99, temporarily deployed 120 seismic stations (both short-period and broadband instruments) around Vrancea region within the programme CRC461 (Wenzel et al., 1998). The network partly covered the inner side region of the Carpathians arc, a region very poorly monitorized by the Romanian national network (Fig. 1) and recorded 77 local earthquakes with magnitude $3 \leq Mw \leq 4.2$.

The analysis of these new data brought into the light a new aspect, missed by all previous experimental studies: the strong frequency-dependent lateral variation of the seismic wave attenuation across the Carpathians. The simple visualization of the seismograms or of their spectra shows amplitudes ten to hundred times smaller and a strong cut-off of the higher frequencies in the back-arc region as compared to the fore-arc region (Popa, 2003; Popa et al., 2003). A series of recent studies, partly in progress, confirms these observations (Popa et al., 2000; Popa et al., 2003).

These features are systematically observed for all the available recordings of waves traveling toward NW. The attenuation effect, in agreement with the seismic tomography (Martin et al., 2001) and heat flow measurements (Demetrescu and Andreescu, 1994), may be tentatively explained by the presence of an astenospheric body in the back-arc side of the subducting slab in Vrancea, at an intermediate-depth range. The low Q values could be related to the upwelling process of the asthenosphere just behind the Vrancea seismogenic zone and it corresponds to the most recent volcanic activity in the Perşani Mountains.

We select, as typical examples, the two Vrancea moderate-size earthquakes listed in Table 1, for which we can use the largest possible number of recordings ever obtained in Romania. The fault plane solutions of the two events are different (Fig. 2). In Fig. 3, the seismograms recorded at two pairs of stations located symmetrically with respect to the Carpathians arc, roughly at equal epicentral distance on a NW-SE direction, are plotted, as an example. The decrease of the peak ground velocity (PGV) in the back-arc region is from 40 to 110 times larger in comparison with the corresponding values in the fore-arc region. At low frequencies (< 1 Hz) the difference practically disappears, as can be seen in Fig. 4. The strong frequency dependence of the seismic wave attenuation across Carpathians is the new and key element in our findings: when looking at low frequencies, there is no clear trend of attenuation in the recorded motion.

Fig. 5 represents the distribution of the PGV as obtained from the records of the events listed in Table 1. To minimize the effect of the differences among the sensors (EpiSensor, Guralp, RefTek), a low-pass Butterworth filter is applied to all the records and the PGV are taken relative to the reference station, VRI, located in the epicentral area. The difference in PGV between back-arc and fore-arc records decreases by a factor of about 10 with decreasing cutoff frequency from 15 Hz to 1 Hz, regardless of the focal mechanism. Therefore we can expect that for the largest Vrancea earthquakes, that radiate mostly at frequencies below 1 Hz (Gusev et al., 2002), the attenuation of PGV is rather isotropic.

Consequences on seismic hazard computations

We deal with one of the most crucial and controversial points for the Vrancea intermediate-depth earthquakes: the asymmetric distribution of the peak values of seismic ground motion, and we have just shown that the sharp attenuation of the seismic motion toward NW (Transylvanian Basin) affects mostly the high-frequency waves (> 1 Hz). This finding has two fundamental consequences: (1) the first-order deterministic seismic zoning of Romania proposed by Radulian et al. (2000) is only apparently in contradiction with the macroseismic observations in Transylvania, and (2) the vulnerability (building eigenperiod) factor seems to play an essential role in explaining the differences between the observed damage in intra- and extra-Carpathians regions.

The frequency content (≤ 1.0 Hz) of the numerical simulations used by Radulian et al. (2000) is representative primarily of the tall buildings (10-storey and higher). The severe damage experienced in Bucharest because of Vrancea intermediate-depth earthquakes (e.g., the collapse of 32 tall buildings during the March 3, 1977 earthquake) is indeed explained by the predominance, in the ground motion, of the period of oscillation around 1-1.5 s.

Our results show that similar periods control the seismic hazard in Transylvania, and, since the predominant buildings here are of one to three storeys (eigenperiods in the range 0.1 – 0.3 s), as we could expect, the damage reported is quite low. Therefore, the discrepancy between the shape of the observed isoseismals and the deterministic estimations of the peak values toward NW is essentially due to the difference in the vulnerability (structural characteristics of the buildings) between the back-arc region and the fore-arc region. The strong attenuation of the high frequencies explains the low damage in the intra-arc region, where the majority of buildings are of small height. The effect of the low frequencies is much more important and evident in the extra-Carpathians area, and above all in Bucharest city, where the greatest number of tall and old buildings is present. Collapses of tall buildings caused by Vrancea earthquakes is reported exclusively in Bucharest, while for the other localities situated in the Carpathians fore-arc region damage is reported mainly for small height constructions (Lungu et al., 1999).

