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Seismic hazard maps for Romania and large populated areas by probabilistic and deterministic approaches, linear and nonlinear methods

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ICTP Advanced Conference on Seismic Risk Mitigation and Sustainable Development

SEISMIC HAZARD MAPS FOR ROMANIA AND LARGE POPULATED AREAS BY PROBABILISTIC AND DETERMINISTIC APPROACHES, LINEAR AND NONLINEAR METHODS

by

Gheorghe MARMUREANU, Carmen Ortanza CIOFLAN

Trieste-Italy. May 10-14,2010

The scenario-based methodology developed at this point is strictly based on observable facts and data and complemented by *physical modeling techniques,* probabilistic and deterministic approaches, linear and nonlinear methods, which can be submitted to a formalized validation process.

Earthquake in Romania have been known since Roman times, when Traian's legionnaires begun the colonization of the rich plains stretching from the Carpathian Mountains to the Danube river.

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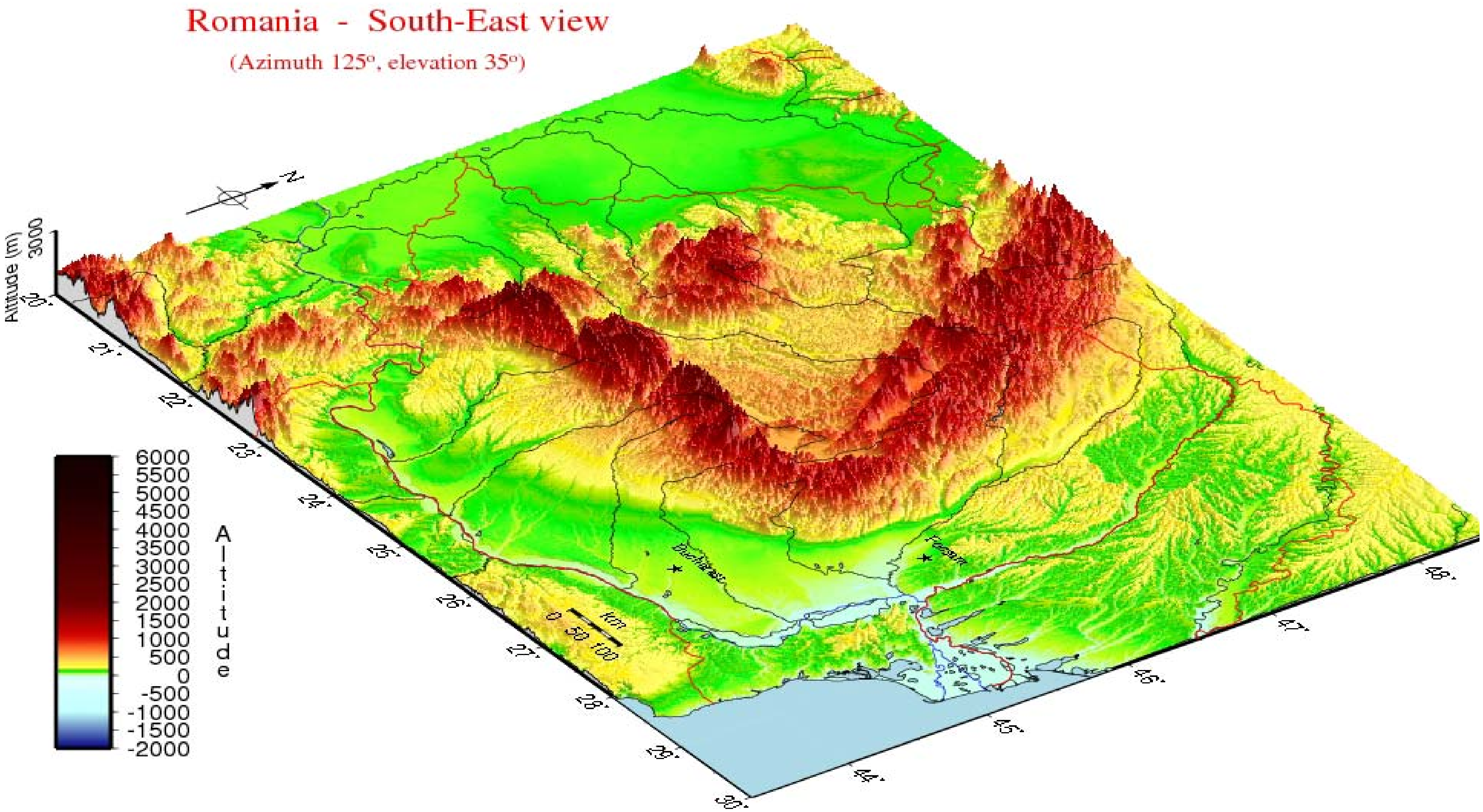

Romania-South East view

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The Vrancea seismogenic zone in Romania denotes a peculiar source of seismic hazard, which represents a major concern in Europe, especially to neighboring regions from Bulgaria, Serbia, Republic of Modova etc. The strong seismic events originating from Vrancea area can generate the most destructive effects experienced in Romania, and may seriously affect high risk man-made structures such as nuclear power plants (Cernavoda, Kosloduj etc.), chemical plants, large dams, and pipelines located within a wide area from Central Europe to Moscow to Rome.

In plan view, the earthquakes are localized to a restricted area in the *bending zone* between the Eastern and Southern Carpathians at least three units in contact: the East European plate, Intra-Alpine and Moesian sub-plates.

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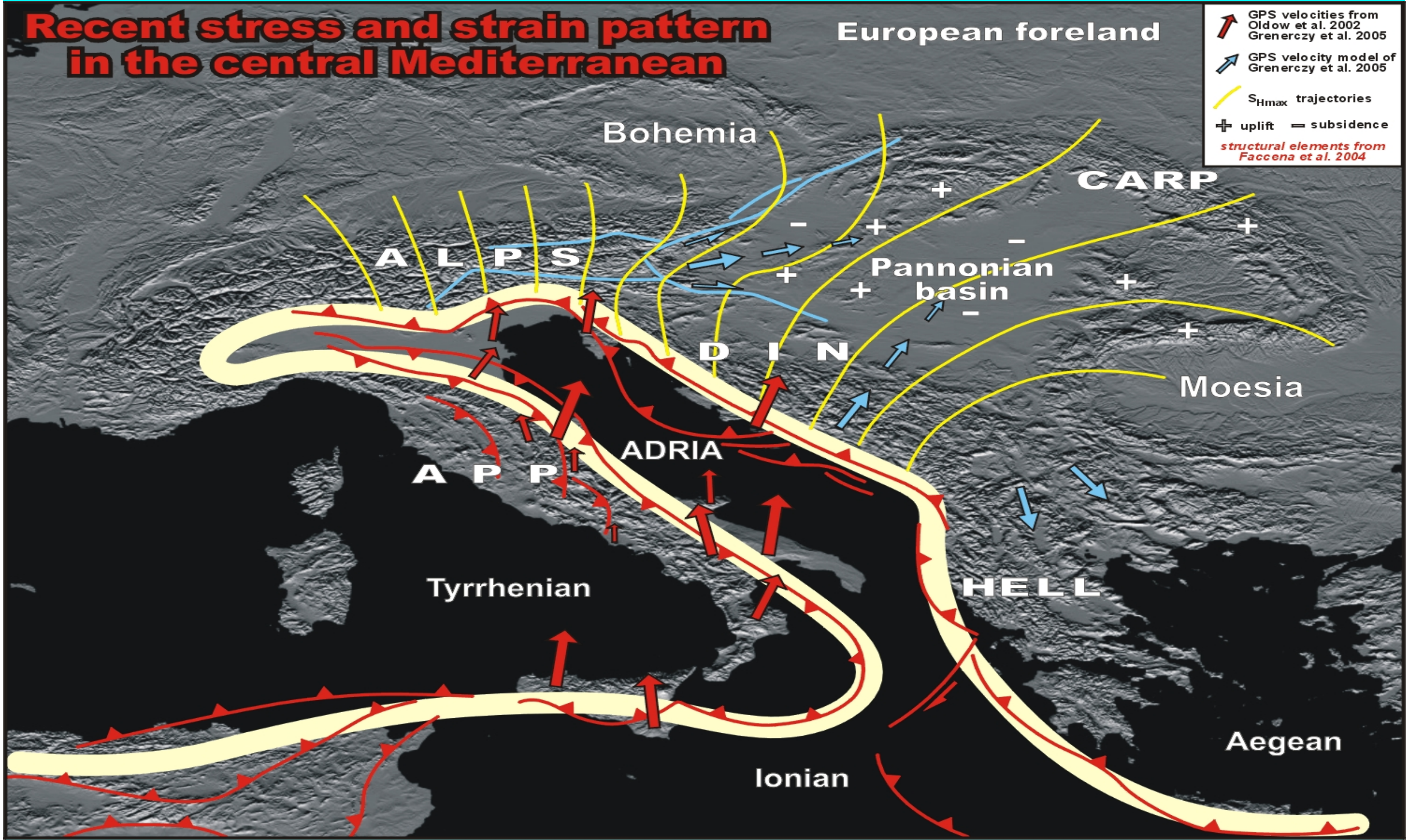

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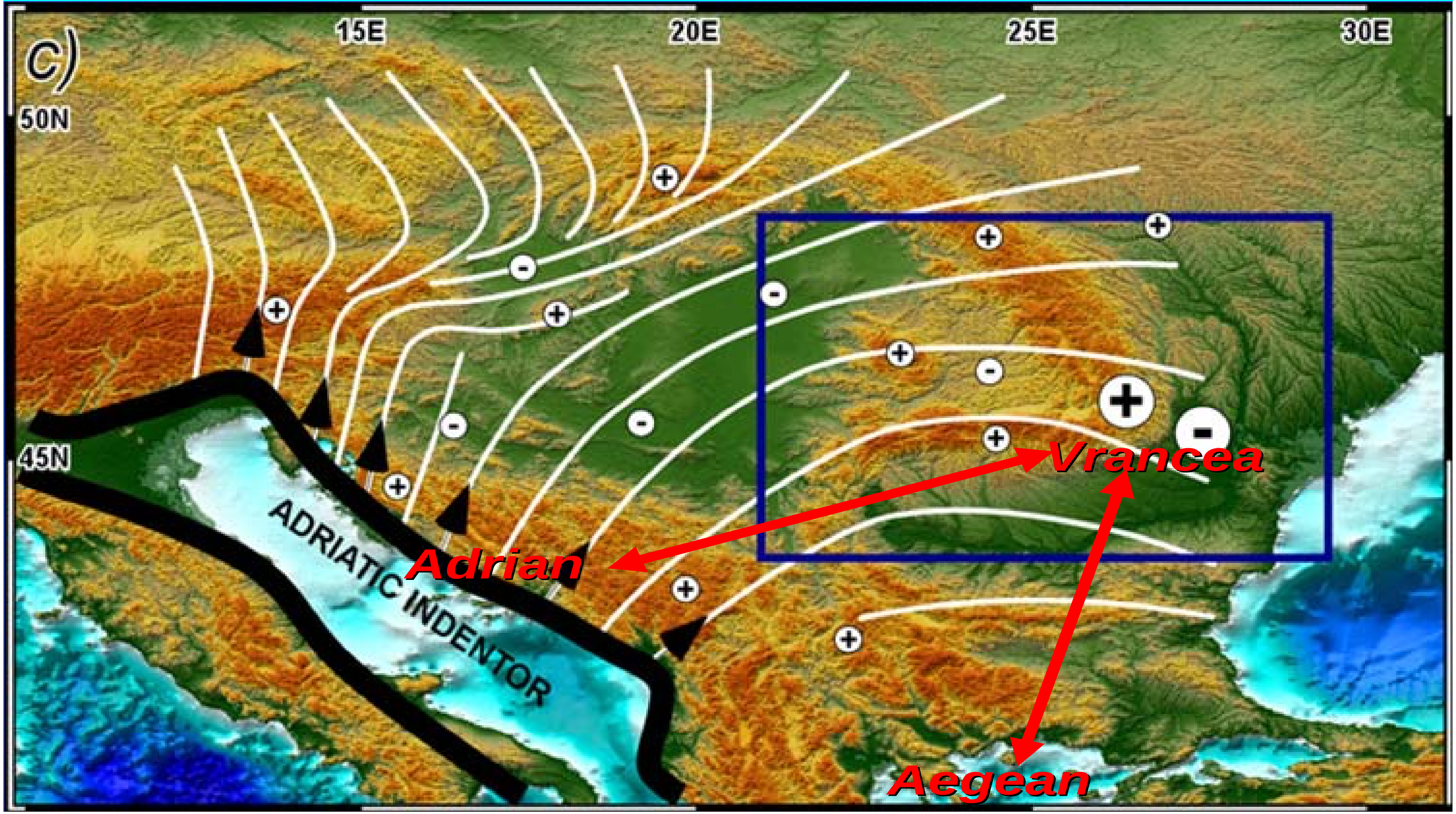

Strain transfer from the active Adriatic, Aegean and Vrancea deformation fronts through the ALCADI- Pannonian System

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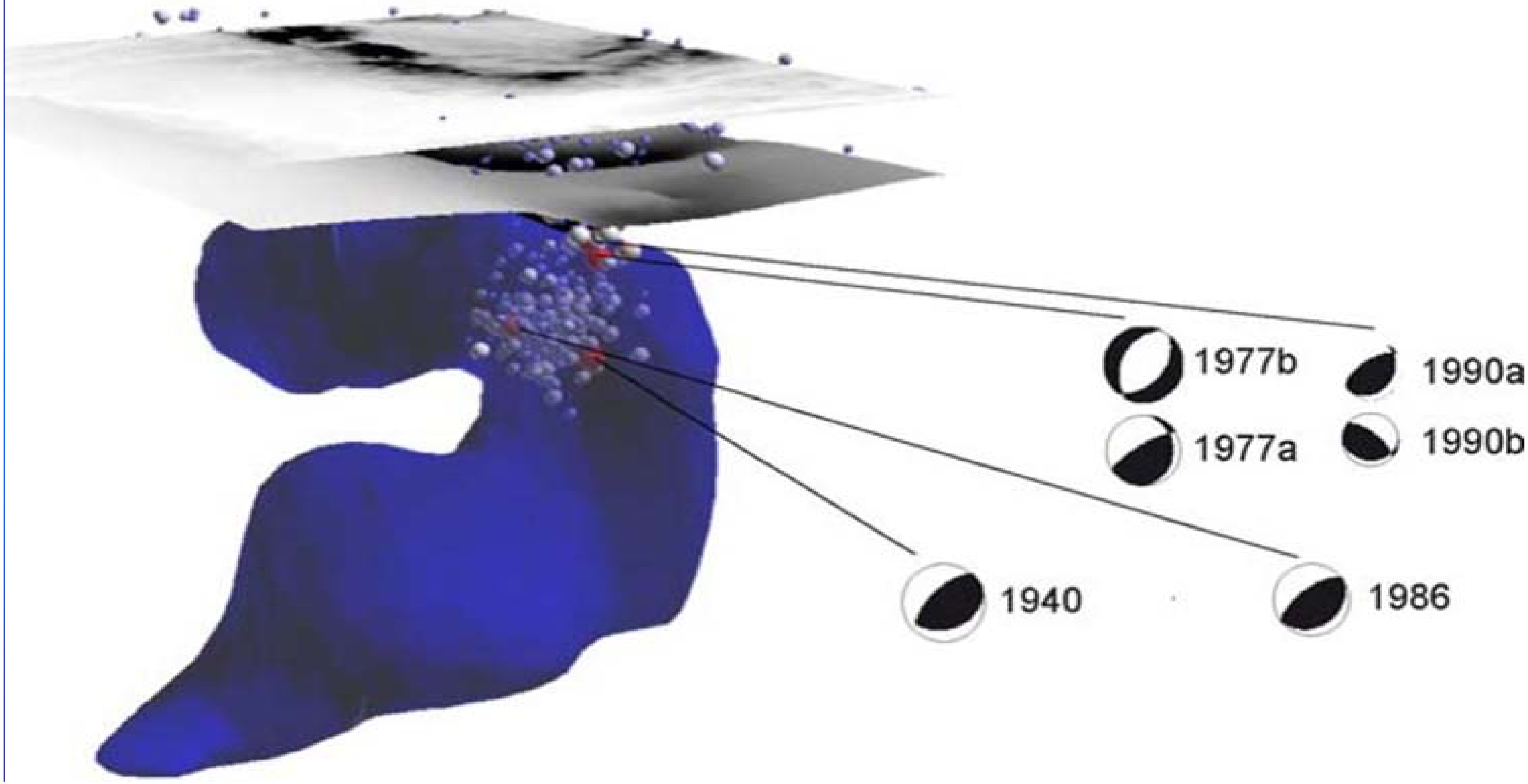

Topograhy and Moho layer and the isosurface of the 2.2% p-wave velocity anomaly of the Vrancea area from the seismic tomography work

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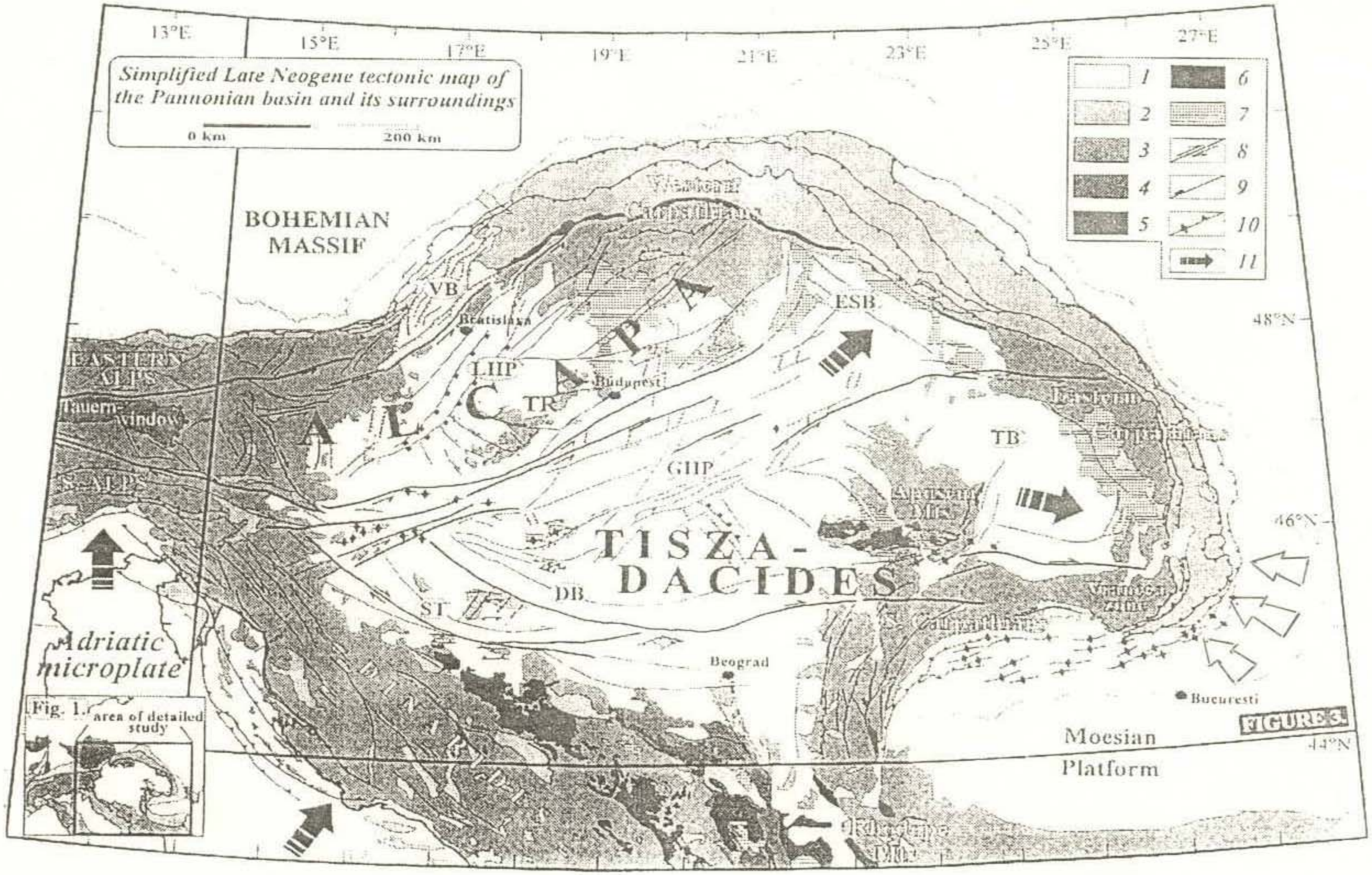

Present day geodynamics of the Pannonian Basin and its surroundings

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- Earthquakes in the Carpathian-Pannonian region are confined to the crust, except the Vrancea zone, where earthquakes with focal depth down to 200 km occurs.
- The ruptured area migrated from 150 km to 180 km (Nov. 10,1940 Vrancea earthquake, Mw =7.7), from 90 to 110 km (March 4,1977 earthquake, Mw =7.4), from 130 to 150 km (August 30,1986, Mw =7.1) and from 70 to 90 km (May 30,1990, Mw =6.9) depth.

The depth interval between 110 km and 130 km remains not ruptured since 1802,October 26,when it was the strongest earthquake occurred in this part of Central Europe. The magnitude is assumed to be Mw =7.9 - 8.0 and this depth interval is a natural candidate for the next strong Vrancea event…

The maximum intensity for strong deep Vrancea earthquakes is function of earthquake depth. In 1977 strong earthquake (MW =7.4 and h=109 km) at its epicenter, in the Vrancea region, the estimated intensity was only VI (MMI scale), while some 170 km away in the capital city of Bucharest, the estimated maximum intensity was IX - IX½ (MMI). In 1940, the effects were in the epicenter area. The intensely deforming Vrancea zone shows a quite enigmatic seismic pattern (peak ground accelerations/intensity one, characteristic response spectra with *large periods of 1.5 seconds* etc.).

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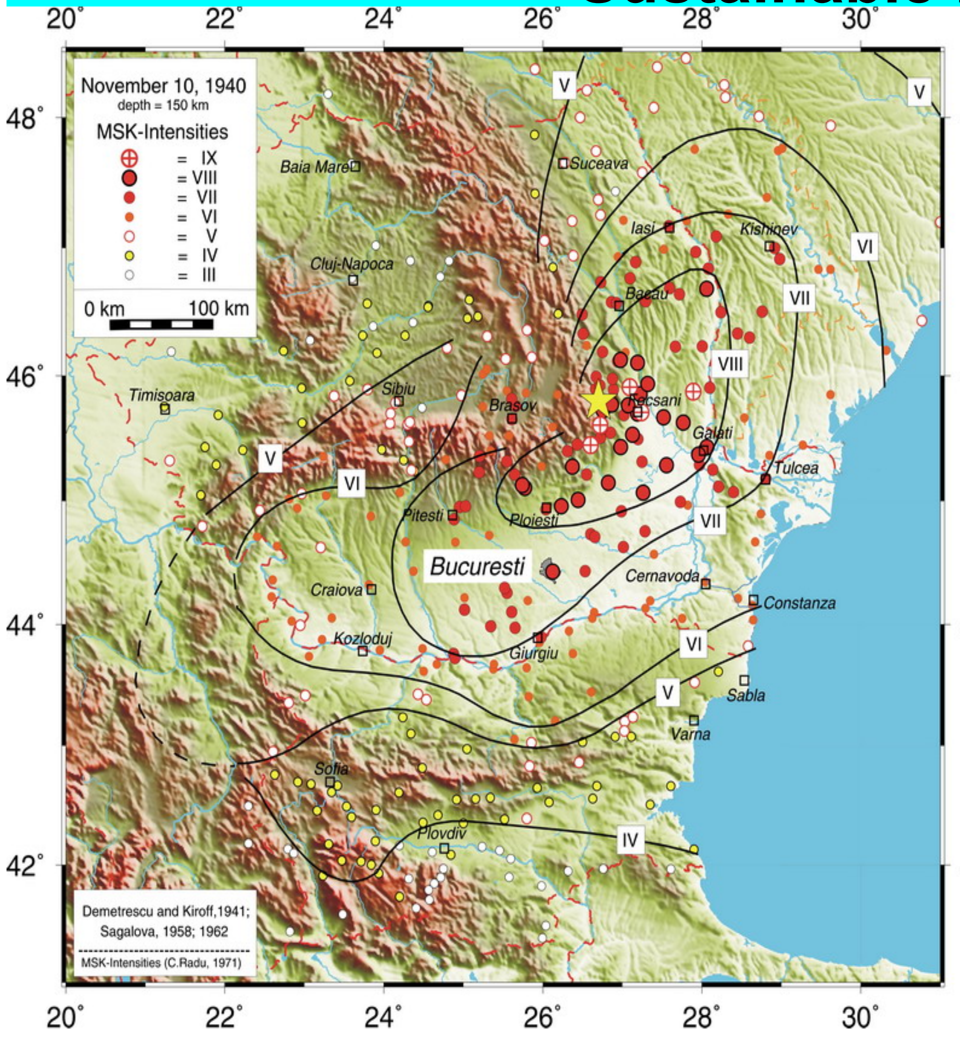

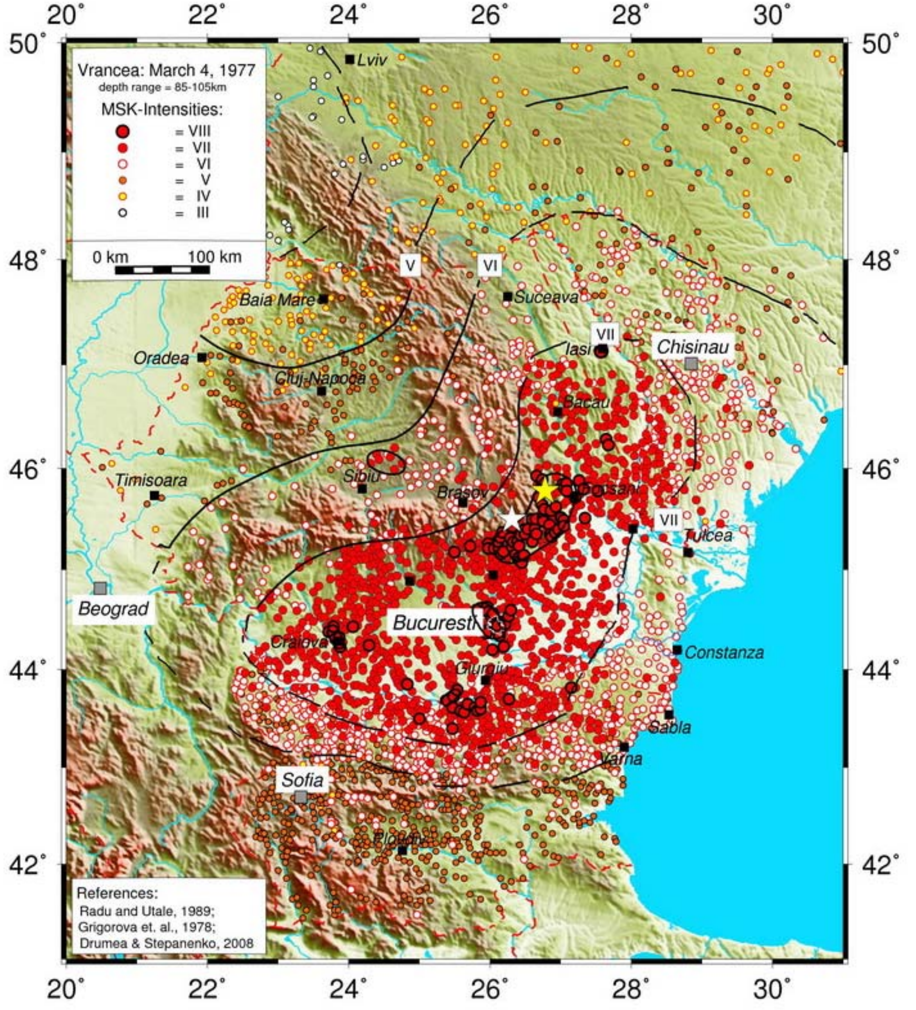

Observed distribution of macroseismic intensity during of large Vrancea earthquakes

November 10,1940, M_{GR} = 7.4 **March 4,1977, M_{GR} = 7.2**.

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The last seismic map, existing since 1993, has areas where seismic intensities are sub-evaluated (e.g. Dobrogea, Banat etc.), and other areas are over-evaluated. Intensities I=IX on Mercalli scale, at which corresponds a *0.4 g* level of acceleration, and *0.8 g* at rupture/yielding, make Vrancea county to become an unsustainable development area for the future. A special situation is represented by the Banat area where the last recorded earthquakes from Banloc, Voitec requires a change in the seismic intensities of this area. *The fundamental unacceptable point of view is that this last design code is in peak ground accelerations which generates a lot of drawbacks to civil structural designers and to insurance companies which are paying all damages and life loses in function of earthquake intensity.*

The concept of seismic intensity (or *severity of earthquake ground motion*) is at present a common concept for seismologists, structural engineers and other specialists, or even non-specialists. Persons working with this concept are recognizing at the same time its importance and some current shortcomings of it. The most important shortcomings that must be emphasized at this place consist of the imperfect definition of the concept, of the fact that the ***main criteria for intensity estimate are based on vulnerability characteristics*** which, at their turn, are defined conditionally upon the intensity (building thus a source of bias and tautology), of the lack of satisfactory correlation between the macroseimic intensity on one hand and the instrumental criteria on the other hand .

Also: MSK, MMI…MMII scale for → Vrancea

The complexity of the geology of the extra-Carpathian region is obvious. The geology of main cities from this area , like Iasi, Bacau, Buzau and Craiova is complex. The scientific problems regarding the waves propagation on source crystalline fundament-free soil path taking into account the *nonlinear behavior* are the most recent researches conducted the NIEP in this domain. This was important especially for the city of Buzau where sedimentary layers thickness is up to 5.0 km and constitutive laws concerning shear and strain dependence are viscoelastic nonlinear. Almost similar case is the city of Iasi where we were dealing with very different sites *topography,* consisting in hills and plane areas. In *next Figures* are given the *Bucharest City area isobaths* and, respectively, the geological section through Quaternary layers from *Ploiesti to Giurgiu and Danube river* .

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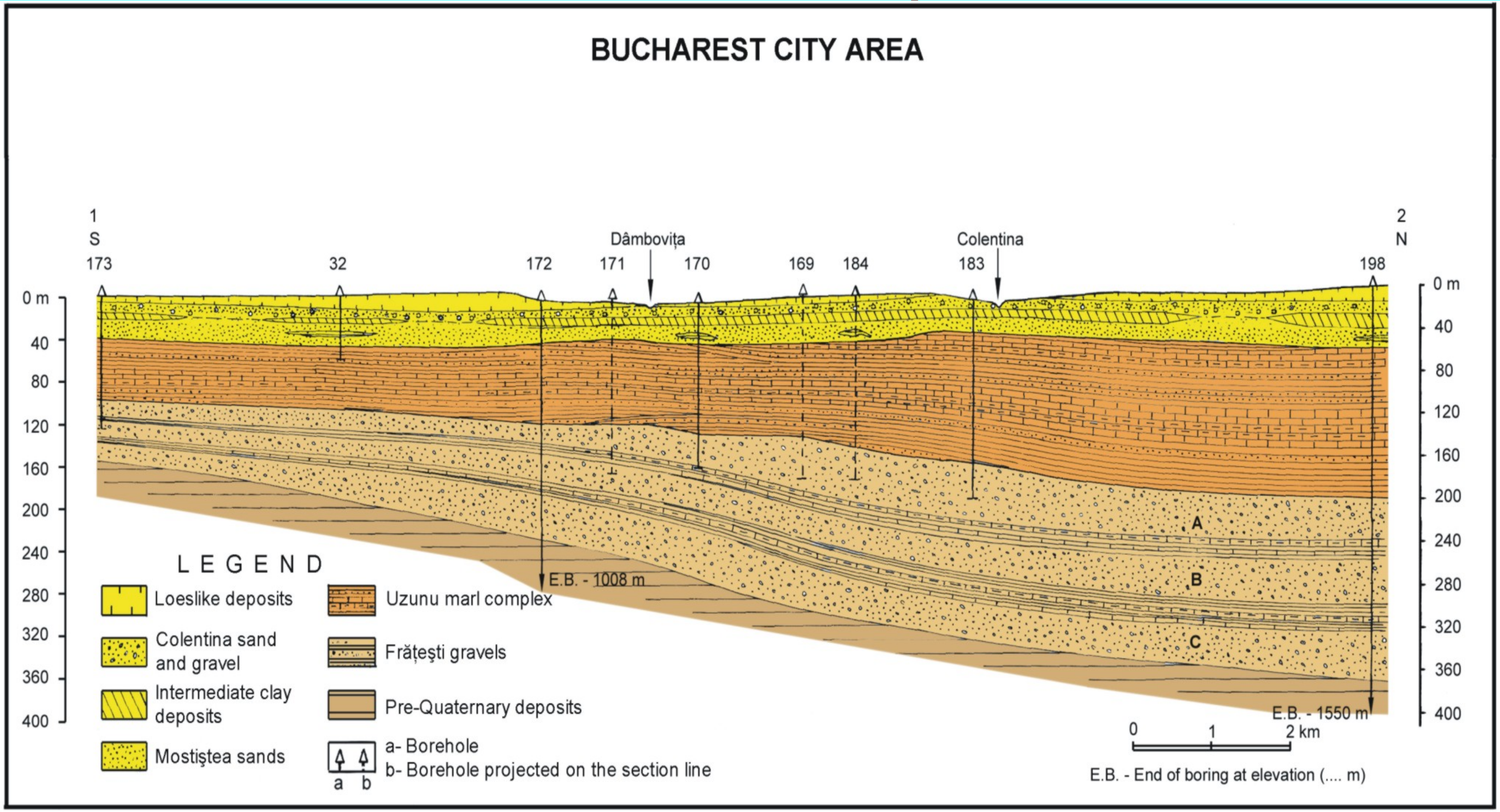

Isobaths are generally oriented from east to west, with a slope of about 8‰ dipping from south to north and layers become thicker and thicker

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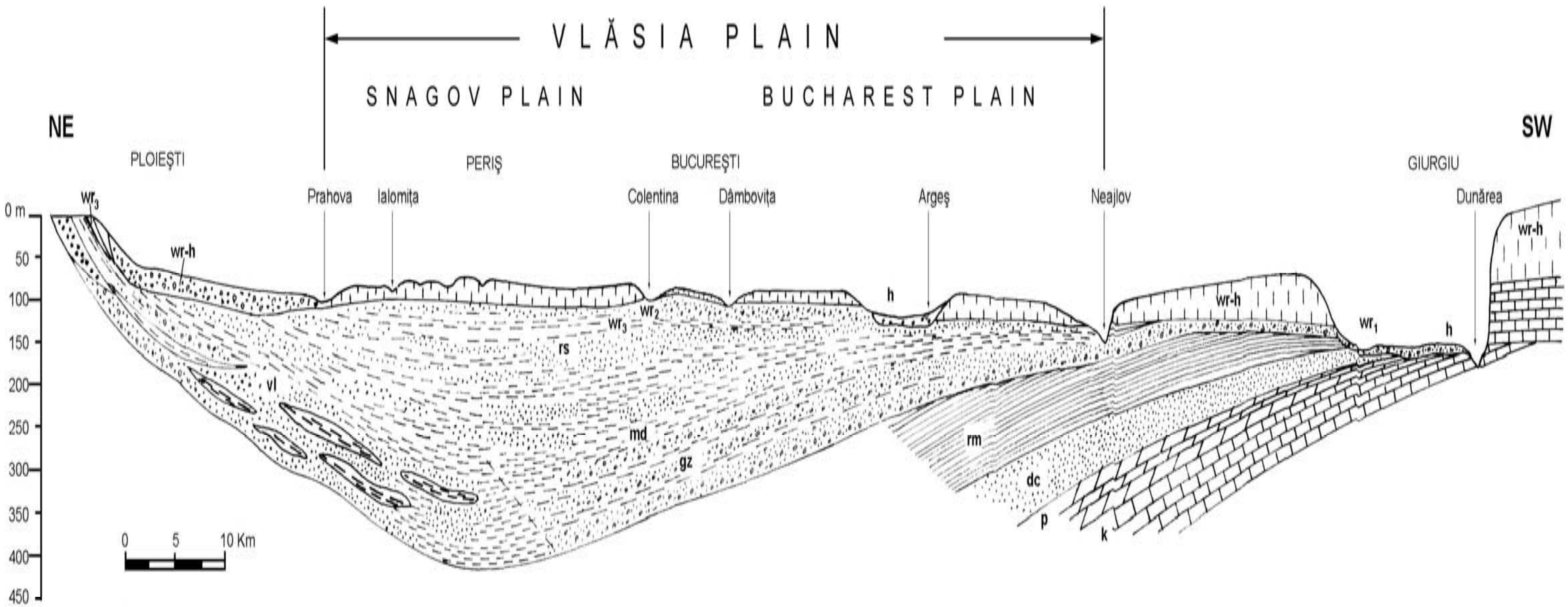
Geological cross-section in the eastern part of the Romanian Plain

(after E. Liteanu and C. Ghenea, 1969, with modifications)



LEGEND

k- Cretaceous; pm- Pontian; dc- Dacian ; rm- Romanian; lower Pleistocene: vl- Villafranchian (Cândesti layers); gz- Günz (Frătesti layers); middle-upper Pleistocene: md- Mindel (marl complex); rs-Riss (Mostistea sands);
wr- Würm (wr_1- low: terace; wr_2- Colentine gravel; wr_3- red clay); wr-h- Würm-Holocene (löesslike deposits); h- Holocene- alluvium deposits.

The “etalon” earthquake concept

Nr	Date	Time	Φ- N	Λ - E	h(km)	M Richter	Mw	Io
1	Nov. 10, 1940	01:39:07	45. 80	26. 70	150	7.4	7.7	IX½
2	March 4, 1977	19:22:15	45. 34	26. 30	109	7.2	7.4	IX
3	Aug. 30, 1986	21:28:37	45. 53	26. 47	135	7.0	7.1	VIII½
4	May 30, 1990	10:40:06	45. 82	26. 90	90	6.7	6.9	VIII

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Nr	Seismic station	a_{max} (cm/s^2)	$a_{max.res.}$ (cm/s^2)	Nr.	Seismic station	a_{max} (cm/s^2)	$a_{max.res.}$ (cm/s^2)
1	Arges (ARR)	24	26	19	Giurgiu (GRG)	60	64
2	Bacau (BAC)	89/**92,7**	110/**119**	20	Iasi (IAS)	100/**181**	108/**216**
3	Baia (BAA)	34	36	21	Istrita (ISR)	109/**127**	111/**14 5**
4	Barlad (BIR)	164	175	22	Lotru (LOT)	14	15
5	Bolintin (BLV)	88	93	23	Muntele Rosu (MLR)	79	80
6	Botosani (BTS)	23	25	24	Onesti (ONS)	158	168
7	Braila (BRL)	110	117	25	Otopeni (OTP)	215	228
8	Branesti (BRN)	92	98	26	Piatra Neamt (PTT)	11	12
9	Bucuresti (BUC)	71-161	75-171	27	Ploiesti (PLS)	218	232
10	Campulung(CMP)	77	82	28	RamnicuSarat(RMS)	153	163
11	Cernavoda (CVD)	63	64	29	Roznov (RZN)	19	21
12	Carcaliu (CFR)	90	96	30	Surduc (SDR)	70	75
13	Constanta (CNT)	34	36	31	Tulcea (TLC)	68	72
14	Craiova (CVR)	81	86	32	Tr.Magurele (TRM)	60	64
15	Deva (DEV)	8	9	33	Vaslui (VSL)	202	215
16	Dochia (DCH)	51	51	34	Valeni Munte (VLM)	193	205
17	Focsani (FOC)	297	312	35	Vrancioaia (VRI)	141/**162**	144/**188**
18	Galati (GLT)	120	128	**PGA recorded on August 30,1986 earthquake Mw=7.1**			

The earthquake on August 30,1986 is used by us as “***control earthquake***” in all studies as it fulfils the following states:

(i)-it was strong (***Mw =7.1***) ;

(ii)-it was recorded in a lot of seismic station on Romanian territory ;

(iii)-***the fall plan solutions are very closed (almost identically)*** to other Vrancea stronger earthquakes (Nov. 10,1940; ***Mw =7.7*** ; March 4,1977; ***Mw =7.4***; May 30,1990; ***Mw=6.9***) and with majority of earthquakes with moderate magnitudes (6.7 < Mw <7.1) ;

(iv)-the depth of hypocenter (h**≈135** km) is very close to medium value of all strong Vrancea earthquakes.

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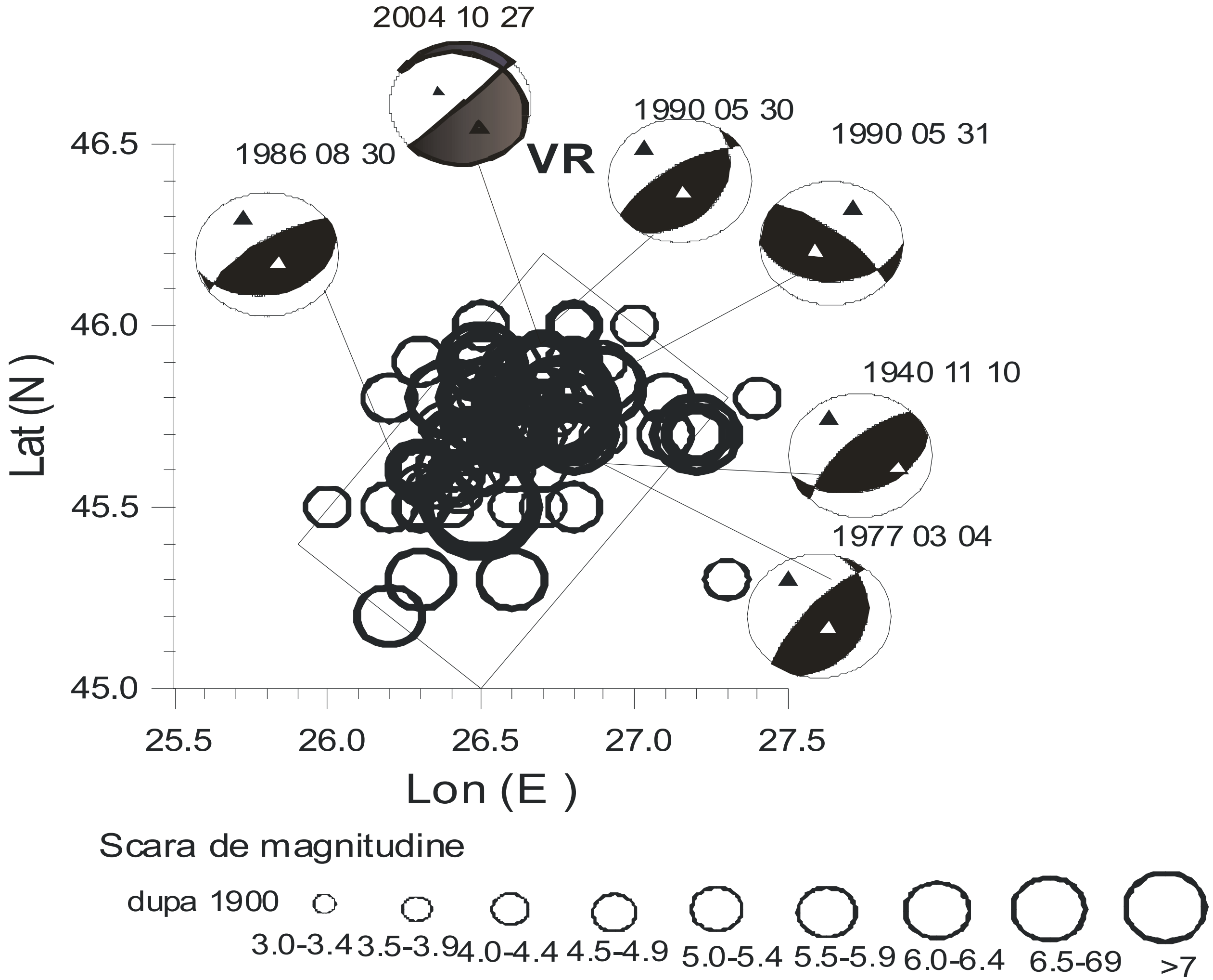
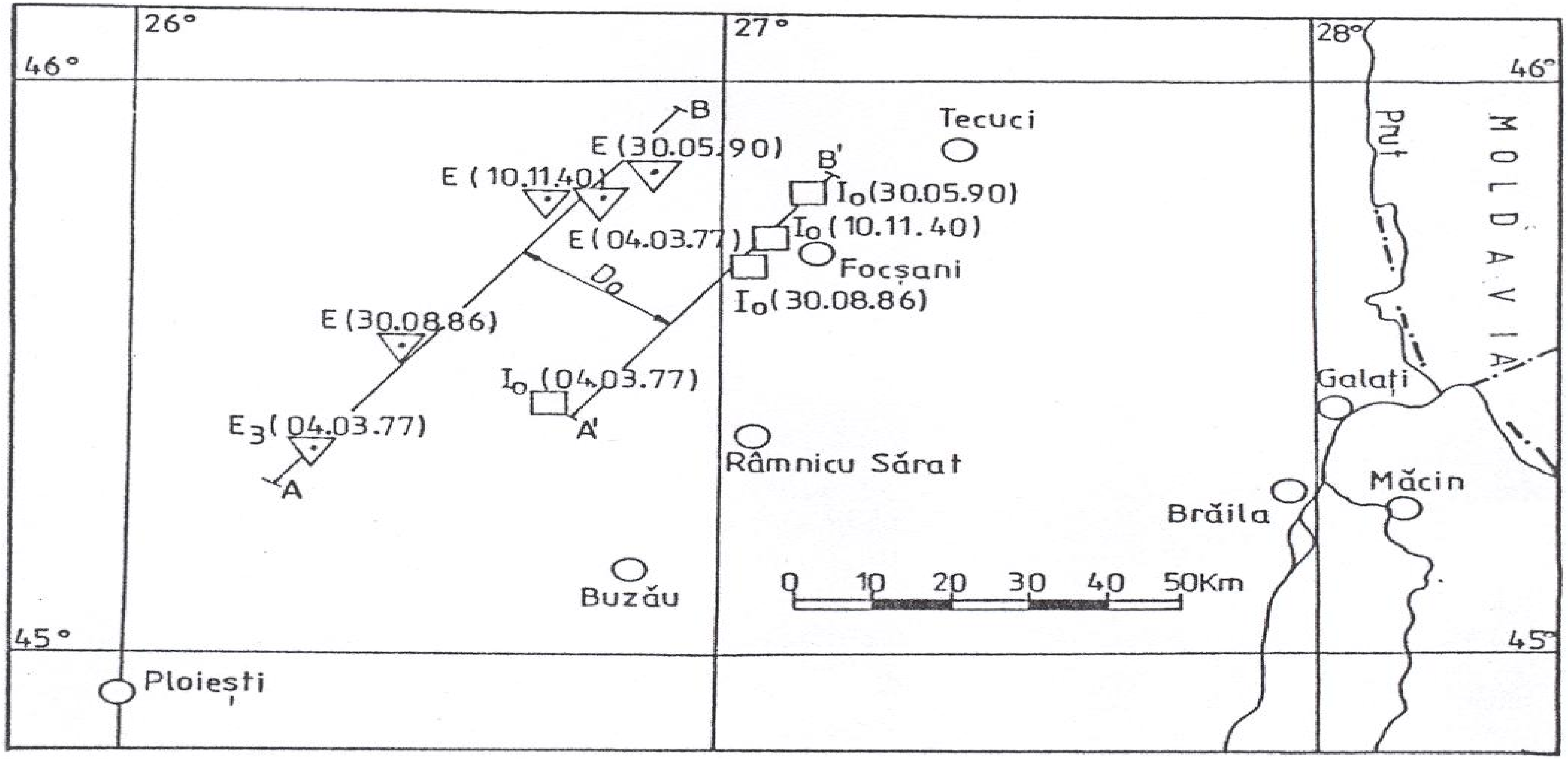


The fall plan solutions of Vrancea strong earthquakes (Nov. 10,1940-Mw =7.7; March 4,1977-Mw =7.4 ;August 30,1986-Mw =7.1 and May 30,1990-Mw =6.9)



Epicenters E (line AB) and Io points (line A'B') at distance Do =23 km, corresponding to the four strong and major earthquakes (Mw ≥ 6.9) occurred in the last 70 years

Using the peak ground accelerations (PGA), recorded during strong Vrancea earthquakes on March 4,1977(Mw =7.4), August 30,1986(Mw =7.1), May 30,1990(Mw =6.9) and May 31, 1990(Mw =6.4) and the corresponding macroseimic intensities, there are the following relations[6]:

$\log a_{max}$ (cm/s2) = $\mathbf{0.2712}\ I + \mathbf{0.1814}$

$\log a_{max..res}$ (cm/s2) = $\mathbf{0.2714}\ I + \mathbf{0.2085}$ for $V \leq I \leq IX$

From *Table* , the *isoseismal map* of the ”*etalon*” (reference) earthquake is given in *Figure* and by using the attenuation curves for 30 azimuths (Az).