The source and the local site properties are important factors shaping the hazard distribution pattern (Panza et al., 2001), but we consider that the seismic wave attenuation in the upper mantle together with the difference in vulnerability are the most plausible causes of the observed striking asymmetry of the macroseismic shape in the NW-SE direction.

The unusually small attenuation at low frequency has important consequences on the seismic hazard assessment not only in Romania, but in the neighboring countries as well (e.g., Bulgaria, Rep. of Moldova, Ukraine and even Russia). This essential effect is not at all noticeable in the probabilistic maps (Musson, 2000), while it is well represented in the deterministic maps (Radulian et al., 2000).

Acknowledgements

The paper is the result of the synergetic efforts of the international projects: Realistic Modelling of Seismic Input for Megacities and Large Urban Areas (UNESCO/IUGS/IGCP project 414); Impact of Vrancea Earthquakes on the Security of Bucharest (NATO SfP project 972266) and the CALIXTO'99 experiment and K2 network within CRC461 programme of University of Karlsruhe (Germany). The work has been supported by the Italian Ministry of Foreign Affairs (MAE), Directorate General for Cultural Promotion and Cooperation, in the framework of the project "Seismic Microzonation of Bucharest for the Mitigation of the Hazard from Vrancea Earthquakes" and by the Romanian Ministry of

Education, Research and Youth in the framework of the project "Source and propagation parameters determination on the basis of the data provided by the digital accelerometer network and CALIXTO network for seismic hazard evaluation", CERES, Contract no. 33/15.10.2001.

References

Demetrescu, C. and Andreescu, M. (1994). On the thermal regime of some tectonic units in a continental collision environment in Romania. Tectonophysics, 230, 265-271.

Gusev, A., Radulian, M., Rizescu, M. and Panza, G.F. (2002). Source scaling for the intermediate-depth Vrancea earthquakes, Geophys. Int. J. 151, 879-889.

Kouteva, M., Panza, G. F. and Paskaleva, I. (2000). An example for ground motions in connection with Vrancea earthquakes (case study in EN Bulgaria, Russe site), 12 WCEE 2000, Auckland, New Zealand, 30 Jan.-4 Feb, 2000, Ref.2185, on CD.

Kouteva M., Panza, G.F., Paskaleva, I. and Romanelli, F. (2001). Modeling of the Ground Motion at Russe site (NE Bulgaria) due to Vrancea Earthquakes, ICTP Preprint, IC/2001/145, University of Trieste.

Lungu, D., Demetriu, S. and Arion, C. (1999). Seismic vulnerability of buildings exposed to Vrancea earthquakes in Romania, *Vrancea Earthquakes: Tectonics, Hazard, and Risk Mitigation*, Editors: Wenzel, F., Lungu, D., Kluwer Academic Publishers, 215-224.

Martin, M., Achauer, U., Kissling, E., Mocanu, V., Musacchio, G., Radulian, M., Wenzel, F. and CALIXTO Working Group (2001). First results from the tomographic experiment CALIXTO'99 in Romania. Geophs. Res. Abstr., vol. 3, EGS, SE1.02.

Moldoveanu, C.L., Marmureanu, G., Panza, G.F., and Vaccari F. (2000). Estimation of site effects in Bucharest, caused by the May 30-31, 1990, Vrancea seismic events, Pure Appl. Geophys., 157, 249-267.

Moldoveanu, C.L. and Panza, G.F. (1999). Modeling for micronization purposes, of the seismic ground motion in Bucharest, due to Vrancea earthquake of May 30, 1990, in: "Vrancea Earthquakes: Tectonics, Hazard and Risk Mitigation" (eds. F. Wenzel, D. Lungu and O. Novak) 85-97, Kluwer Academy Publishers.

Musson, R.M.W. (2000). Generalized seismic hazard maps for the Pannonian basin using probabilistic methods, in: "Seismic Hazard of the Circum-Pannonian Region" (eds. G. F. Panza, M. Radulian, C.-I. Trifu), Pure Appl. Geophys. 157, 147-169.

Panza, G.F., Romanelli, F. and Vaccari, F. (2001). Seismic wave propagation in laterally heterogeneous anelastic media: Theory and applications to seismic zonation. Advances in Geophysics, 43, 1-95.

Popa, M. (2003). Contributions to the knowledge of the deep structure in Vrancea zone, PhD Thesis, University of Bucharest, 2003.

Popa, M., Russo, R., Mocanu, V. and Radulian, M. (2000). Seismic attenuation in and around the Carpathians, Romania, from K2 network data, AGU Falling Meeting, San Francisco, 2000.

Popa, M., Grecu, B., Popescu, E., Plăcintă, A. and Radulian, M. (2003). Asymmetric distribution of seismic motion across South-Eastern Carpathians (Romania) and its implications, Romanian Reports in Physics (in print).

Radulian M., Vaccari F., Mandrescu N., Panza G. F. and Moldoveanu C. (2000). Seismic hazard of Romania: A deterministic approach, in "Seismic Hazard of the Circum-Pannonian Region", eds. G. F. Panza, M. Radulian, C.-I. Trifu, Pure Appl. Geophys. 157, 221-247.

SR 11100 (1993). Seismic zoning. Macrozoning of the territory of Romania, Institutul Român de Standardizare (IRS, in Romanian).

Wenzel, F., Achauer, U., Enescu, D., Kissling, E., Russo, R., Mocanu, V., Mussachio, G. (1998). The final stage of plate detachment; International tomographic experiment in Romania aims to a high-resolution snapshot of this process. EOS, 79: 589, 592-594.

Table 1. Intermediate-depth Vrancea earthquakes considered in this study

Date	hour:min:sec	Lat. (N°)	Lon. (E°)	h (km)	M_W
1999/06/20	00:09:06.17	45.587	26.510	139	3.6
1999/06/29	20:04:06.87	45.601	26.530	138	4.2

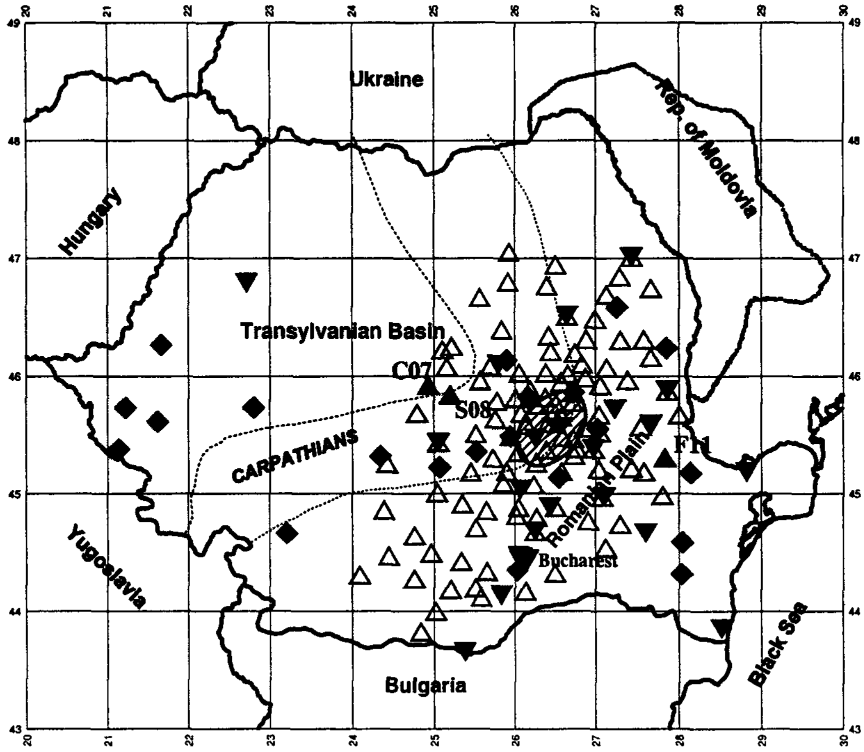

Fig. 1. Location of Vrancea zone and seismic stations on the Romanian territory. Vrancea epicentral area is represented as a dashed ellipse area. The epicenters of the two selected earthquakes are plotted as stars. The stations, whose records has been selected as examples, are evidenced by full triangles. The CALIXTO'99 stations are plotted as empty triangles. The solid diamonds are the Romanian telemetered stations. The full reversed triangles are the digital accelerometer stations (University of Karlsruhe).