Site local amplifications were evaluated by using *Very Hard Rock*(VHR), *Joint Source Site Determination* (JSSD) methods or by using down-hole seismic measurements performed in Bucharest(*Table 3*), Iasi, Timisoara etc.

Also, deterministic evaluations of local effects in metropolitan area Bucharest were made by using hybrid and analitical methods.

The amplifications of PGA during of Vrancea earthquake on Oct. 27, 2004 (Mw =6.00) in other 6 boreholes made in Bucharest City with deep sensors at -153m,-78m,-70m,-68m,-66m,- 52m and shallow sensors, respectively, at -24m,-28m,-30m,-28m,-28m and -28 m (*Table*) are more representative . All of them are real data. There is a large scattering of the amplifications between PGA recorded by deep ,shallow and surface/free field K2 sensors. The ratio is between 2.115 and 5.708 (average *3.912*).

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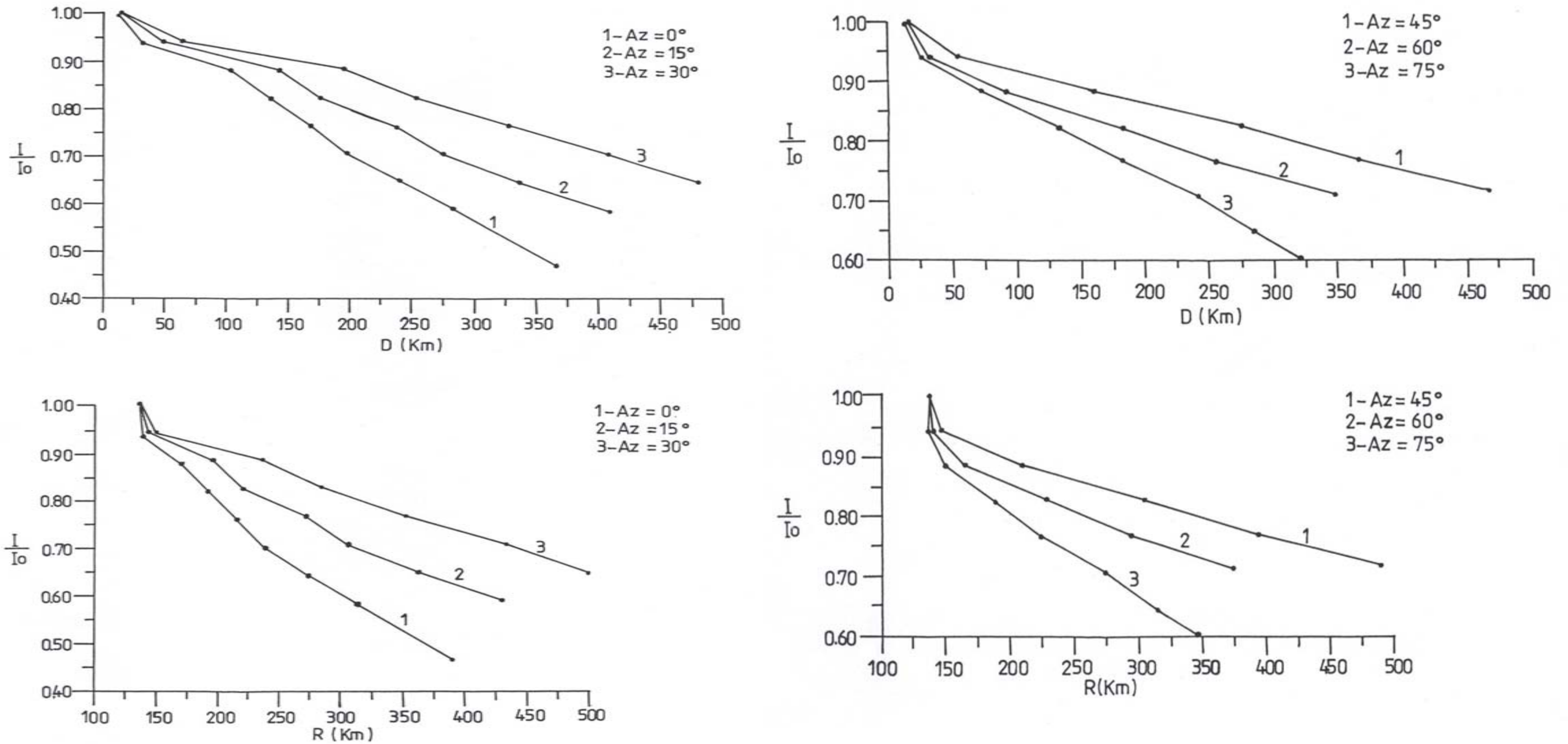

Attenuation curves(***30***) corresponding for the “***etalon***”earthquake for **Az=0, 15, 30, 45,60,75…** x-axis is epicenter distance D, respectively, hypocenter distance, R and on y-axis is de ration between macroseismic intensity ***I*** in a point on the Earth's surface and the maximum macroseismic intensity, Io (named “Io point”) on line A'B'.

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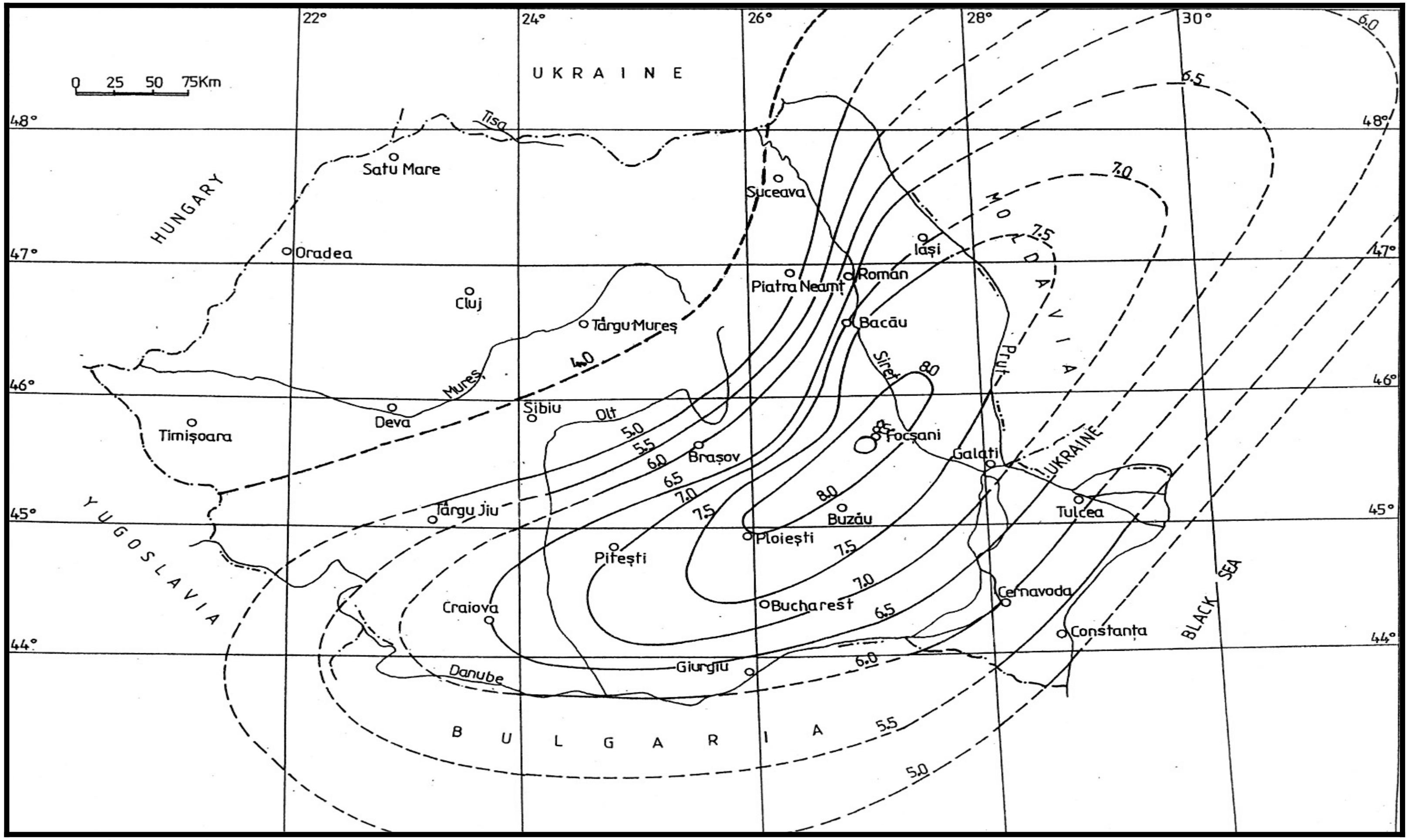

Isoseismal map of the „etalon “earthquake

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In order to prepare the results obtained for the „etalon (reference) earthquake" to other intermediary-depth Vrancea earthquakes, we have to take into consideration the depth factor of the focus, which is different from one earthquake to another. Firstly, we tried to use a relation containing a function f(h):

$$\mathbf{Log\ I - Log\ Io = a\text{-}b\ Log\ [R/f(h)]}$$

$$\mathbf{Log\ (I/Io) = a' - b Log\ R}$$

$$\mathbf{a' = a + b\ Log\ f(h)}$$

and using the data attenuation curves ,we computed by using the least square method the coefficients a' and b from relation and the coefficient a=a' –b Log f(h) for different azimuths Az. The family of attenuation curves for the "*etalon*" earthquake ,in other form, has the following equation:

$$Log(Ie/Ioe)(Az) = a(Az)\text{-}b(Az\ Log\ [Re\ /f(he\ )]$$

$$Log(Ie/Ioe)(Az) = a'(Az)\text{-}b(Az)\ Log\ Re$$

where: Ioe is the maximum intensity of the "etalon" earthquake; Ie is the intensity of the "*etalon*" earthquake at a hypocenter distance Re (along de direction defined by azimuth AZ): a' (Az) = a(Az) +b (Az) Log f(he) ; a & b are constant coefficients for a given Az; h=135 km is focal depth of the "*etalon*" earthquake.

To obtain the *"banana" shape* of the attenuation curves of the macroseimic intensity I along the direction defined by azimuth Az ,in the case of Vrancea deep earth-quakes at a depth 80 ≤ x < 160 km, has the following equation :

$$\text{Log } I_{x,Az} = \text{Log } I_{ox} + \text{Log } (I_e / I_{oe})_{Az} + b(AZ) \text{ Log}\{[R_e / f(h_e)] / [R_x / f(x)]\}_{Az} + [c \text{Log } \delta]_{Az}$$

where : Iox is the maximum intensity of an earthquake at a depth h= x; δ is the directivity factor of the rupture propaga-tion in the focus ; „c" is the way how the directivity factor may influence the directivity of the seismic source;

$$R_e = (D^2 + h_e^2)^{1/2} \; ; \; R_x = (D^2 + x^2)^{1/2} \; ;$$

D is distance between the observation point and the point of maximum macroseismic intensity.

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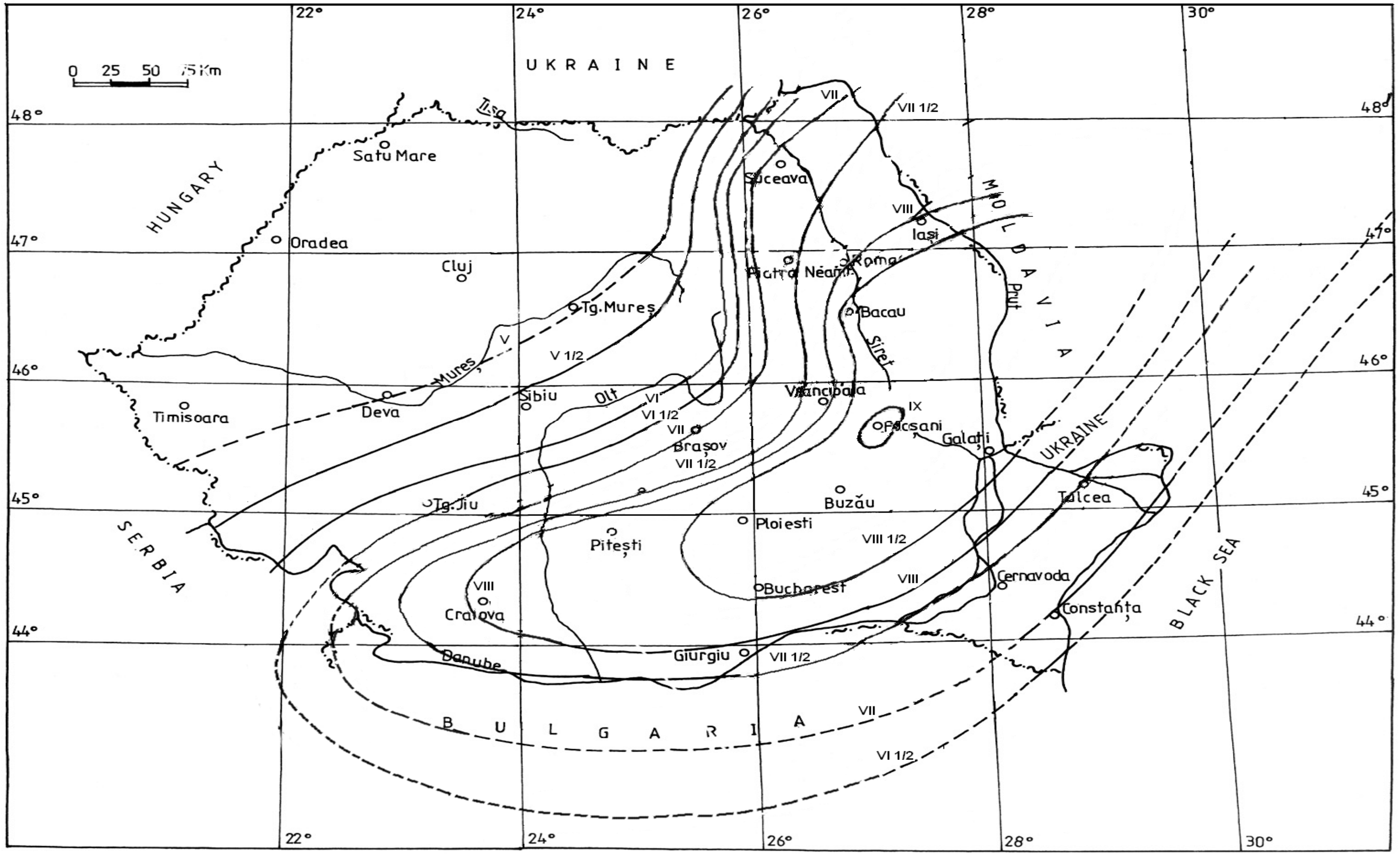

The isoseismal map of the *maximum credible Vrancea earthquake* or *maximum probable Vrancea earthquake* (*Mw = 7.7*)

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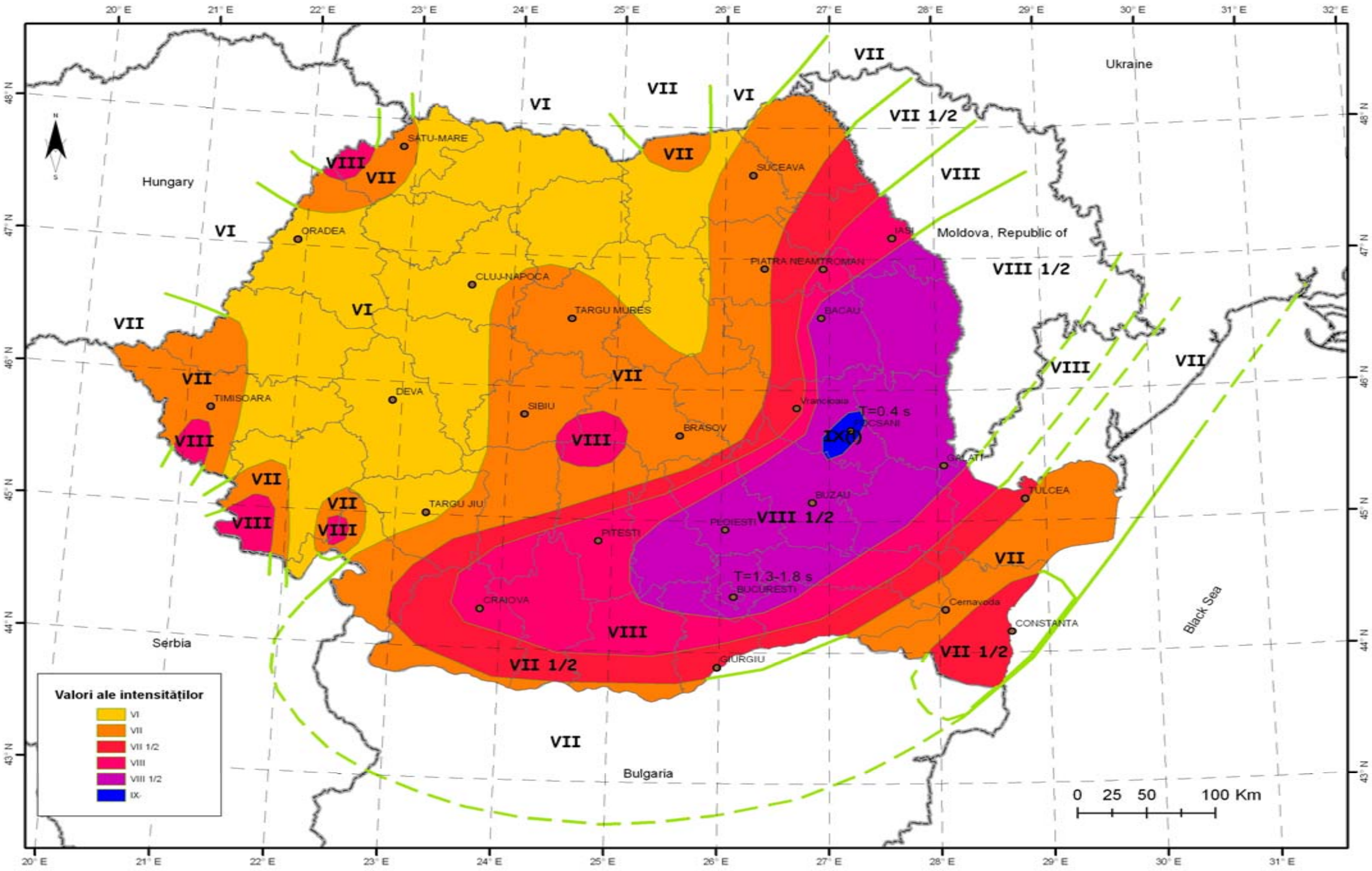

The isoseismal map of the *maximum credible Vrancea earthquake* or *maximum probable Vrancea earthquake* and *crustal ones* (*Mw = 7.7*)

At local level it is asked to any city to make microzoning seismic maps (***local hazard maps***) to put into evidence the differences which occurs during a strong earthquake.

The sustainable design of structures asks a local hazard map (microzonation map). If we refer to the specific objectives of this field regarding the Earth physics research, the natural disasters and the environment, the evaluation, prognosis and monitoring methods of the earth phenomena, in Romania there is a

Gov. Law no.372/2004 – ***National Program of the Seismic Risk Management***

where is specified (pg.5) the objective number 10, named "***Macrozoning of the Romanian territory and seismic hazard zoning in densely populated urban cities.***

Bucharest,***Timisoara***,***Arad***,***Sibiu***,***Craiova***,***Ploiesti***,***Buzau***,***Iasi Bacau***, ***Galati*** & ***Tulcea*** Cities, the analyses were carried out by using the two alternative approaches for the seismic hazard assessment:

(i)-the probabilistic approach and,

(ii)-the (neo) deterministic one, linear and nonlinear methods by developing the ***nonlinear seismology concept***

In any site, first steps were to make:

(i)-identification of local and Vrancea events that can occur and have adverse consequences;

(ii)-estimation of the likelihood of those events occurring;

(iii)-estimation of the potential consequences.

In the (*neo*)deterministic analysis there are determined *the maximum credible Vrancea earthquake*, the etalon or controlling earthquake effects at the site. At high distances from the source (far field), wavelength like, and the main contribution at the solution is given by Rayleigh and Love modes. An original method, called EERA, created by NIEP and *University of Trieste,Department of Earth Sciences*, , especially for Vrancea particular strong earthquakes, consists in realistic and quick evaluation of seismic effects in the selected site.

The seismic signal coming from the bedrock was computed by using modal summation method until it reaches "soft" layers; after that, a 1D analysis was carried out on vertical propagation through local geological structure by using various modifications on software.

These analyses were made by using a linear viscoelastic model or by using a nonlinear viscoelastic one (the equivalent solid approach), case in which are necessary the parameters: dynamic torsion functions, G=G(γ) and damping function, D=D(γ) for each of the rock/soil sample, γ=shear strain determined in Hardin and Drnevich resonant columns at NIEP. Even more, deterministic evaluation used on the path focus-bedrock-free surface of the site, after a "*calibration*" for a recorded earthquake in each site where it was possible. This calibration helped us to "*building and correction of structures*" on the path focus-bedrock-free surface of the site, even if nonlinear effects for maximum possible earthquake were reevaluated by taking into account the nonlinear relations between dynamic amplification factors and magnitude , determined by NIEP.

Aspects on Fuzzy Set Theory concept which occurs on interpretation of seismic hazard maps in probabilistic analysis

A problem that arises in such representations is that the *uncertainties* wherewith are evaluated quantities which are subjected to research, inherent uncertainties to physical nature of them.

To approach these issues *propagation phase indeterminacy* of the "input" to *the final outcome* had become possible in last time on account of „*Fuzzy Set Theory*" extension to this field of research which have been relatively few attempts so far.

The fundamental concept of the „"Fuzzy Set Theory is that it replaces the relationship of affiliation from classical theory of sets by a „*affiliation function*", and the consequences of such fundamental changes proved to be extraordinary not only on action plan of the mathematical operators but also in mathematical logic performed

The models which have been developed to assess the likelihood that some elements of soil particle movement beyond the level considered critical (or dangerous) for a given area requires processing of informations such as: (i)-depths of focus ;(ii)-geometry and focal mechanism; (iii)-the direction of active faults/fault style ;(iv)- earthquake magnitudes in the area of interest; (v)-relationships between magnitude and rupture length ;(vi)-frequency-magnitude distribution of earthquakes ; (vii)-the average return periods etc.

All these information contributes to the assessment of probability P (Y> y) for a given location (A) and in a given period of time (T), the value of parameter Y (which may be: *macroseismic intensity*, *acceleration*, *velocity* , *ground displacement etc.)* to exceed a given value „y” as a result of an earth-quake no matter where they are its source. In terms of classical theory of sets, to determine whether a point x is on the fault lies in making a statement P (x) on the relation of affiliation between point „x” and the set of all fault points:

$$F = \{ x / P(x) \}$$

where: **P(x)** is the proposition: „ *point x belongs to the fault plane*”.

This sentence can take only two values: A (true) or F (false).

In various fields of Geophysics are studied *geographical distributions* of values of certain geophysical quantities (as is the case of *seismic hazard* values) and in practice it is a representation of these distributions in the form of ***„Maps with isolines”***.

According to the classical definition currently applied in all scientific papers, ***„****The izoline* Γ***v for parameter (****for example : intensity,accelerations etc****) M ”*** *is the locus of points* ***Pi (*** φ***i*** ;λ***i)*** *on a certain area* ***(*** Σ ***)*** *for which the respective parameter* ***(M*** *) has the same value* ***(v)****:*

$$\Gamma \mathbf{v} = \{ \mathbf{Pi} (\varphi \mathbf{i} ; \lambda \mathbf{i}) \mid \mathbf{Pi} (\varphi \mathbf{i} ; \lambda \mathbf{i}) \in \Sigma \ \textbf{şi} \ \mathbf{M} (\varphi \mathbf{i} ; \lambda \mathbf{i}) = \mathbf{v} = \textbf{constant} \} \quad \text{(i)}$$

where: φ**i** and λ**i** are geographical coordinates of point **Pi** (i = 1, 2, ..., n), all the n points belongs to surface Σ (whose dimensions can be as high to those where the local maps are built , at continental and even global scales)

In all such representations, indifferent of studied parameter from geophysics (acceleration, intensity ,displacement etc.), appears as a *common definition* that the relationship itself (i) for the "***izoline"*** concept has to be interpreted as such fuzzy concepts, that is, as ***„Fuzzy Set Theory”***.

Let's consider a general case in which the values of the studied parameter have measurable errors **ε.** This means that the measured value (**V**) can have any value in the range (k - ε , k + ε) where **k** is the average size measured (in the meaning of the *theory of errors of measurement):*

$$\mathbf{V} \in (\mathbf{k} - \varepsilon \; ; \; \mathbf{k} + \varepsilon) \qquad \text{(ii)}$$

It follows that the set of points which can be attributed „k" measured value to that parameter consists not in a curve Γ**v** given by definition (i) ,but a ***"band"*** centered on Γ**v** curve, and bounded by the envelope curves (***Figure***) corresponding to the interval edges (ii). This confirms the ***nature of fuzzy*** (that is, fuzzy, vague…) of sets of points and their associated values meaning that the affiliation a point to isoline has not to be considered as a relation of affiliation in classical sense ***but as a series of transitional situations, degrees of affiliations with values between 0 and 1.***

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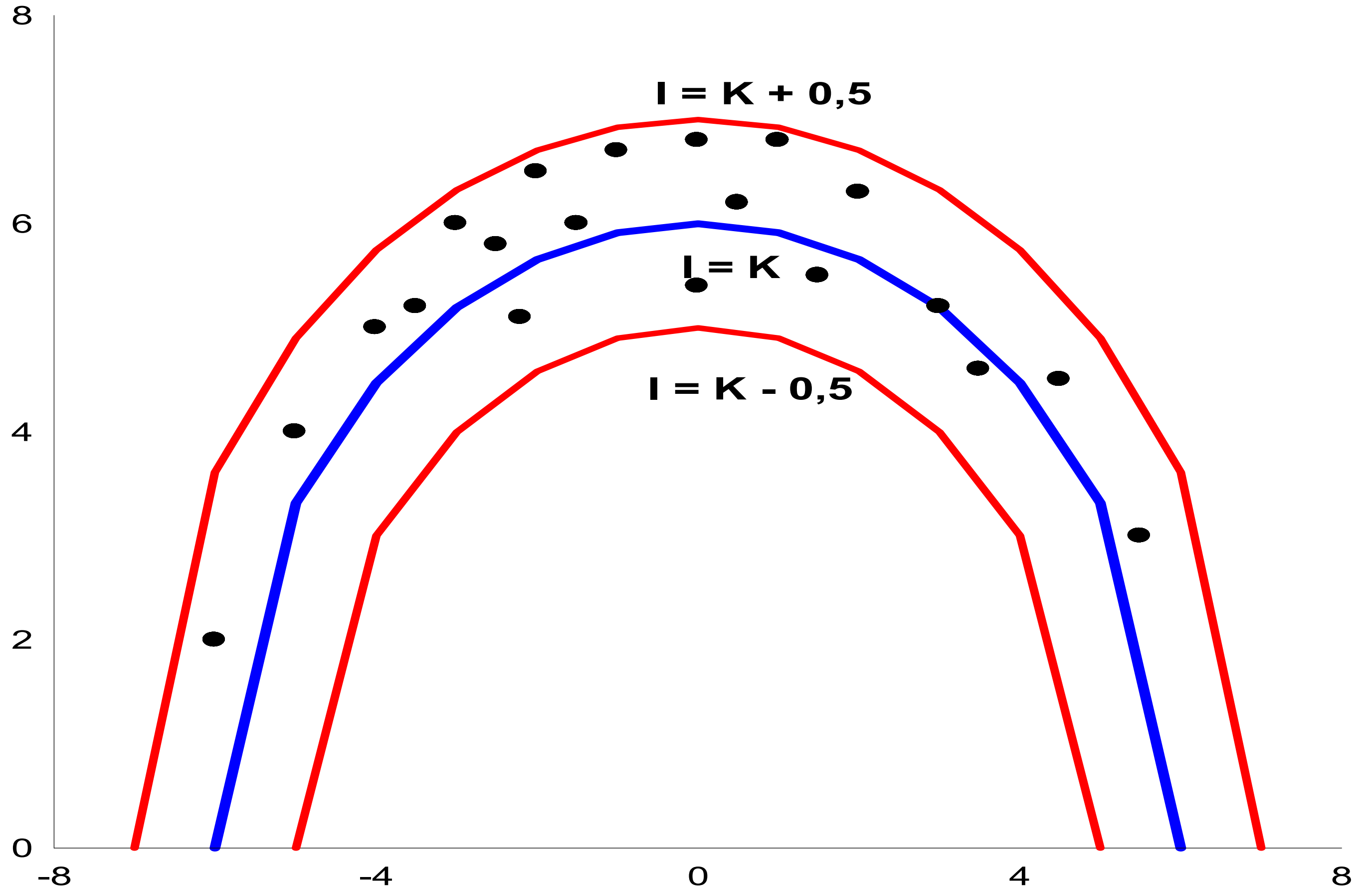

Fuzzy nature of maps with isolines

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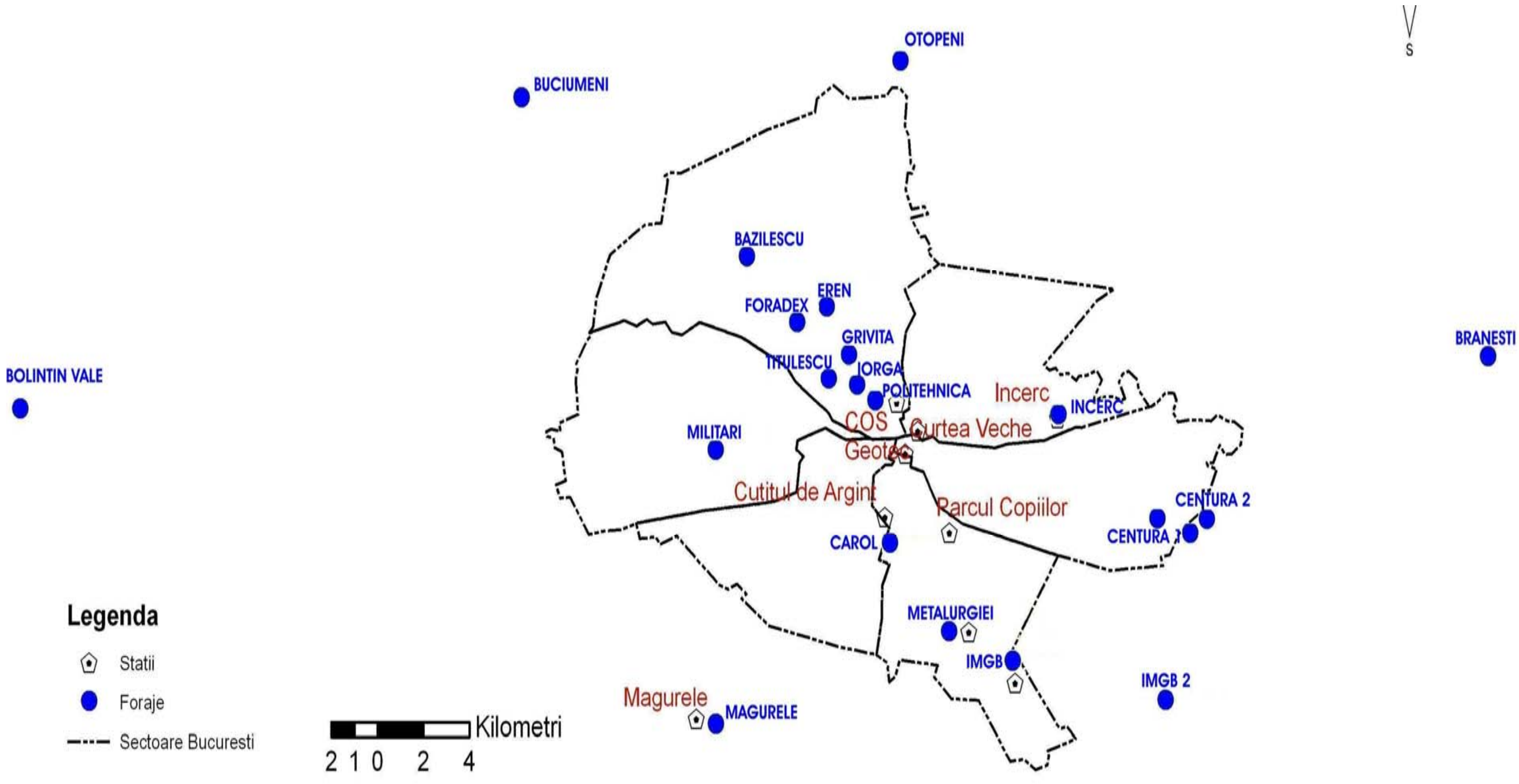
N_0	Station		Deep sensor		Shallow sensor		Surface sensor/free field		
			Depth	PGA	Depth	PGA	PGA	The amplification	
				1		2	3	3:1	3:2
1	**UTCB**	NS	**-78 m**	0.0165 g	**-28 m**	0.0285 g	0.0349 g	**2.115**	**1.225**
		EW		0.0231 g		0.0146 g	0.0584 g	**2.528**	**4.000**
		V		0.0098 g		0.0111 g	0.0344 g	**3.510**	**3.099**
2	**UTCB**	NS	**-66 m**	0.0156 g	**-28 m**	0.0216 g	0.0416 g	**2.667**	**1.926**
		EW		0.0235 g		0.0168 g	0.0409 g	**1.740**	**2.435**
		V		0.0070 g		0.0115 g	0.0248 g	**3.543**	**2.157**
3	**NCSRR/ INCERC**	NS	**-153 m**	0.0113 g	**-24 m**	0.0139 g	0.0297 g	**2.628**	**2.137**
		EW		0.0114 g		0.0125 g	0.0296 g	**2.596**	**2.365**
		V		0.0067 g		0.0083 g	0.0249 g	**3.716**	**3.000**
4	**Civil Prot. Headquarter**	NS	**-68 m**	0.0127 g	**-28 m**	0.0203 g	0.0290 g	**2.283**	**2.283**
		EW		0.0194 g		0.0131 g	0.0492 g	**2.536**	**3.756**
		V		0.0088 g		0.0112 g	0.0340 g	**3.864**	**3.036**
5	**City Hall**	NS	**-52 m**	**0.0132 g**	**-28 m**	0.0166 g	0.0298 g	**2.258**	**1.795**
		EW		**0.0222 g**		**0.0377 g**	**0.0790 g**	**3.559**	**2.095**
		V		0.0096 g		0.0118 g	0.0331 g	**3.448**	**2.805**
6	**Municipal Hospital**	NS	**-70 m**	0.0126 g	**-30 m**	0.0116 g	0.0546 g	**2.459**	**4.707**
		EW		0.0181 g		0.0185 g	0.0445 g	**2.459**	**2.405**
		V		0.0089 g		0.0082 g	0.0508 g	**5.708**	**6.195**

Site local amplifications were evaluated by using *Very Hard Rock*(VHR), *Joint Source Site Determination* (JSSD) methods or by using down-hole seismic measurements performed in Bucharest(*Table 3*), Iasi, Timisoara etc. Also, deterministic estimation of local effects in metropolitan area Bucharest were made by using hybrid and analitical methods.

The amplifications of PGA during of Vrancea earthquake on Oct. 27, 2004 (Mw =6.00) in other 6 boreholes made in Bucharest City with deep sensors at -153m,-78m,-70m,-68m,-66m,- 52m and shallow sensors, respectively, at -24m,-28m,-30m,-28m,-28m and -28 m (*Table*) are more representative . All of them are real data. There is a large scattering of the amplifications between PGA recorded by deep ,shallow and surface/free field K2 sensors. The ratio is between 2.115 and 5.708 (average *3.912*).

Interval velocities of the VP and VS waves for the lithological complexes, determined through seismic profile, *up-hole* and *down-hole* seismic measurements

No. Layer	Lithological Complex	Soil type	Thickness (m)	Interval velocity	
				V_P (m/s)	V_S (m/s)
1	Backfill, topsoil	-	0-8	200-400	90-180
2	Loesslike deposits	Silty clay	3-20	485-750	210-320
3	Colentina gravel	Gravel and sand	4-18	1200-1695	300-350
4	Intermediate clay	Clays	0-20	1650-2050	320-450
5	Mostistea sand	Fine sands	8-20	1200-1900	350-400
6	Marl Complex M	Marl and fine sands	60-140	1660-2000	375-460
7	Fratesti gravel	Gravel and sand	50-200	1830-2300	600-700



Boreholes and seismic stations on Bucharest metropolitan area

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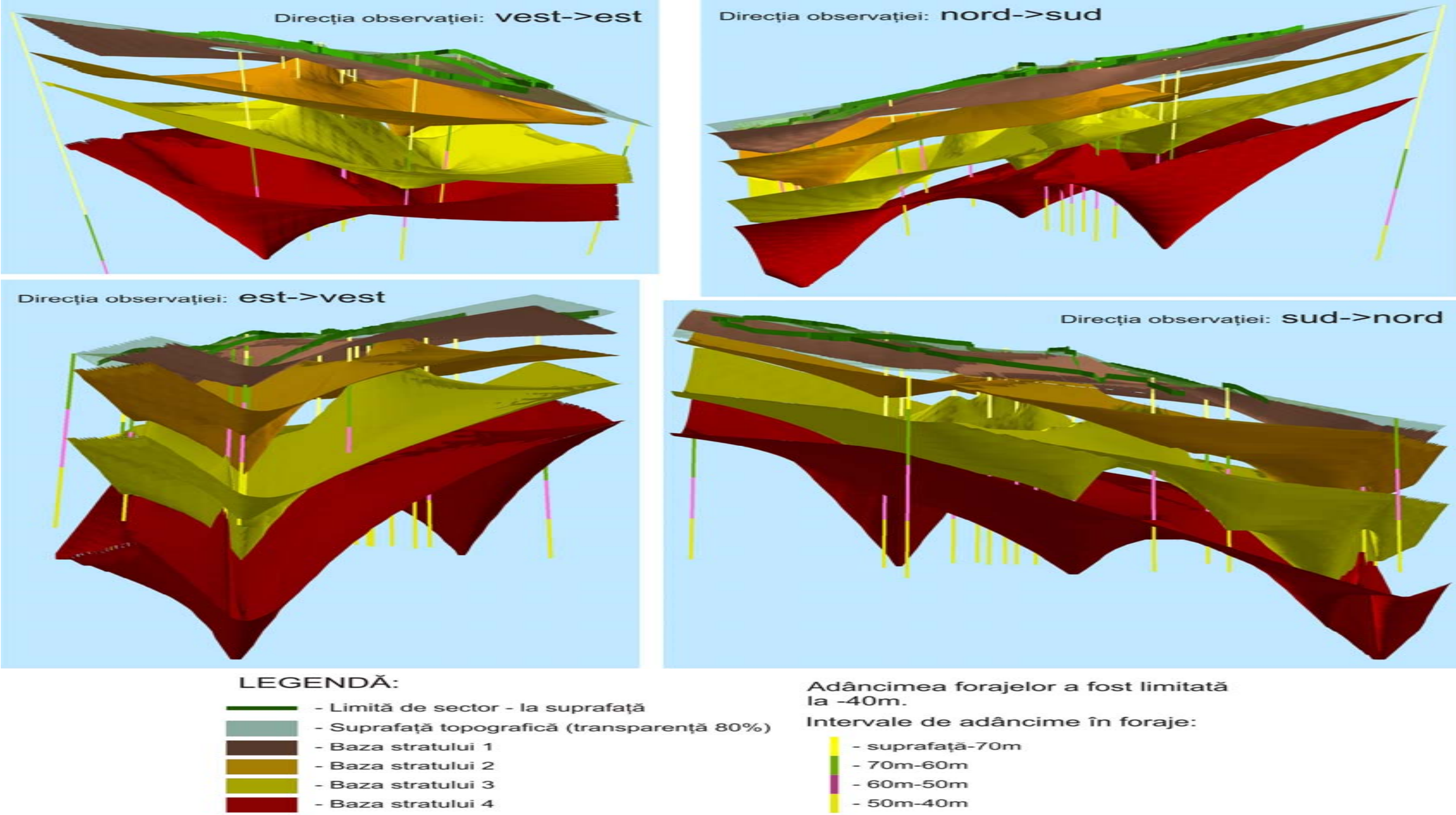

Bucharest. Local geological structure until Marl Complex- 4 layers-GIS modeling

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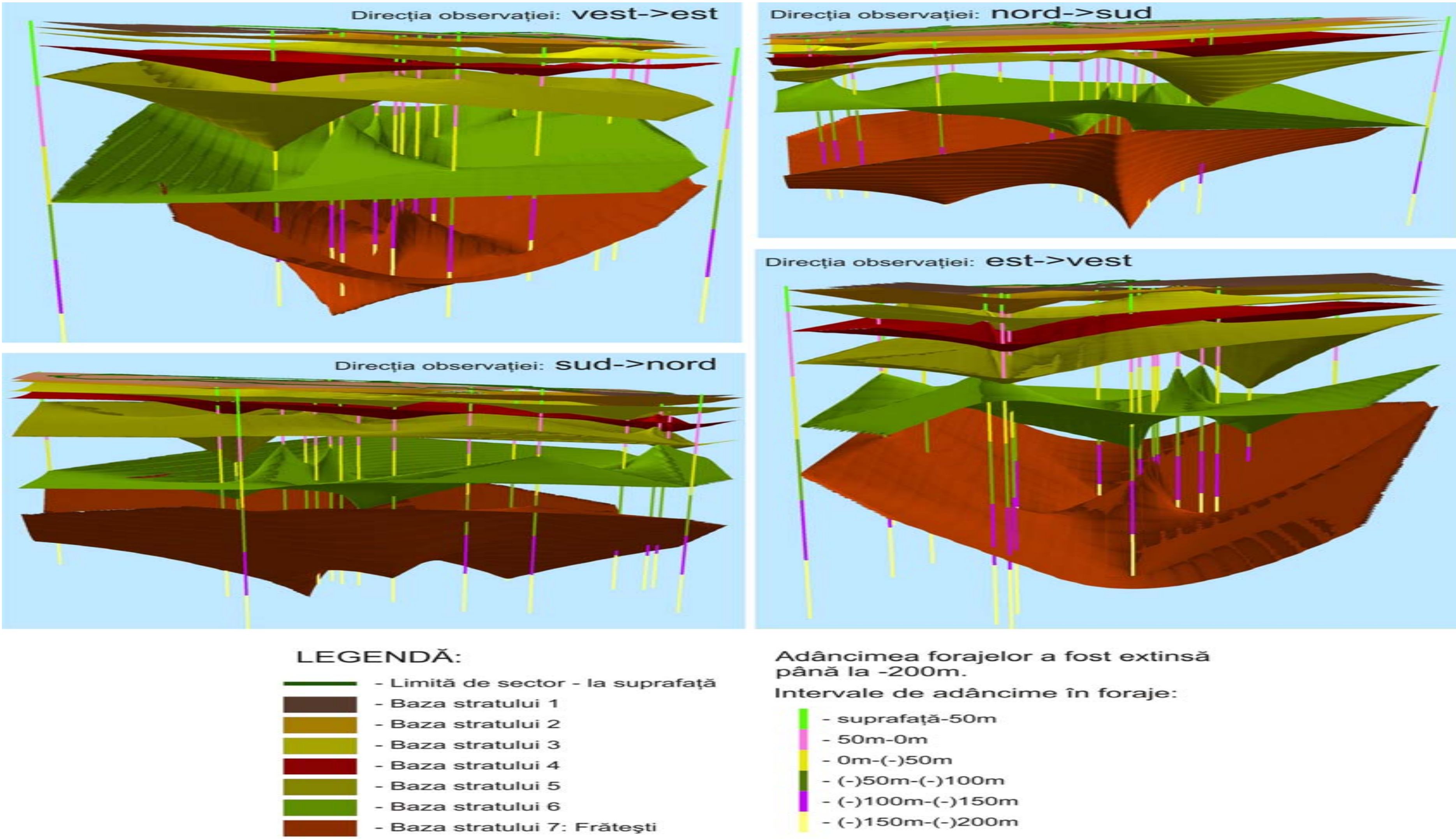

Bucharest.Local geological structure until Fratesti gravel -7 layers -GIS modellig

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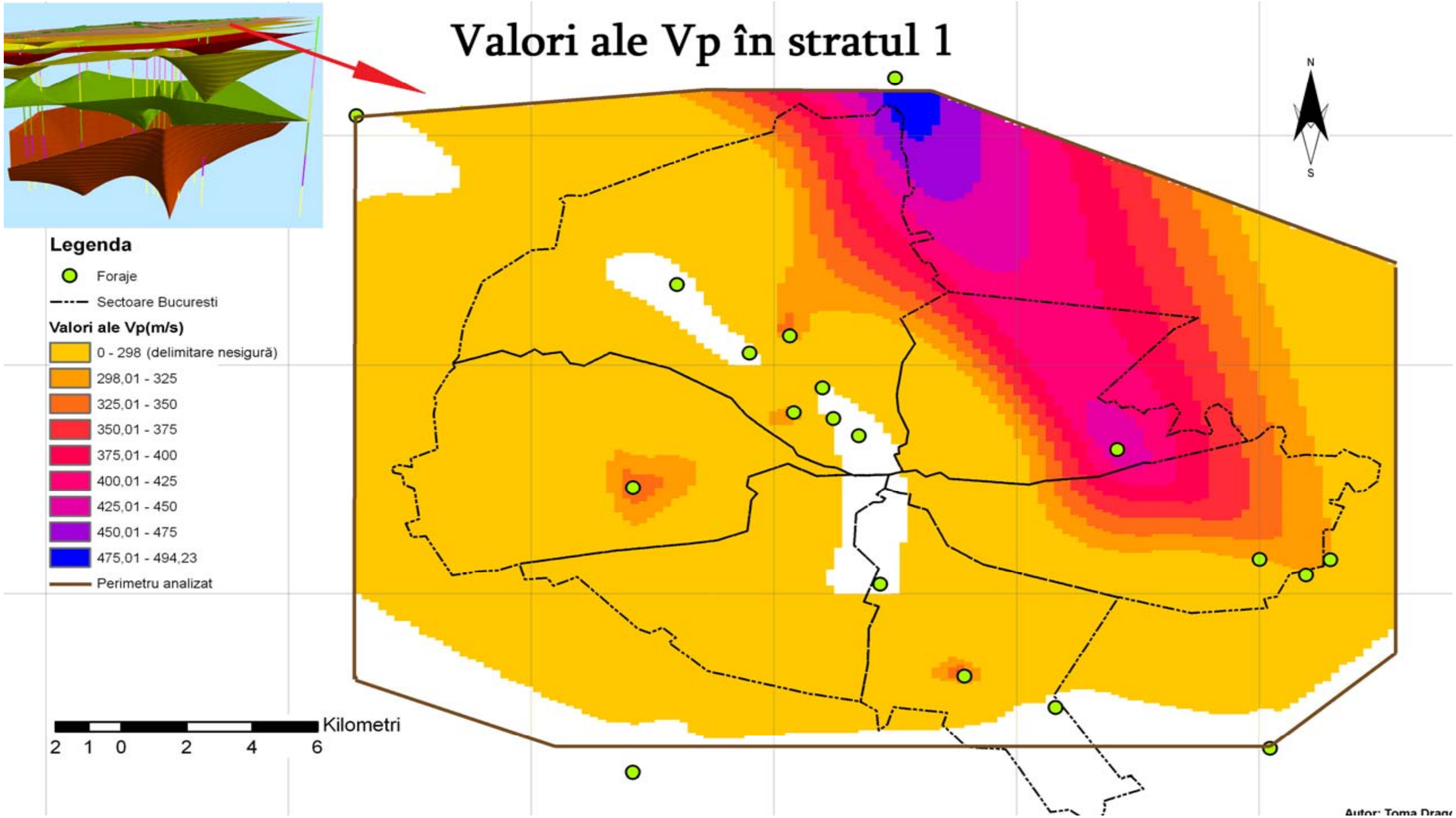

Values of seismic waves V_P in layer 1 of superficially geological structure of Bucharest metropolitan area -GIS modeling