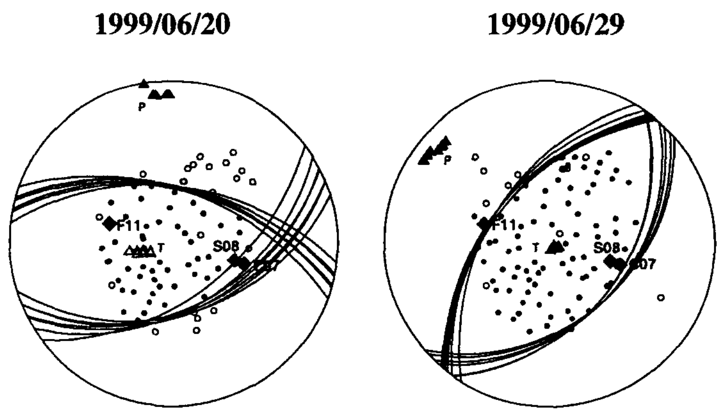

Fig. 2. Fault-plane solutions, for the studied earthquakes, obtained using first P-wave polarities. The solutions are well constrained. The position, on the focal sphere, of the two stations, whose records are shown in Fig. 3, is given by the labeled diamonds.

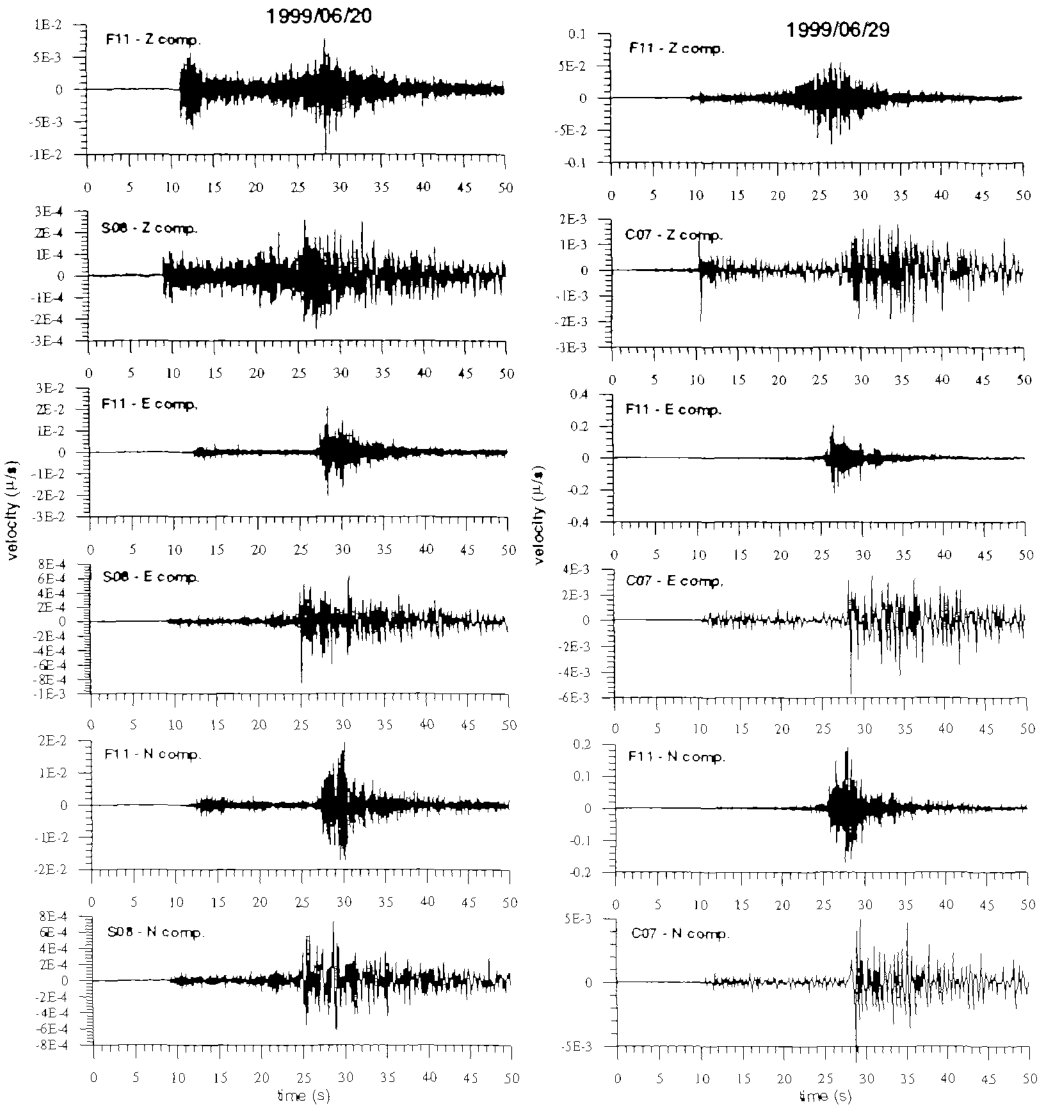

Fig. 3. Synoptic representation of examples of seismograms (velocigrams) typical for a back-arc station (S08 – 107 km epicentral distance and C07 – 129 km epicentral distance) and fore-arc station (F11 – 107 km epicentral distance). The Vrancea events considered, listed in Table 1, have markedly different fault plane solutions.