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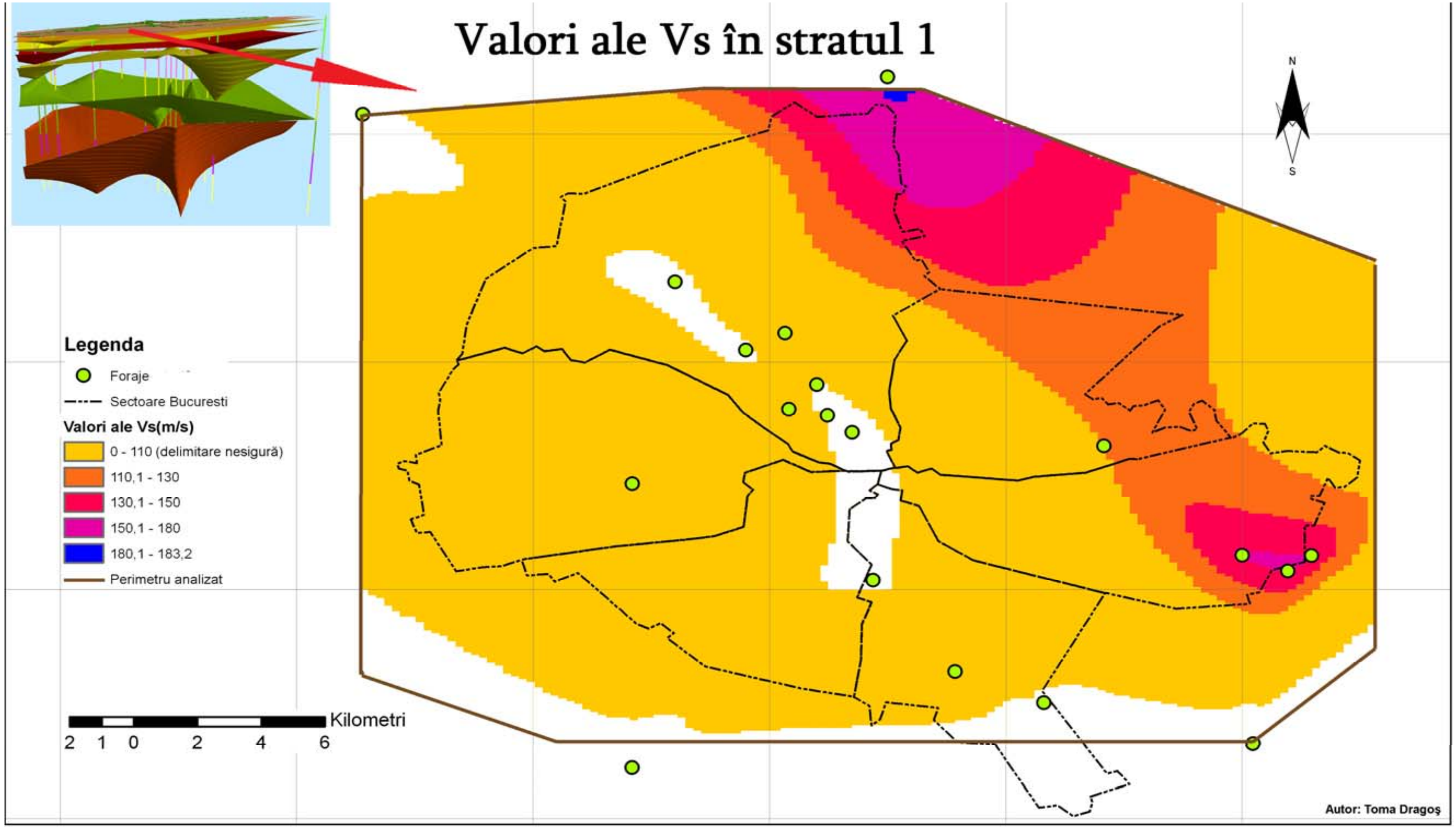

Values of seismic waves V_S in layer 1 of superficially geological structure of Bucharest metropolitan area-GIS modeling

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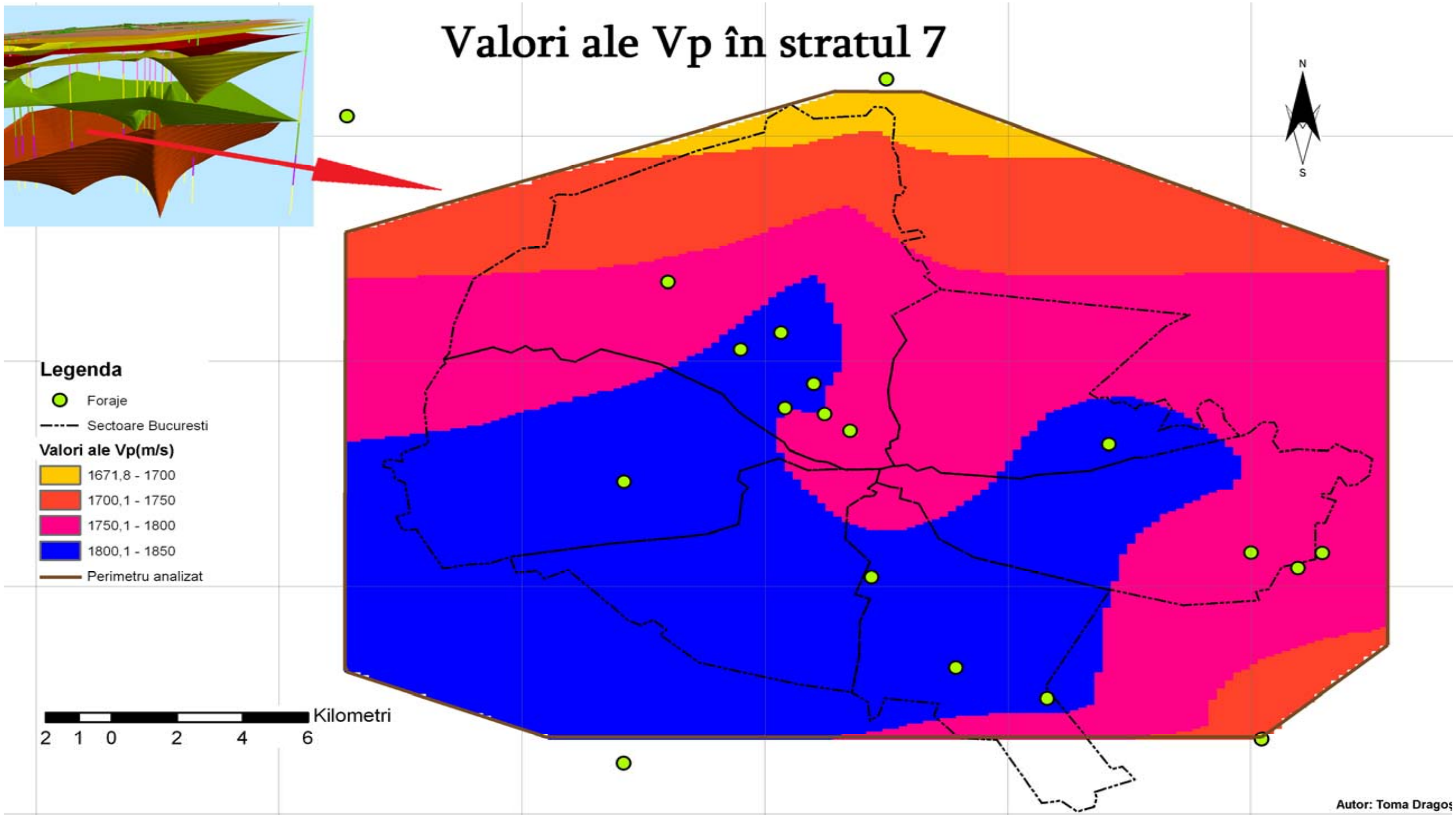

Values of seismic waves V_P in layer 7 of superficially geological structure of Bucharest metropolitan area-GIS modeling

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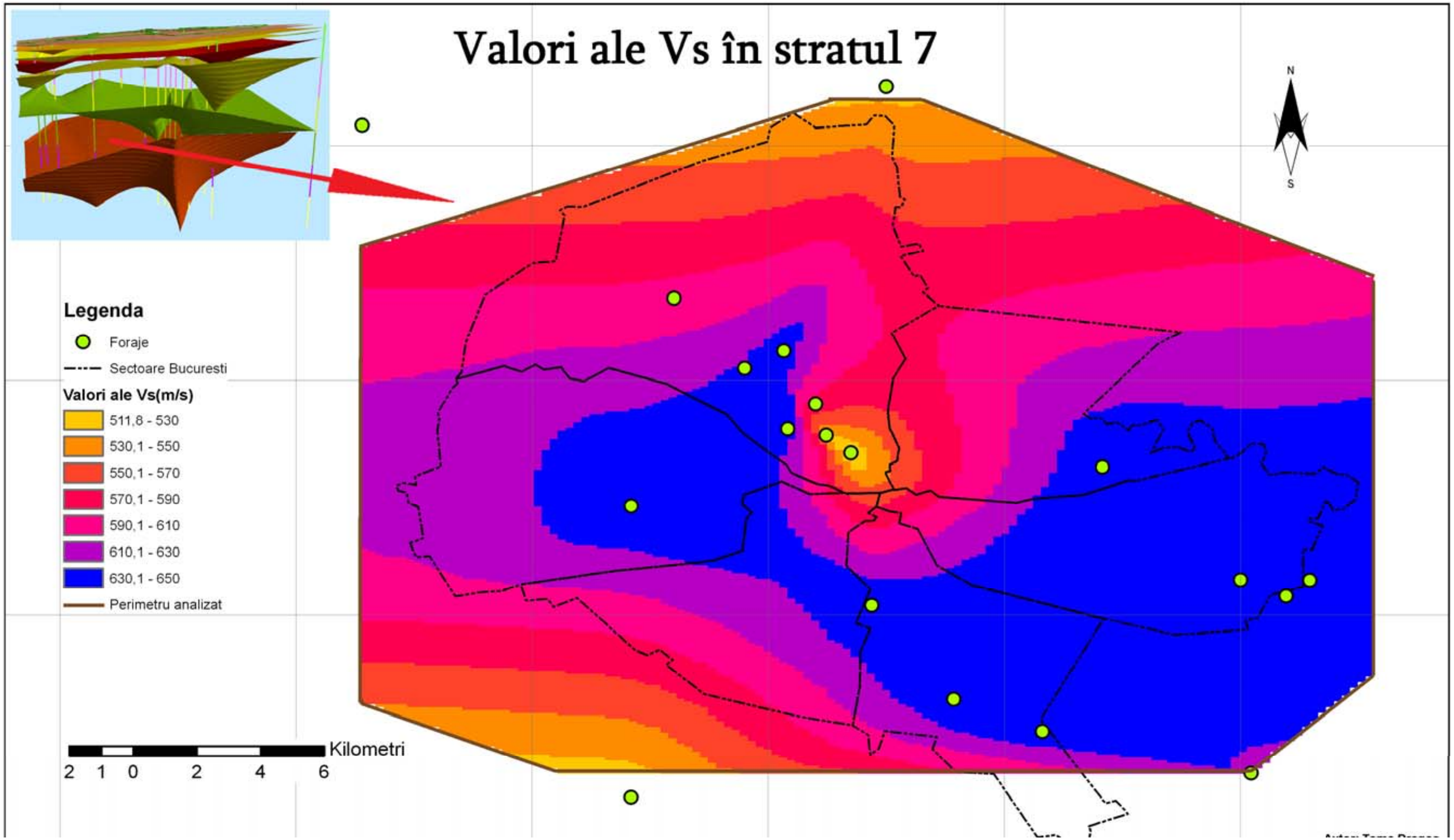

Values of seismic waves V_S in layer 7 of superficially geological structure of Bucharest metropolitan area-GIS modeling

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Aki wrote:

„Nonlinear amplification at sediments sites appears to be more pervasive than seismologists used to think…Any attempt at seismic zonation must take into account the local site condition and this nonlinear amplification". In other words, the seismological detection of the nonlinear site effects requires a simultaneous understanding of the effects of earthquake source, propagation path and local geological site conditions. ***The difficulty for seismologists in demonstrating the nonlinear site effects has been due to the effect being overshadowed by the overall patterns of shock generation and propagation.***

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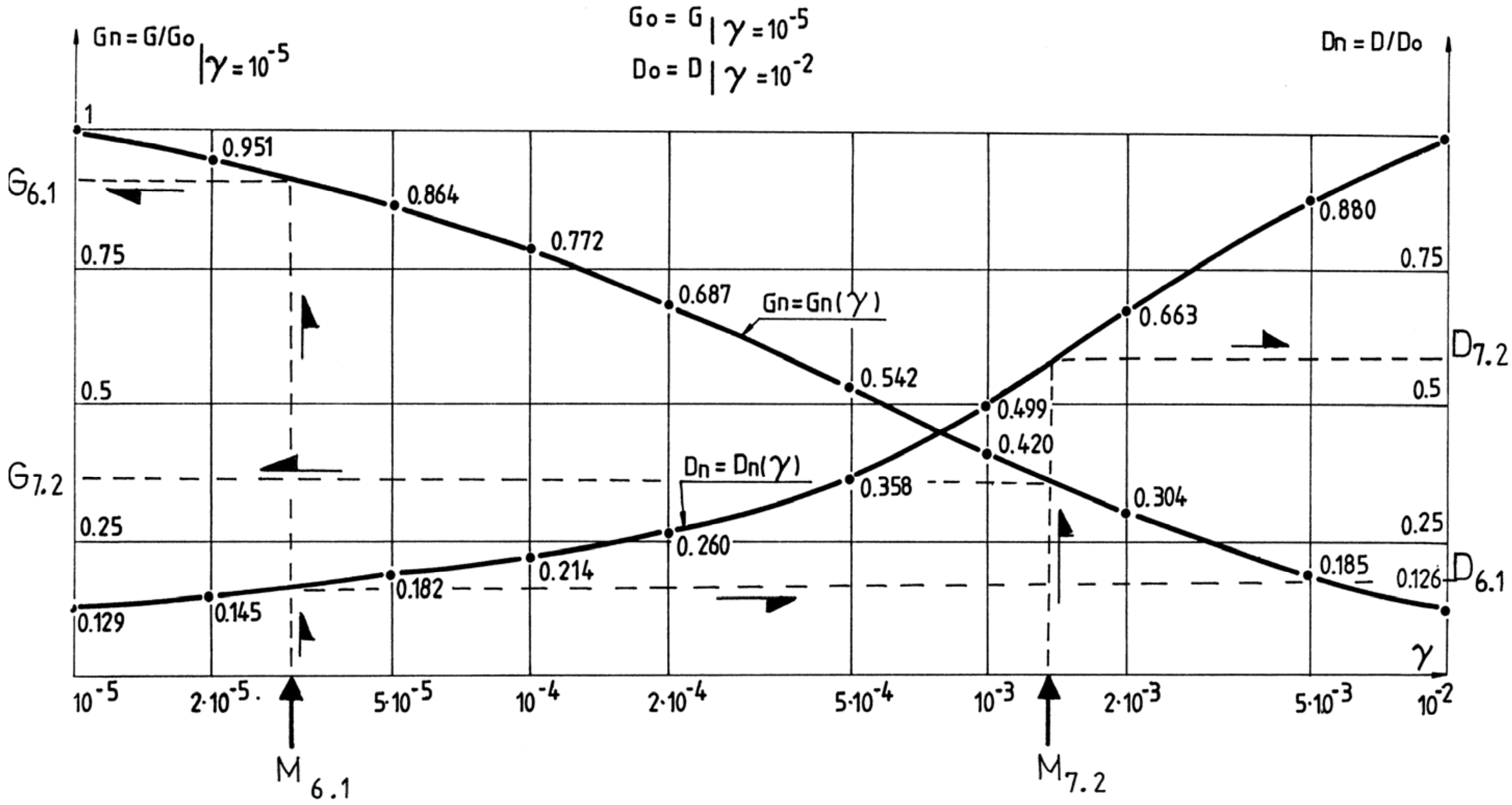


Nonlinear normalized curves for sand with gravel from Hardin and Drnevich resonant columns (NIEP)

Earthquake	a_{max}(g) (recorded)	S_a^{max}(g)	S_a^{max}/a_{max} (SAF)	c= (SAF)1990/ (SAF) later	S_a^* (g)	$a^*(g)_{max}$	%
30.08.1 986 M_{GR} = 7.0	0.0736	0.298	4.0489	1.4557	0.4338	0. 1070	45.57
30.05.1990 M_{GR} = 6.7	0.1350	0.697	5.1629	1.1416	0.7957	0. 1540	14.16
31.05.1990 M_{GR} = 6.1	0.0643	0.379	5.8942	1. 000	0.3790	0. 0643	-

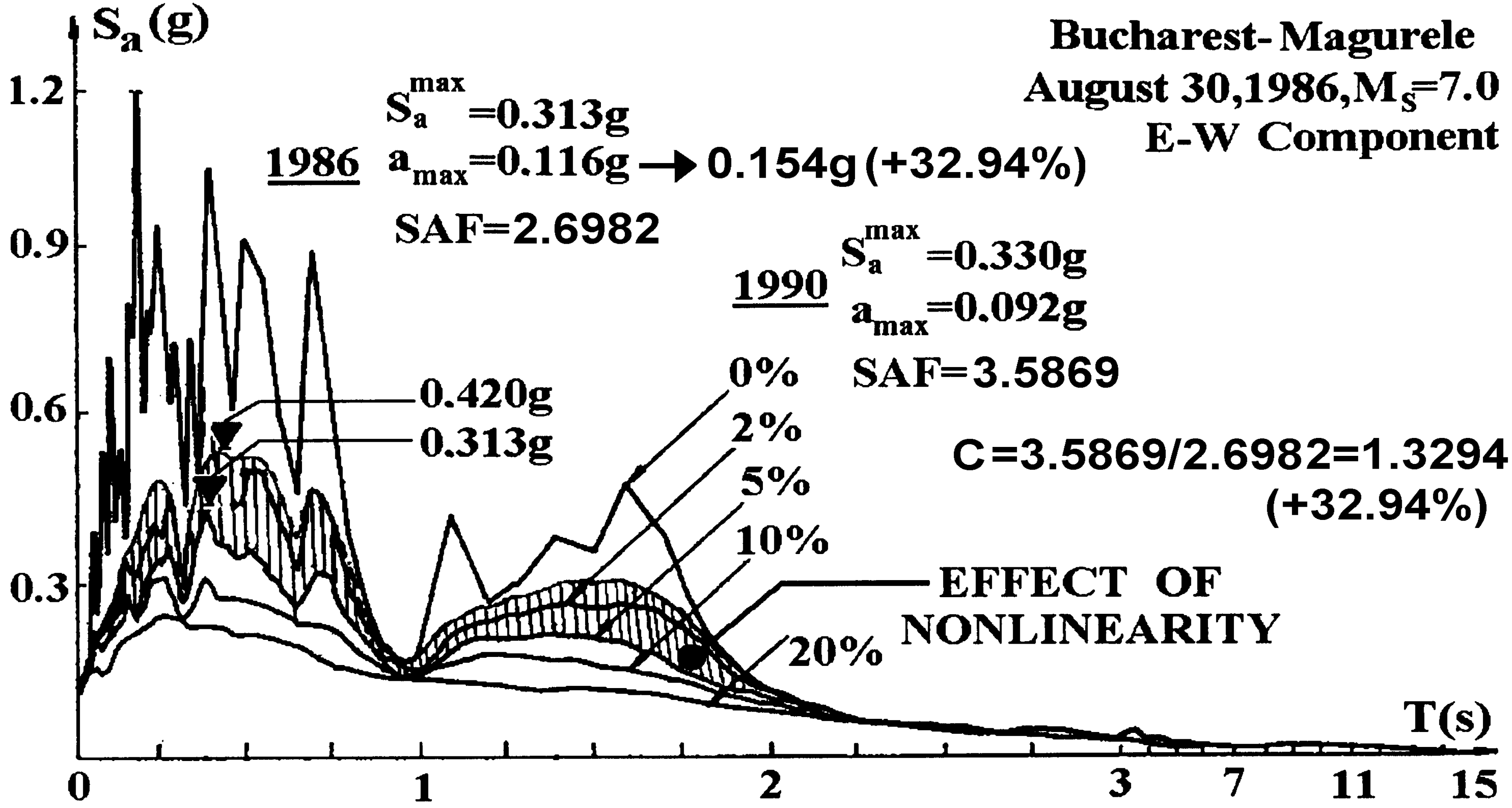
If we maintain the same amplification factor (SAF=5.8942) as for relatively strong earthquake on May 31,1990 with M_{GR} = 6,1 then at Bacau station for earthquake on May 30, 1990 (M_{GR} =6.7) the peak acceleration has to be a^*_{max} = 0.154g(+14.16%) and the actual recorded was only, a_{max} =0.135g.Also, for Vrancea earthquake on August 30,1986, the peak acceleration has to be a*max = 0.107g (+45,57%) instead of real value of 0.0736 g recorded at Bacau seismic station.

1.Bacau Seismic Station

Earthquake	$a_{max}(g)$ (recorded)	$S_a^{max}(g)$	S_a^{max}/a_{max} (SAF)	c	S_a^* (g)	$a^*(g)_{max}$	%
30.08.1 986 $M_{GR} = 7.0$	0.116	0.313	2.6982	1.3294	0.4169	0. 1542	32.94
30.05.1990 $M_{GR} = 6.7$	0.092	0.330	3.5869	1.000	0.330	0. 0920	14.16

Sa* (g) and a*(g) are the maximum spectral acceleration, respectively, maximum acceleration if the system would have a linear response (behavior) to fundamental period. Vrancea earthquake on May 31,1990 (M_{GR} =6.1) could be assumed that the response is in elastic domain and then we have the possibility to compare to it. Coefficient „c" is the ration between SAF for May 31,1990 Vrancea earthquakes and SAF for each earthquake before.

2.Bucharest-Magurele Seismic Station

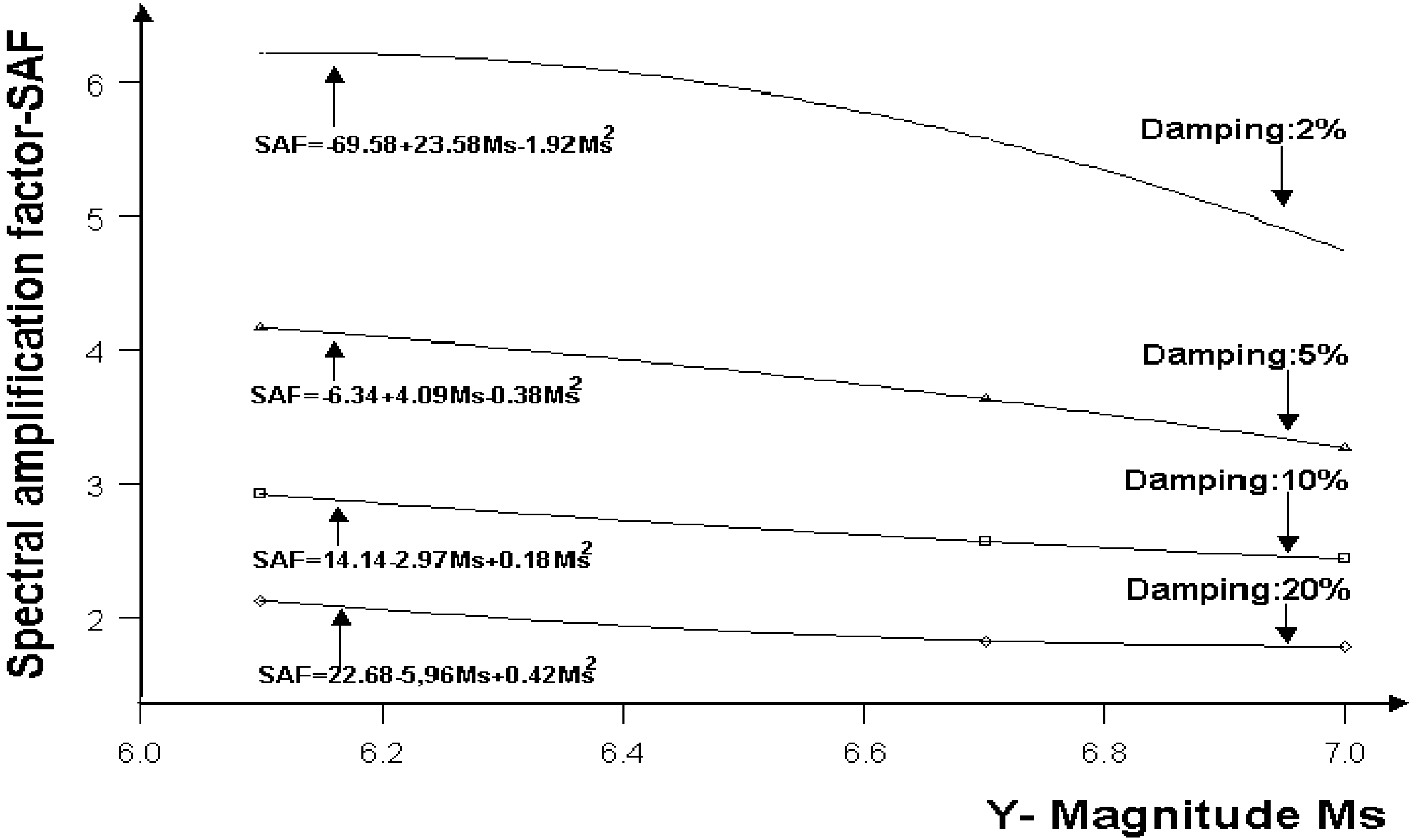


The effect of nonlinearity in Bucharest - Magurele seismic station

The median values of the SAF of the last strong Vrancea earthquakes

ξ =%	Aug 30,1986,M_{GR}=**7.0**		May 30,1990,M_{GR} =**6.7**		May 31,1990,M_{GR}= **6.1**	
	S_a^{max}/a_{max}	S_v^{max}/v_{max}	S_a^{max}/a_{max}	S_v^{max}/v_{max}	S_a^{max}/a_{max}	S_v^{max}/v_{max}
2%	4.74	3.61	5.58	3.72	6.22	4.84
5%	**3.26**	2.69	**3.63**	2.95	**4.16**	3.48
10%	2.43	2.99	2.56	2.14	2.92	2.69
20%	1.78	1.50	1.82	1.58	2.13	1.86

The median values of the spectral amplification factors of the last strong Vrancea earthquakes for damping ξ =5% are: **4.16; 3.63** and **3.26** corresponding to May 31, 1990, May 30,1990, respectively, August 30, 1986. At the same seismic station, for example at Bacau, for 5% damping, SAF for accelerations is **5.22** for May 31,1990 (M =6.1);**4.32** for May 30, 1990 (MGR =6.7) and **3,94** for August 30,1986(MGR =7.0) earthquakes.