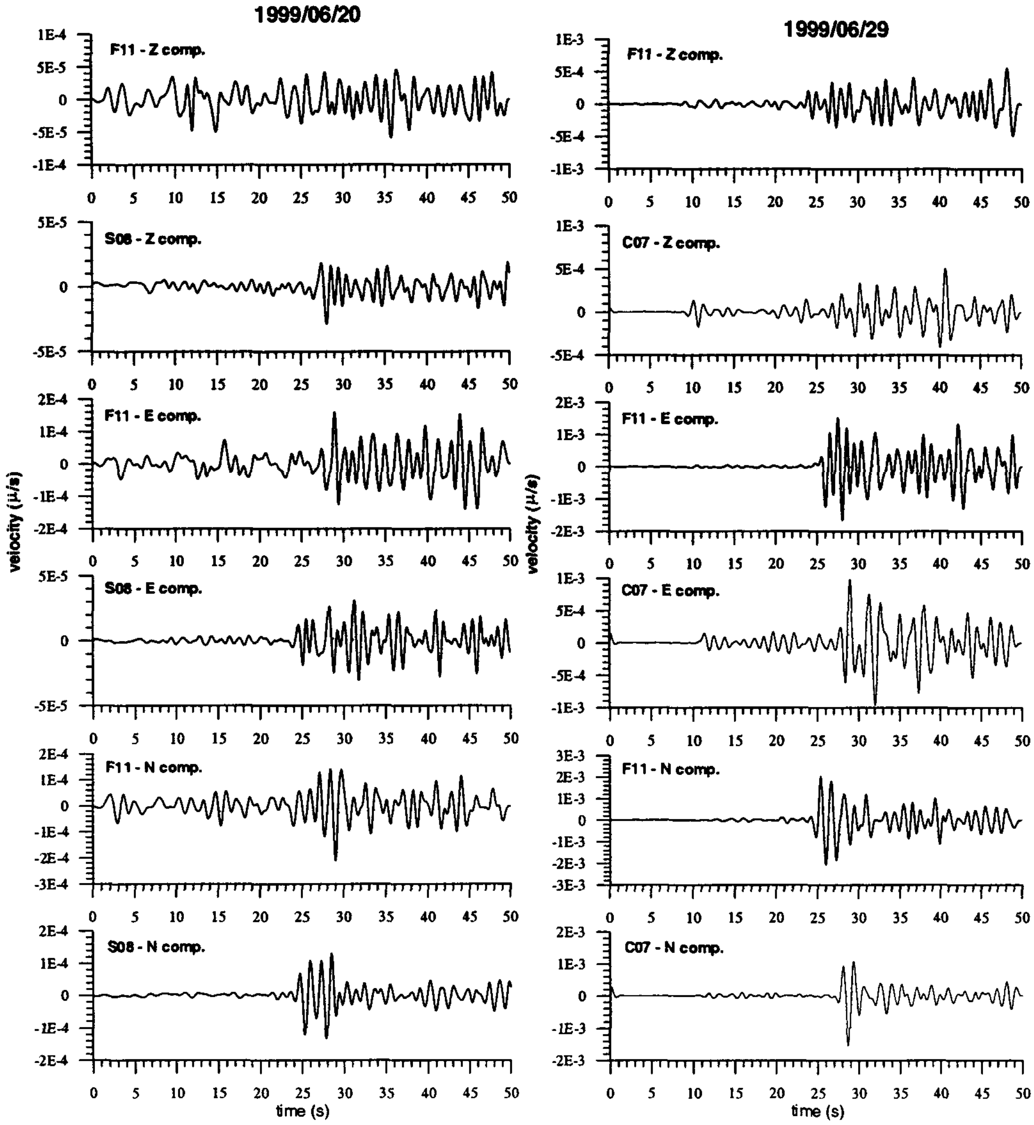

Fig. 4. The same seismograms shown in Fig. 3, but low-passed filtered with cutoff at 1 Hz.