The dependence of the spectral amplification factor (SAF) of Vrancea earthquake magnitude

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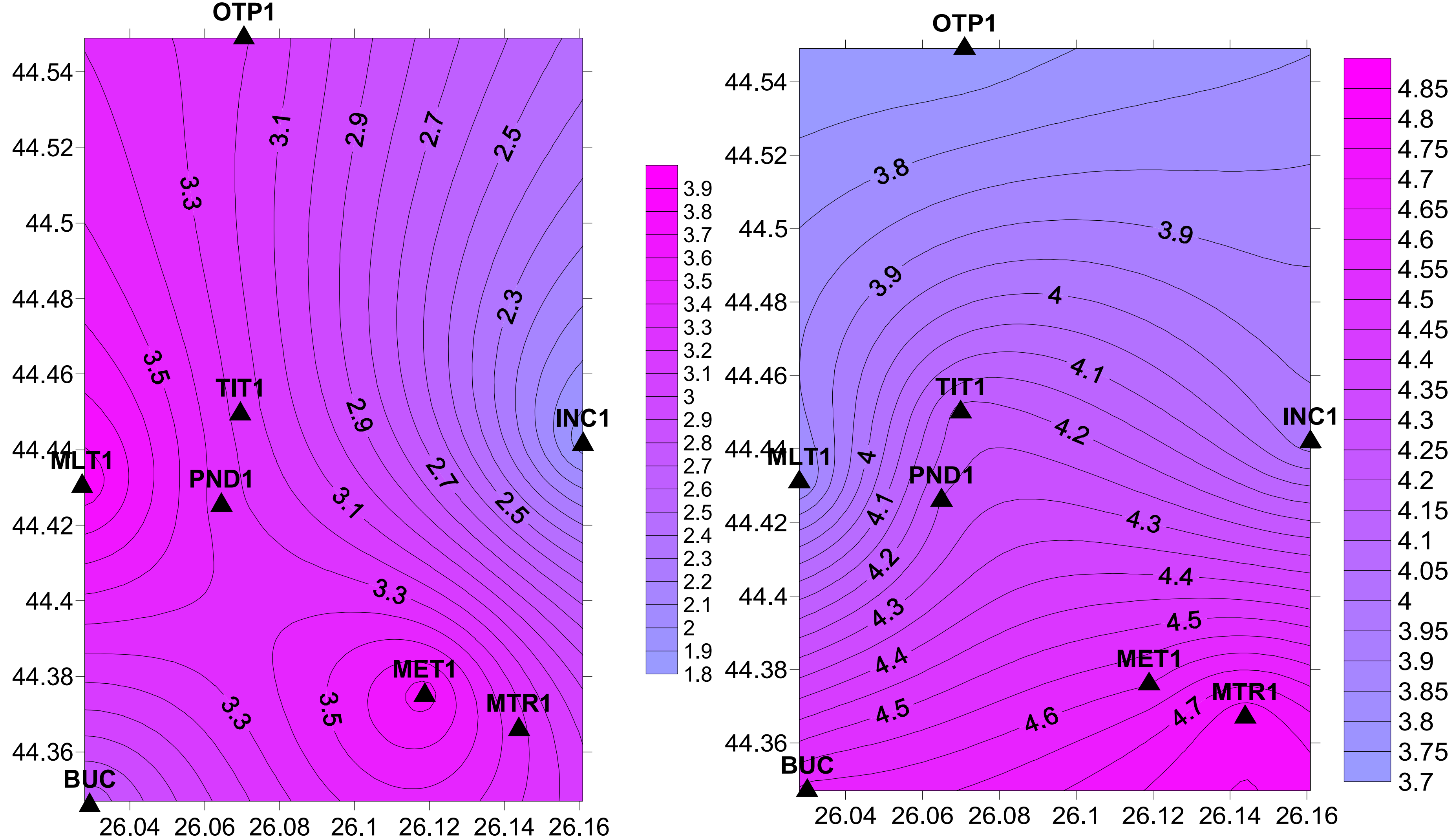

Non-filtered (OTO 1) ***Otopeni Seismic Station*** **0.005-1.0 Hz**

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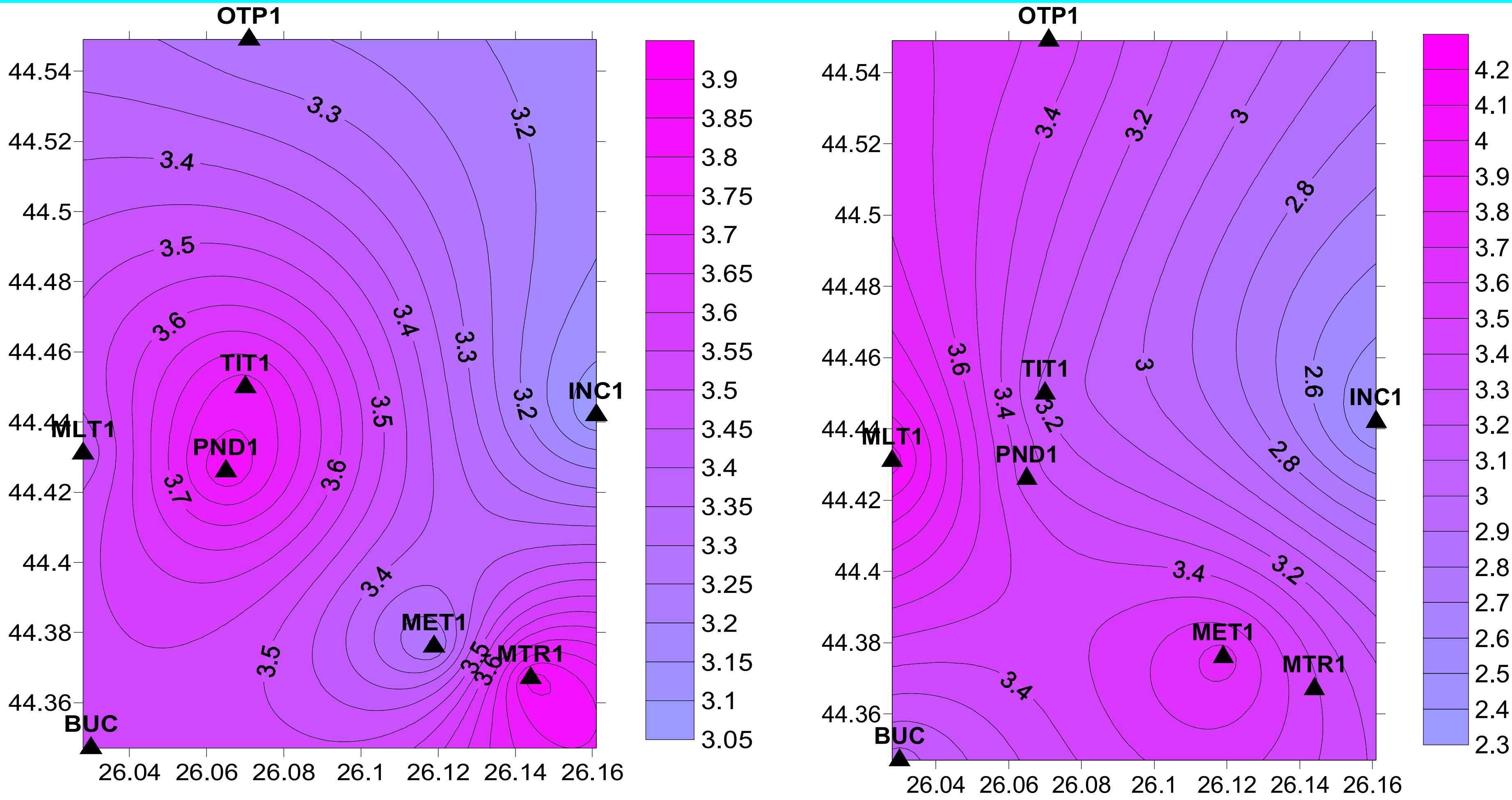

0.05- 2 Hz ***Otopeni Seismic Station*** **0.05- 5 Hz**

Space distribution of the SAF values for each frequency domain in Bucharest area from Vrancea earthquake on August 30,1986 (Mw =7.1

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During of last stronger Vrancea earthquakes (August 1986,Mw= 7.1 and May 30,1990,Mw = 6.9) the highest values of acceleration were recorded in the north of Bucharest and the smallest one in the south-east of it. More, PGA in epicenter area (Vrancioaia) during of August 30, 1986 Vrancea earthquake (Mw =7.0) was **162,6 cm/s2** , in the north of Bucha-rest was **156,2 cm/s2**-EREN Station and **219,8 cm/s2** Otopeni site , while in the south-east of it was only **76,3 cm/s2** (Metalurgiei site).All time we were looking to get ***"banana"*** shape for ***distribution of macroseismic intensity*** Vrancea earthquakes. Also, in our attention was to make the frequency dependent PGA/PGV analysis in generation of attenuation laws. For rapid assessment of the seismic ground motion level in Bucharest, we used the equation:

$$\mathbf{Ln(a_{max}) = 4.726 + 0.976\, M_{GR} - 1.146 \ln R - 0.0066\, h + 0.353\, P}$$

and setting P=0 (average curve) in Equation → Table

Earthquake	M_{GR}	Depth (km)	Δ(km)	R(km)	(a_{max}) recorded	(a_{max}) computed by using Equation
March 4, 1977	**7.2**	110	100.37	148.91	**198.00 cm/s²**	**199.00 cm/s²**
Aug. 30, 1986	**7.0**	143	123.25	188.78	**95.30 cm/s²**	**95.55 cm/s²**
May 30, 1990	**6.7**	90	173.53	195.48	**98.70 cm/s²**	**102.05 cm/s²**

The predictions for this station show the smallest error with respect to the observations for all stations in the Bucharest area, hence, INCERC is used as a "*reference station* in all studies[21]. In the microzoning map (local seismic hazard) for Bucharest for maxi-mum possible earthquake in Romania (MGR=7.5).There are 14 zones and each zone is characterized by maximum acceleration (a-max), maximum MMI intensity (Imax) and fundamental period for soil (T). Each parameter for each zone is obtained from "***reference station***" **INCERC**

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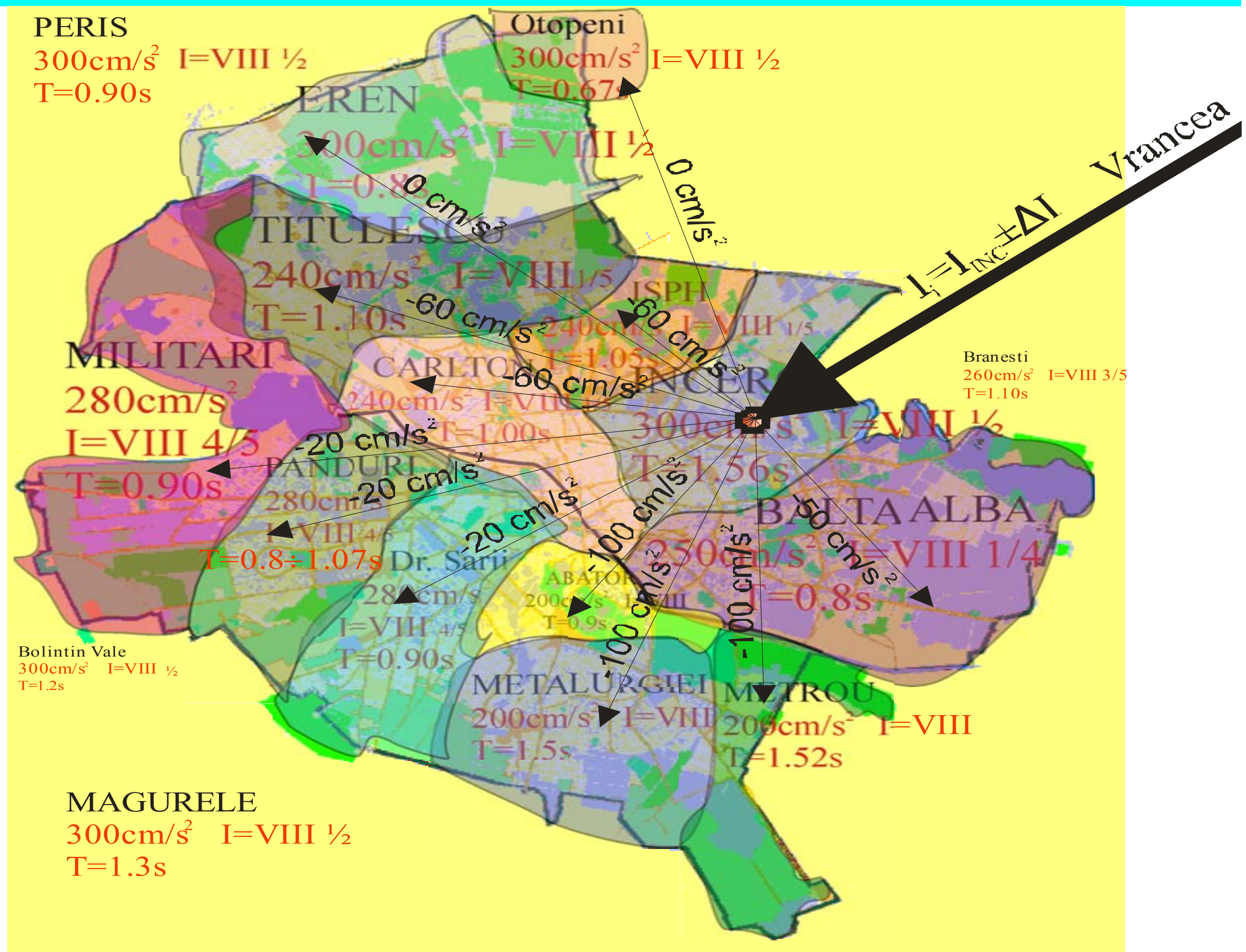
Izone = **I**INCERC ± Δ **I**
(MMI scale)
(**a**-max)zone = (**a**-max)
INCERC ± Δ **a** (cm/s2)
(**T**soil)zone =
(**T**soil)INCERC ± Δ **T**soil
(seconds)



Local seismic hazard (microzonation) map of Bucharest with:(i)- MMI intensities (**I**); (ii)- **PGA**(cm/s2) and, (iii)- fundamental periods of soils (**T**) for ***maximum credible Vrancea earthquake*** (MGR =7.5) in Romania

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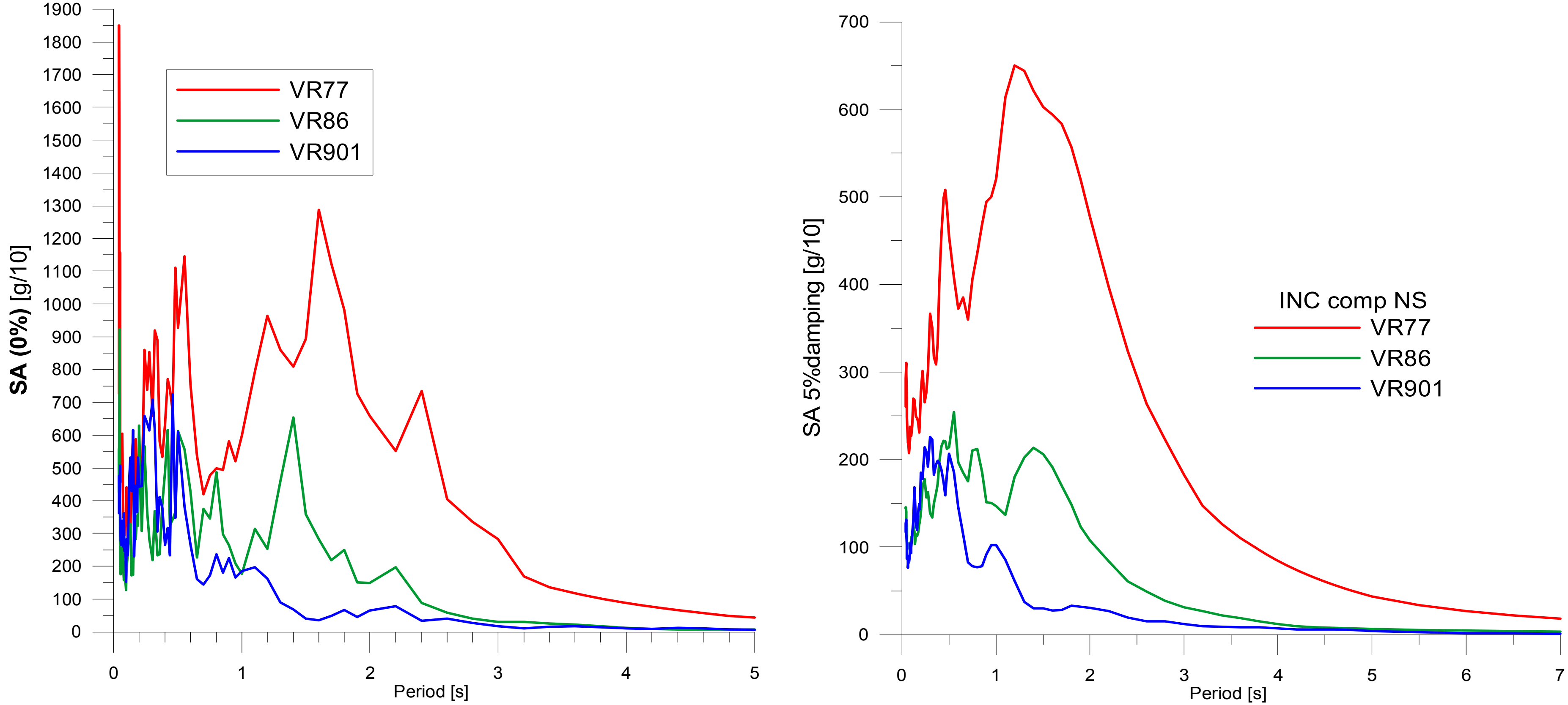

Response acceleration spectra for last Vrancea earthquakes : March 4,1977(Mw =7.4) **T=1.54 s**), August 30,1986(Mw =7.1)-**T=1,22 s**) and May 30,1990 (Mw =6.9) -T=**0.47 s** recorded at INCERC -Bucharest (N-S component) for **ξ =0%** (left).
For **ζ =5% (**right**)** all periods are smaller.

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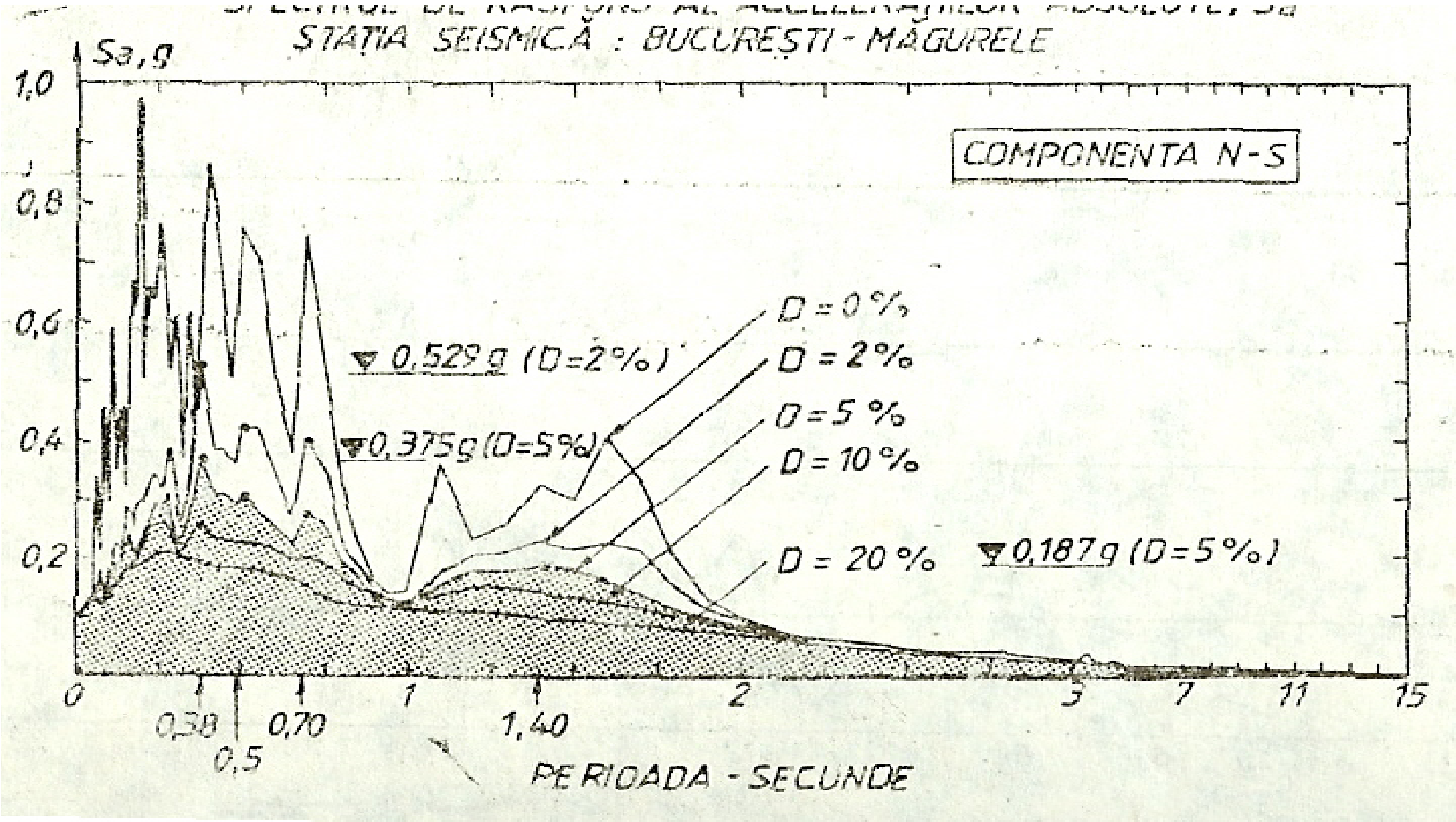

August 30,1986(Mw=7.1) recorded at Bucharest-Magurele. Response spectra on N-S component has 2 "**locks"** with periods **T1=0,38** seconds and **T2=1,5** seconds for **ζ =5%** and **T1=0,32** seconds and **T2=1,65** seconds for **ζ= 0,0%**. Second "**lock**" is developing more when Vrancea earthquake magnitude is increasing.

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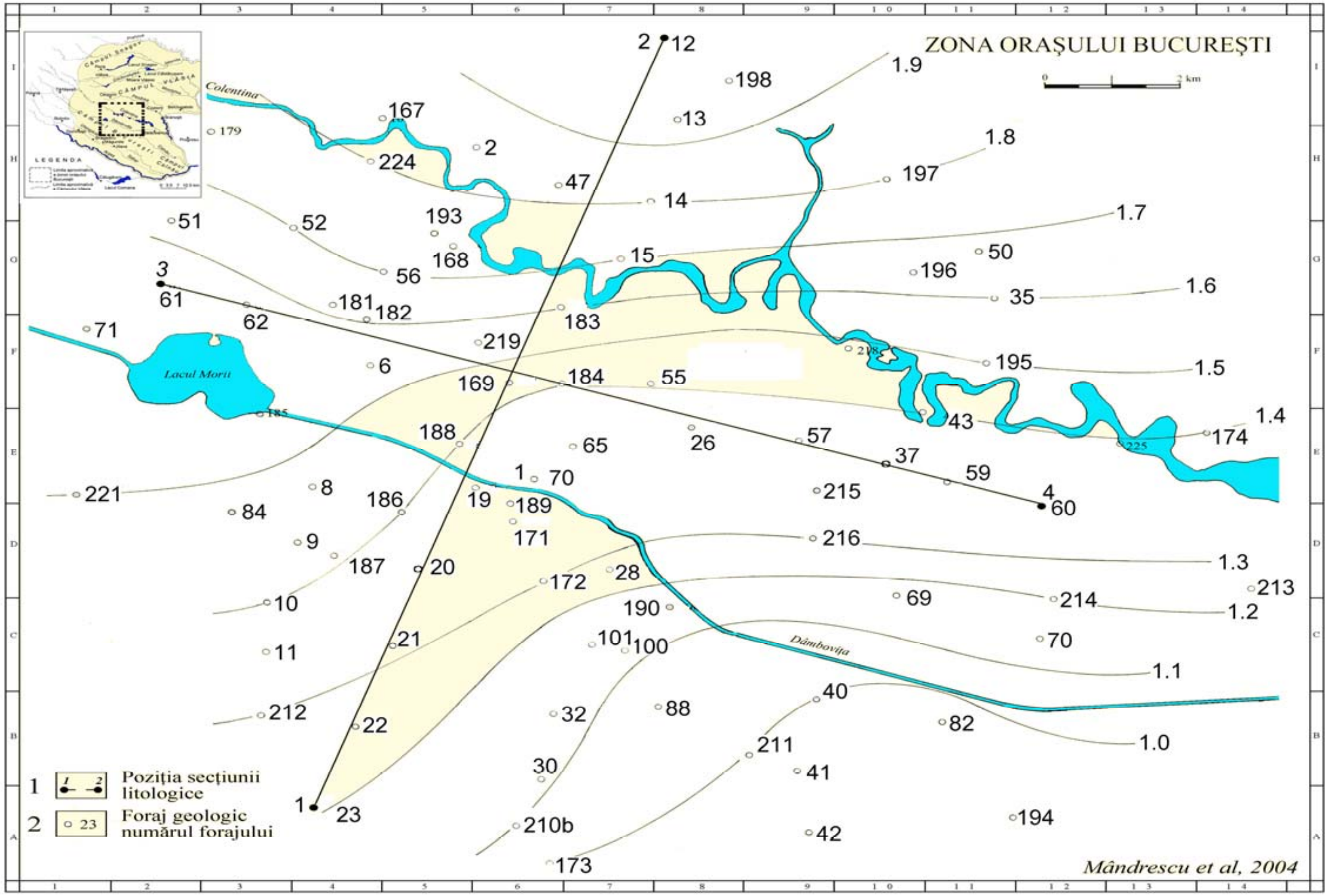

Distribution of the fundamental soil periods in ***Bucharest*** for strong Vrancea earthquakes.

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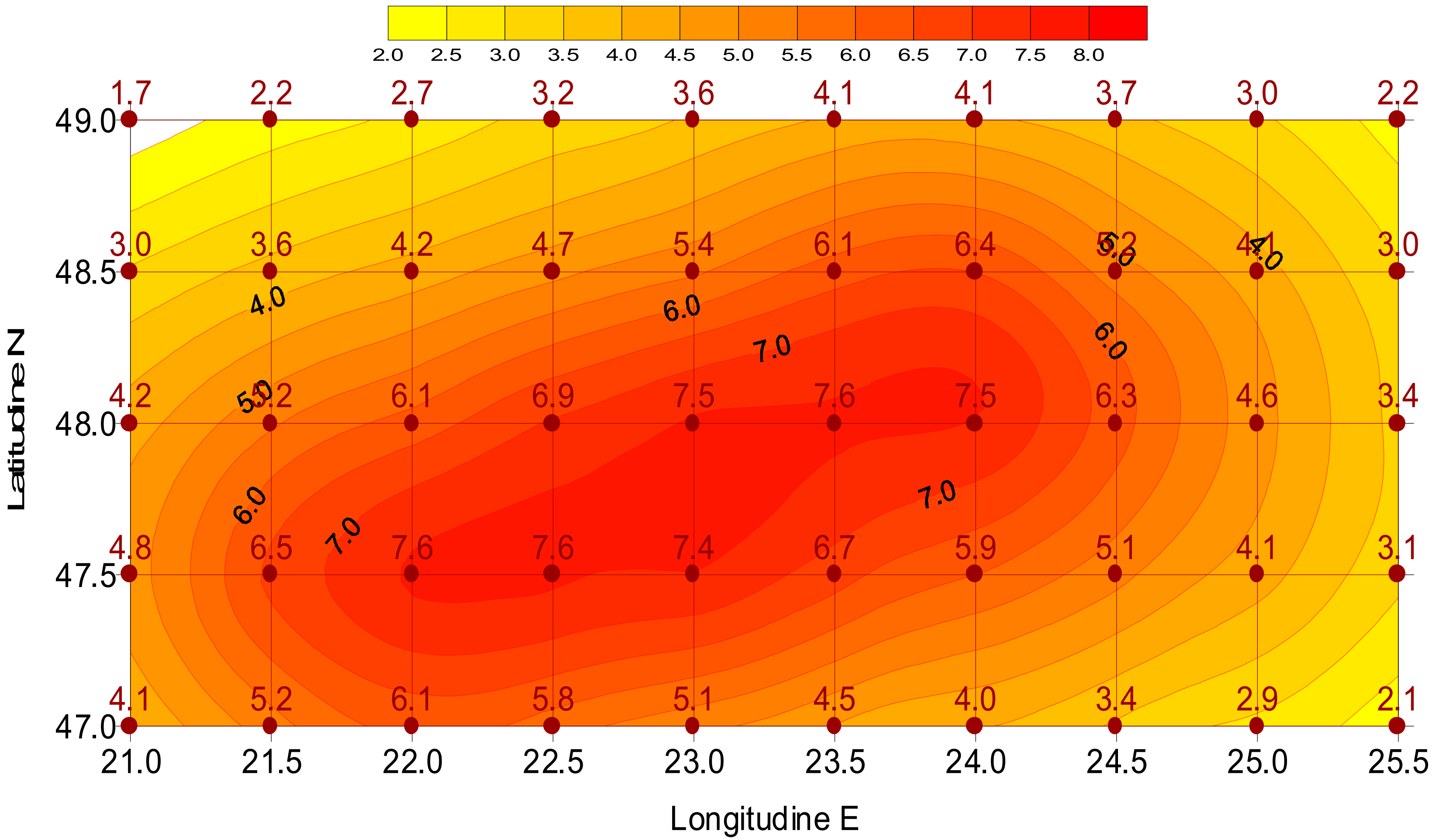

Seismic hazard map **for local and Vrancea deep earthquakes -*Crisana-Maramures-Baia Mare* area for a recurrence period , T=100 years (Intensities MMI)**

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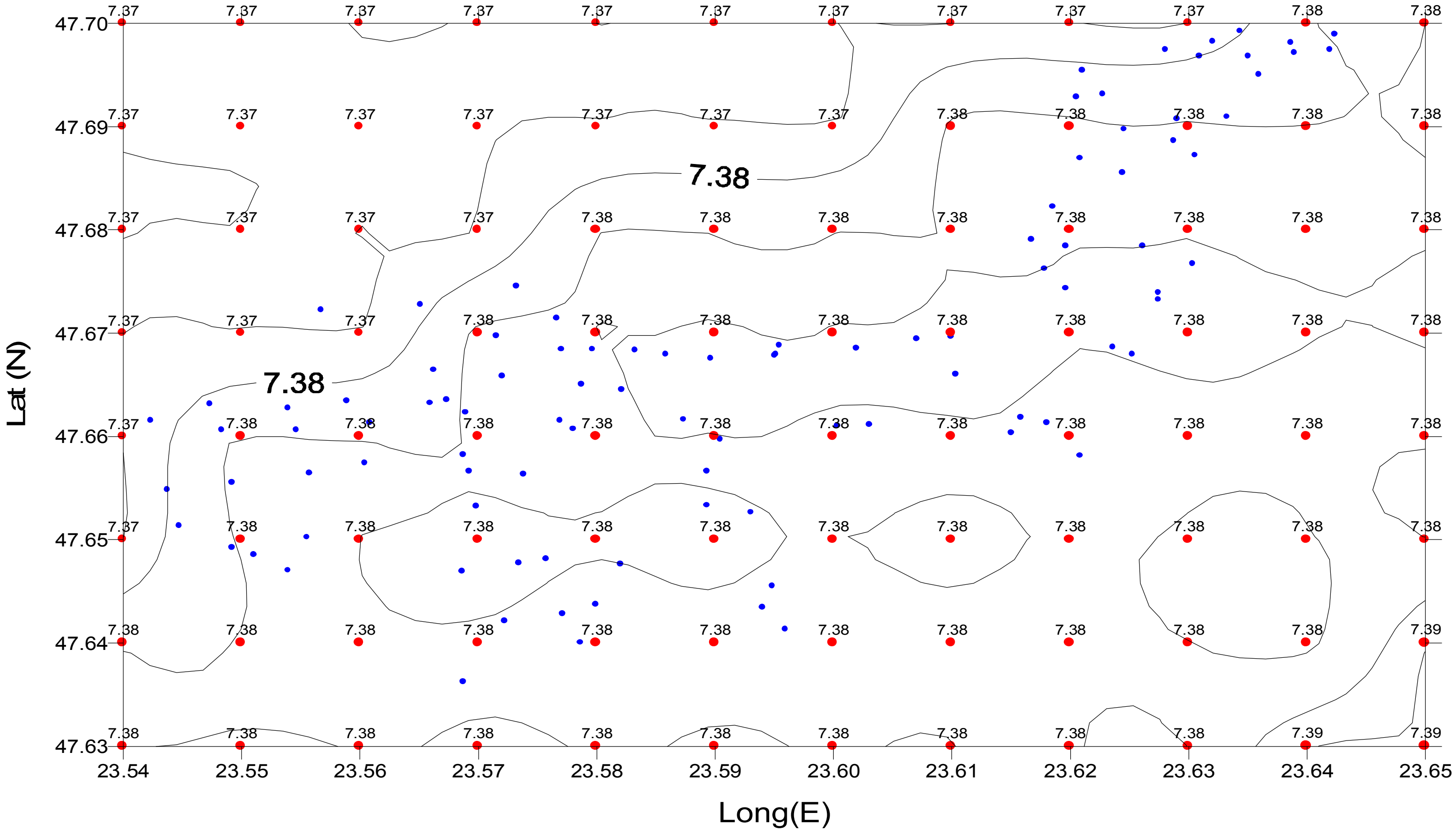

Local seismic hazard(microzonation) for ***Baia Mare City*** for a recurrence period T=100 years (MMI) by using classical methods and „***Fuzzy Set Theory*** “

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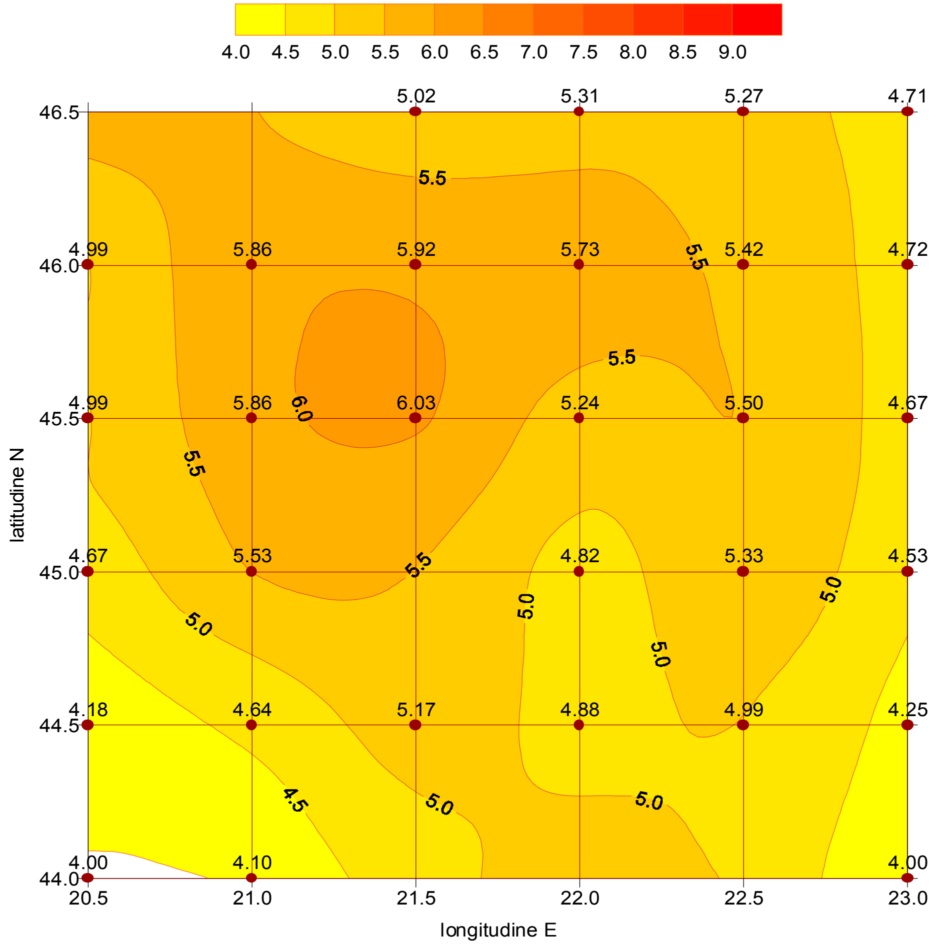
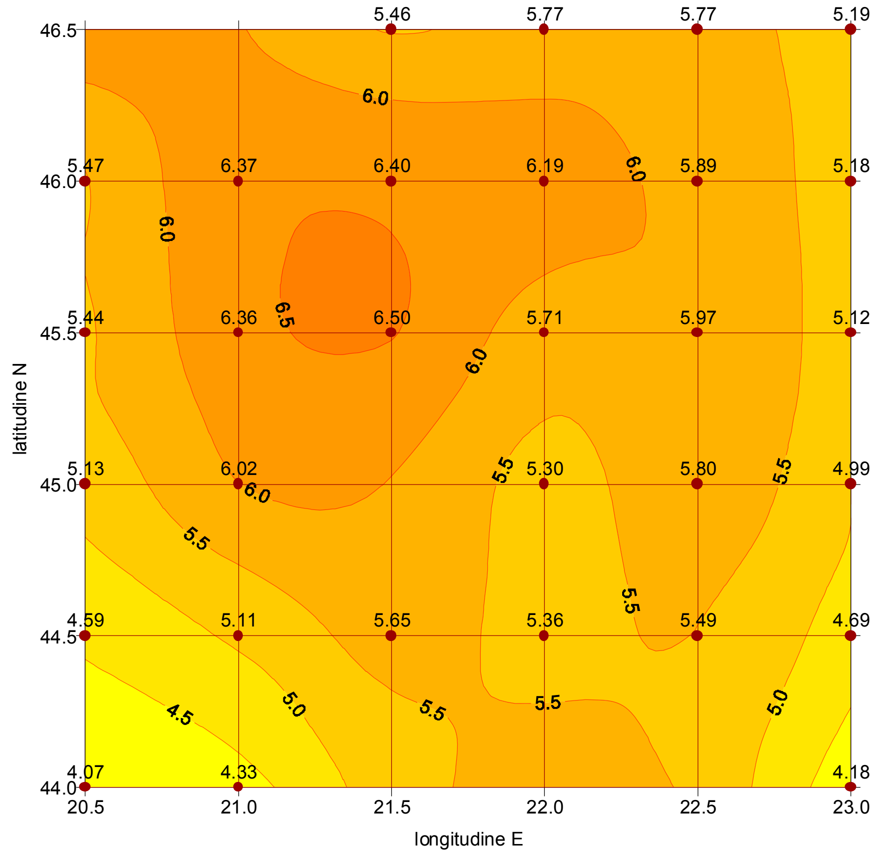
a. *H1 an =0.02; Tr=50 years*



b.*H1 an =0.01; Tr=100 years*



Seismic hazard map for local and Vrancea deep earthquakes –***Banat county*** for a recurrence periods : T= 50 and 100 years(MMI).Probablistic anaysis.

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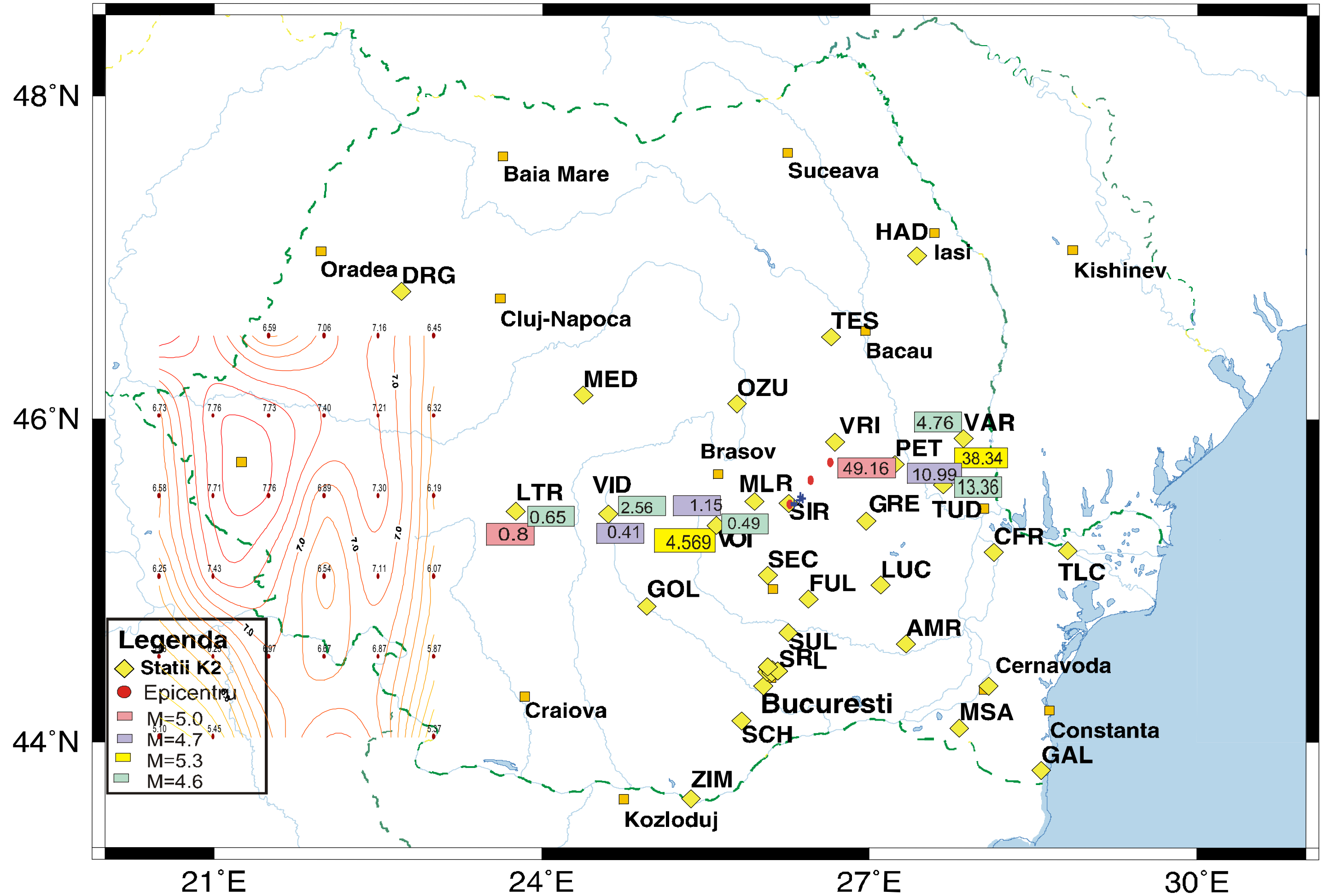

Seismic hazard map for ***Banat zone*** for recurrence period : TR = 1000 years (Intensities MMI). Probabilistic analysis.