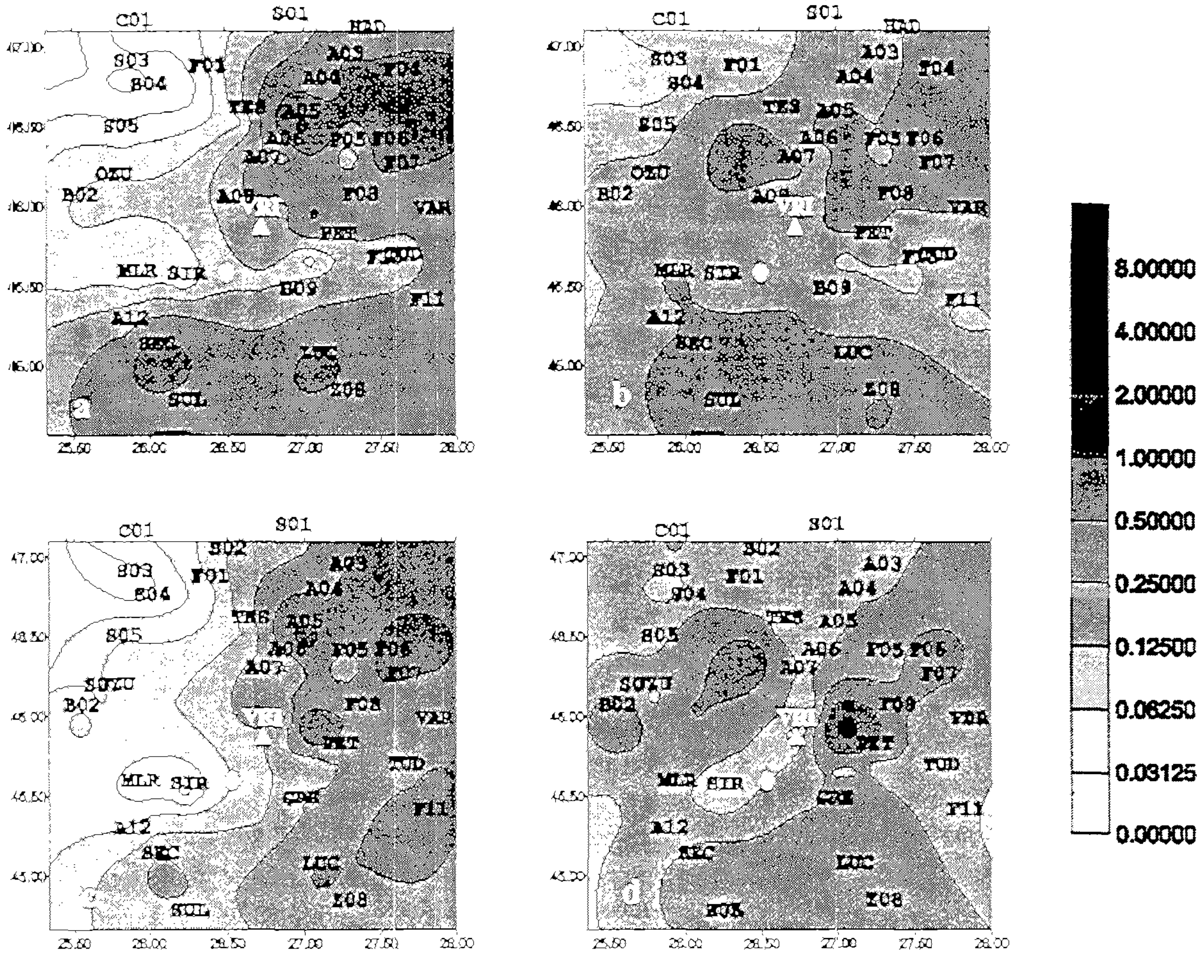

Fig. 5. Representation of the peak ground velocity distribution for 1999/06/20 (a and b) and 1999/06/29 (c and d) earthquakes. Maps a and c are based on 15 Hz cutoff frequency records, while maps b and d are based on 1 Hz cutoff frequency records. The scale refers to the amplification factors (powers of 2) relative to VRI station, selected as reference station. The empty circle is the epicenter. For low frequencies (< 1 Hz), the fault plane solution controls the orientation of the area of relative minimum close to the epicenter (b and d). This effect is still visible at high frequencies (1 < f < 15 Hz), but only for event the of 1999/06/20 (a). (see also Fig. 2).