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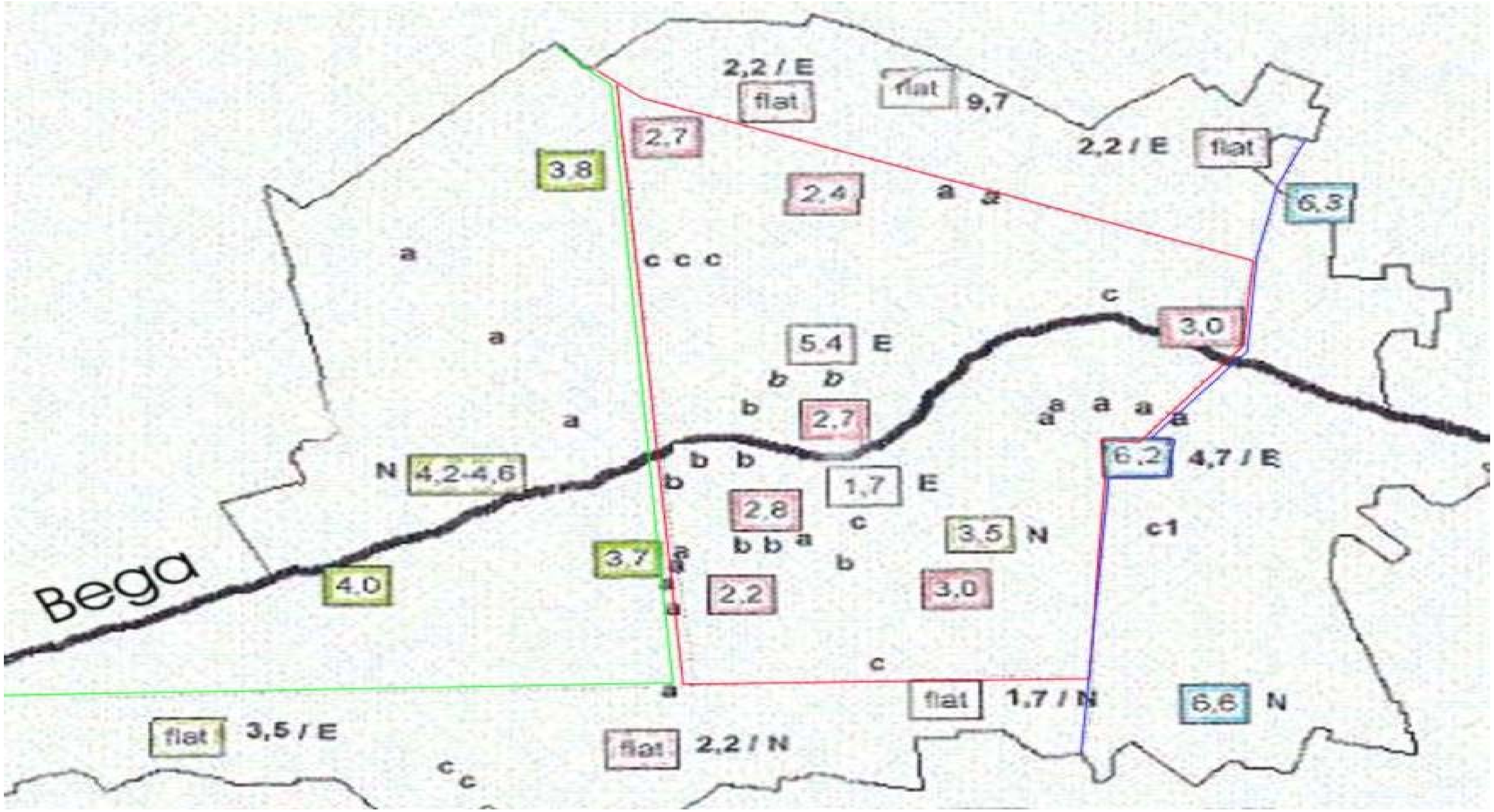

Local seismic hazard(microzonation) map (***in frequencies)*** of Timisoara City

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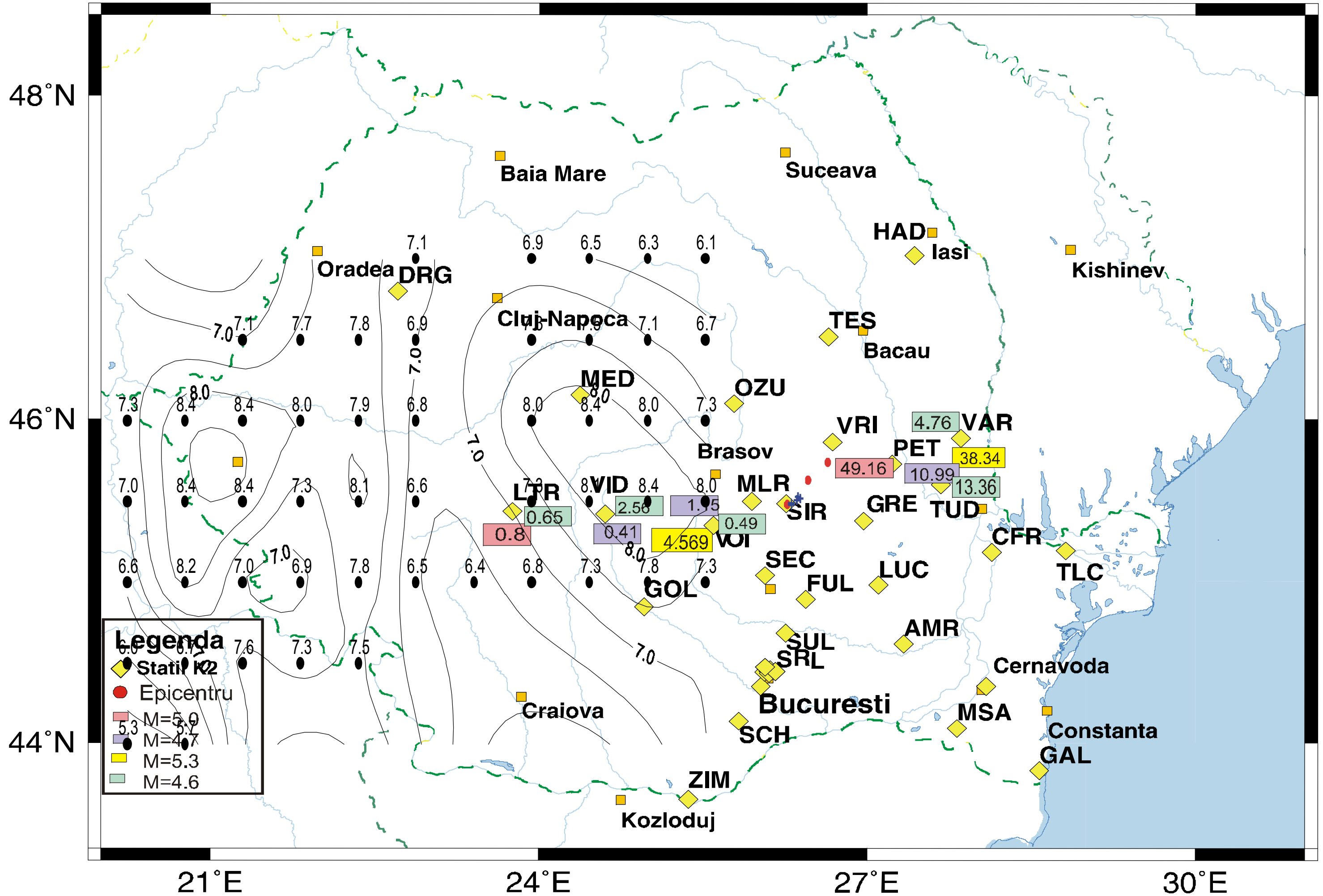

Seismic hazard map for *Banat, Transilvania and North West* part of Muntenia area for a recurrence period , T=1000 years (MMI) to local and deep Vrancea eartquakes

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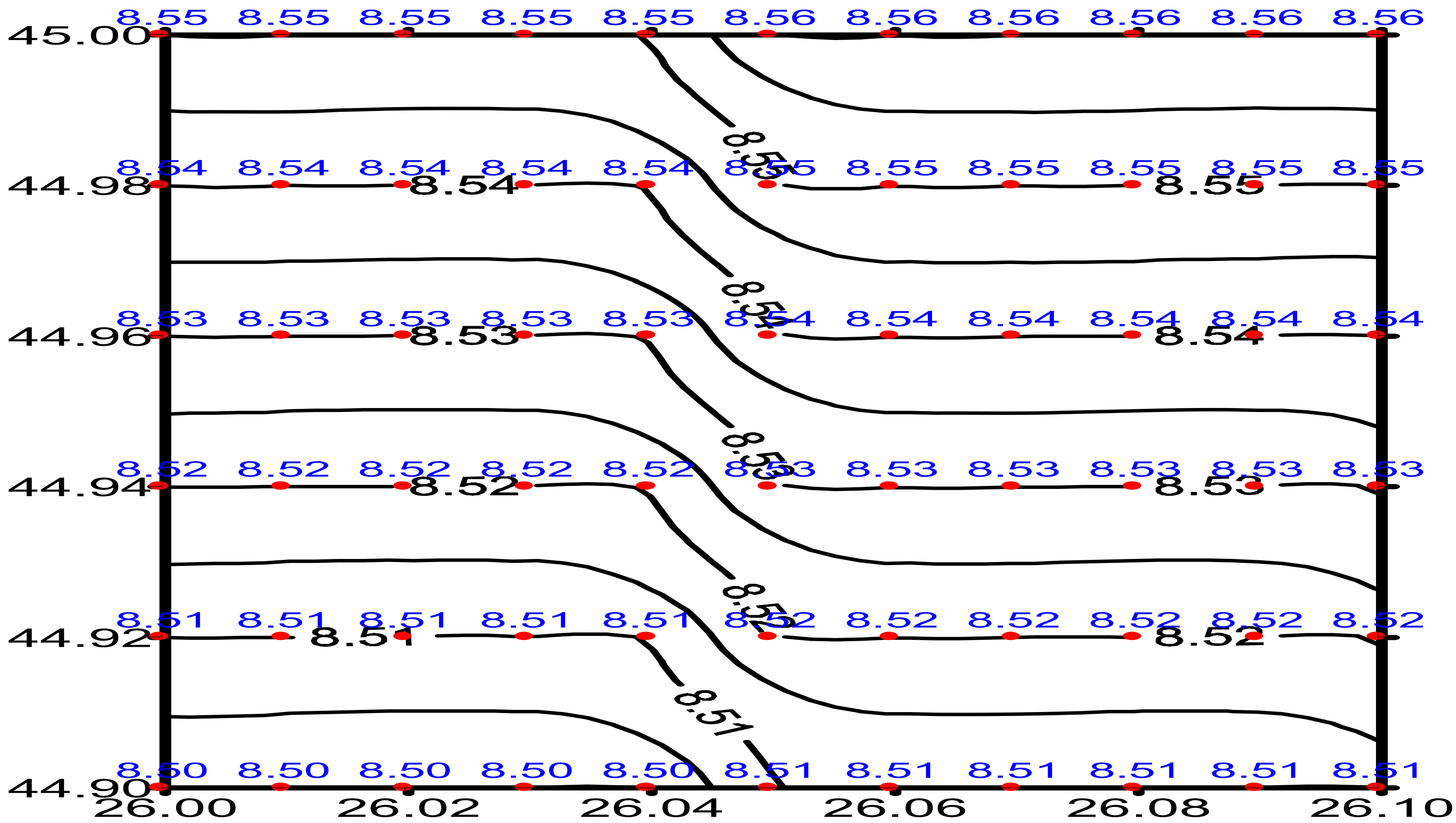

Local seismic hazard (microzonation) for *Ploiesti City* for a recurrence period , T=100 years (MMI). Probabilistic analysis. Local and deep Vrancea eartquakes

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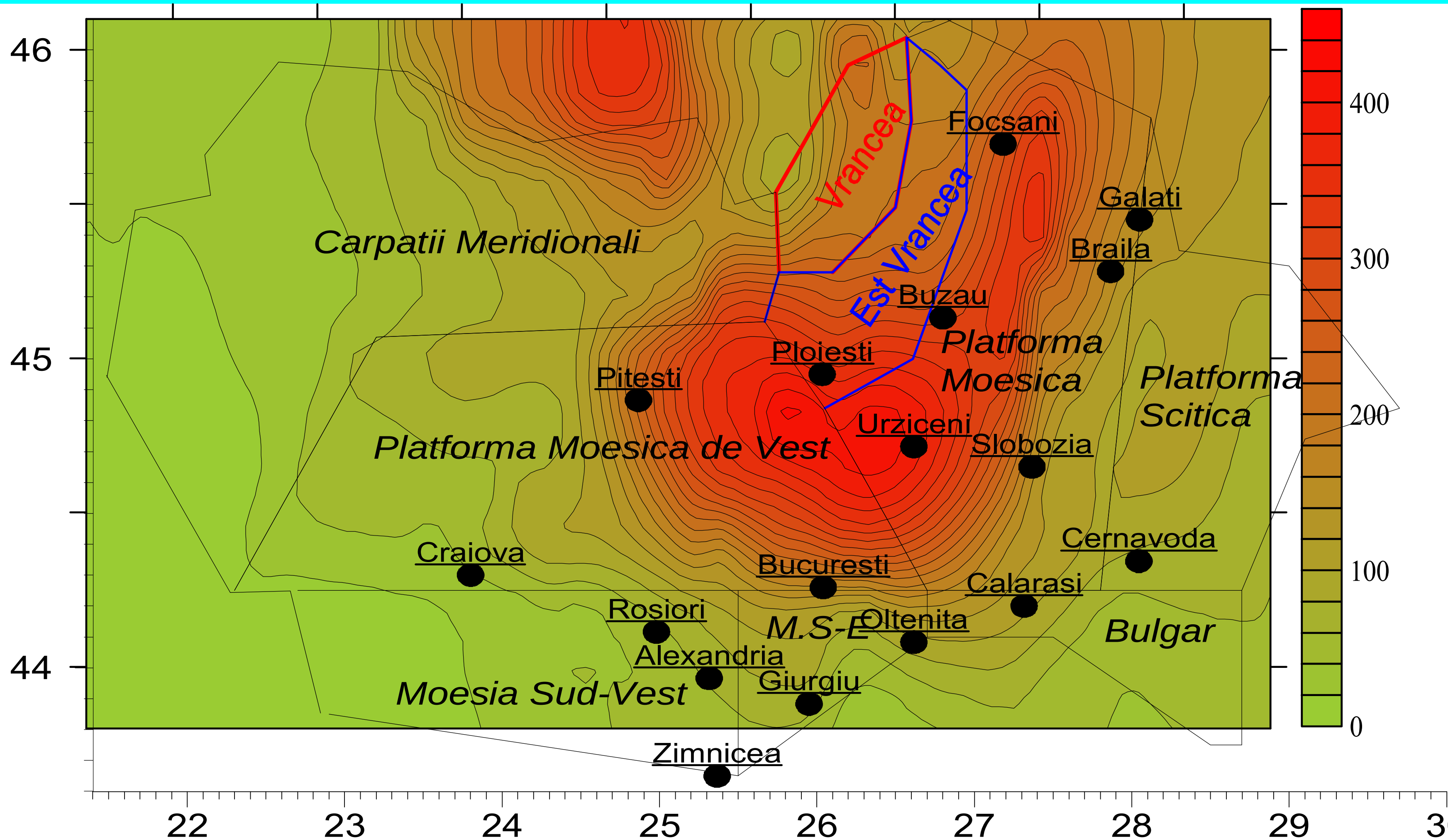

Seismic hazard map for Muntenia and south of Moldova (in design accelerations) to strong Vrancea earthquake (h=90 km ,Mw =7.2)

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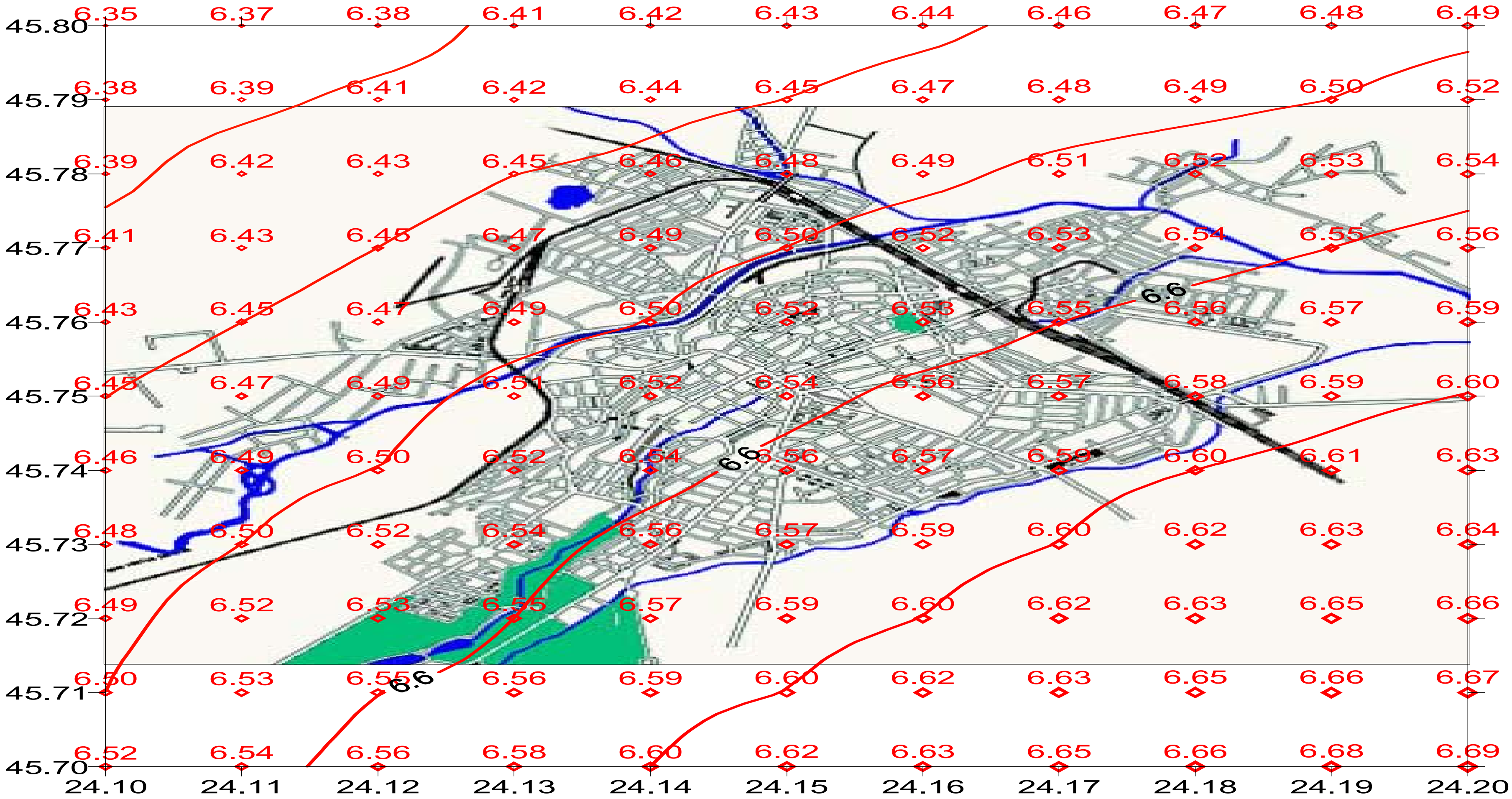

Local seismic hazard(microzonation) for *Sibiu City* for a recurrence period , T=100 years (Intensities)-Probabilistic analysis. Fagaras local eartquakes .

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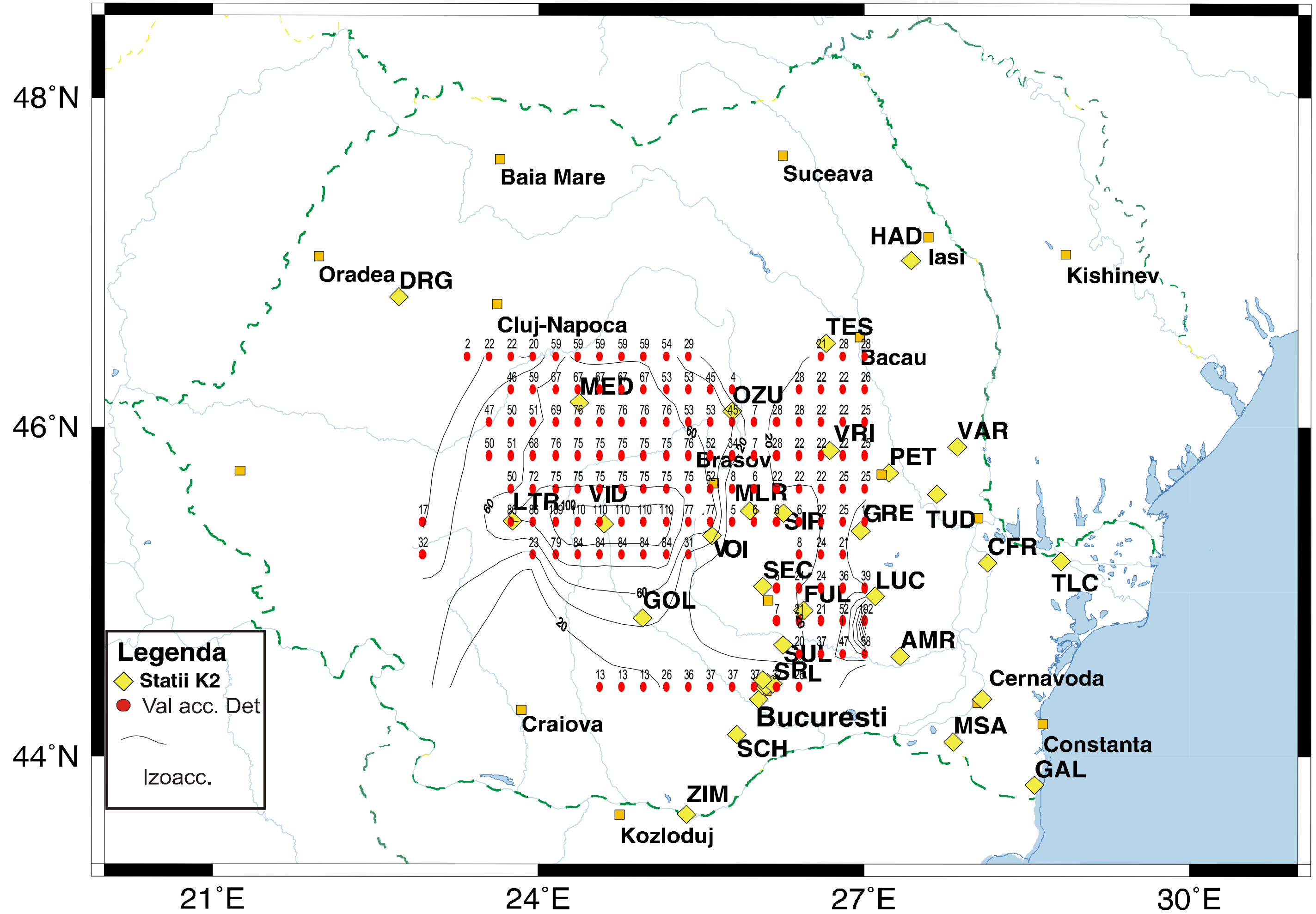

Seismic hazard map for *Sibiu zone* to crustal eartquakes from Fagaras-Campulung .All data are in units of gravitational accelerations(g)

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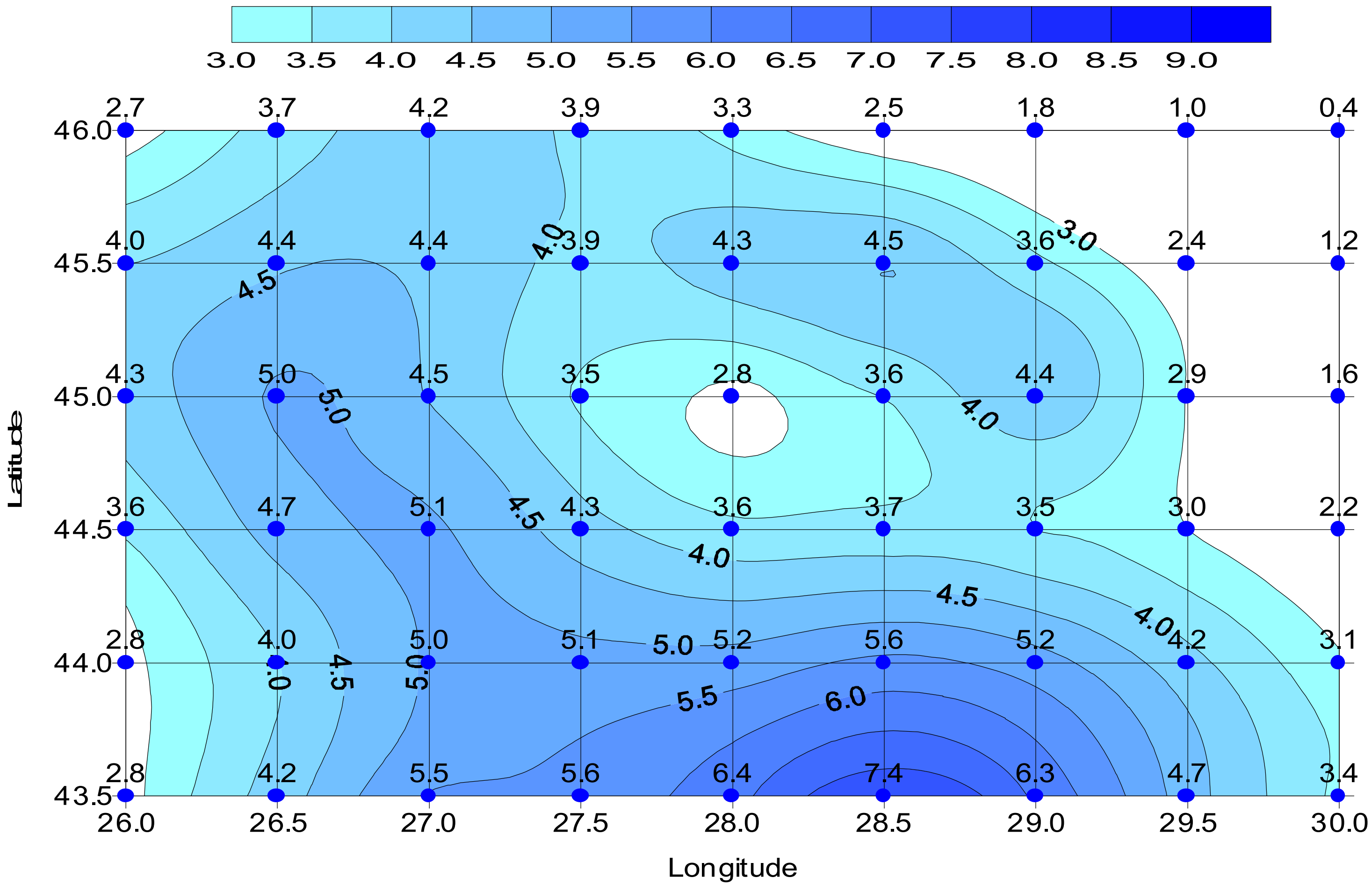

Seismic hazard map for crustal earthquakes in *Dobrogea-Tulcea* area for a recurrence period , T=200 years (Intensities MMI)

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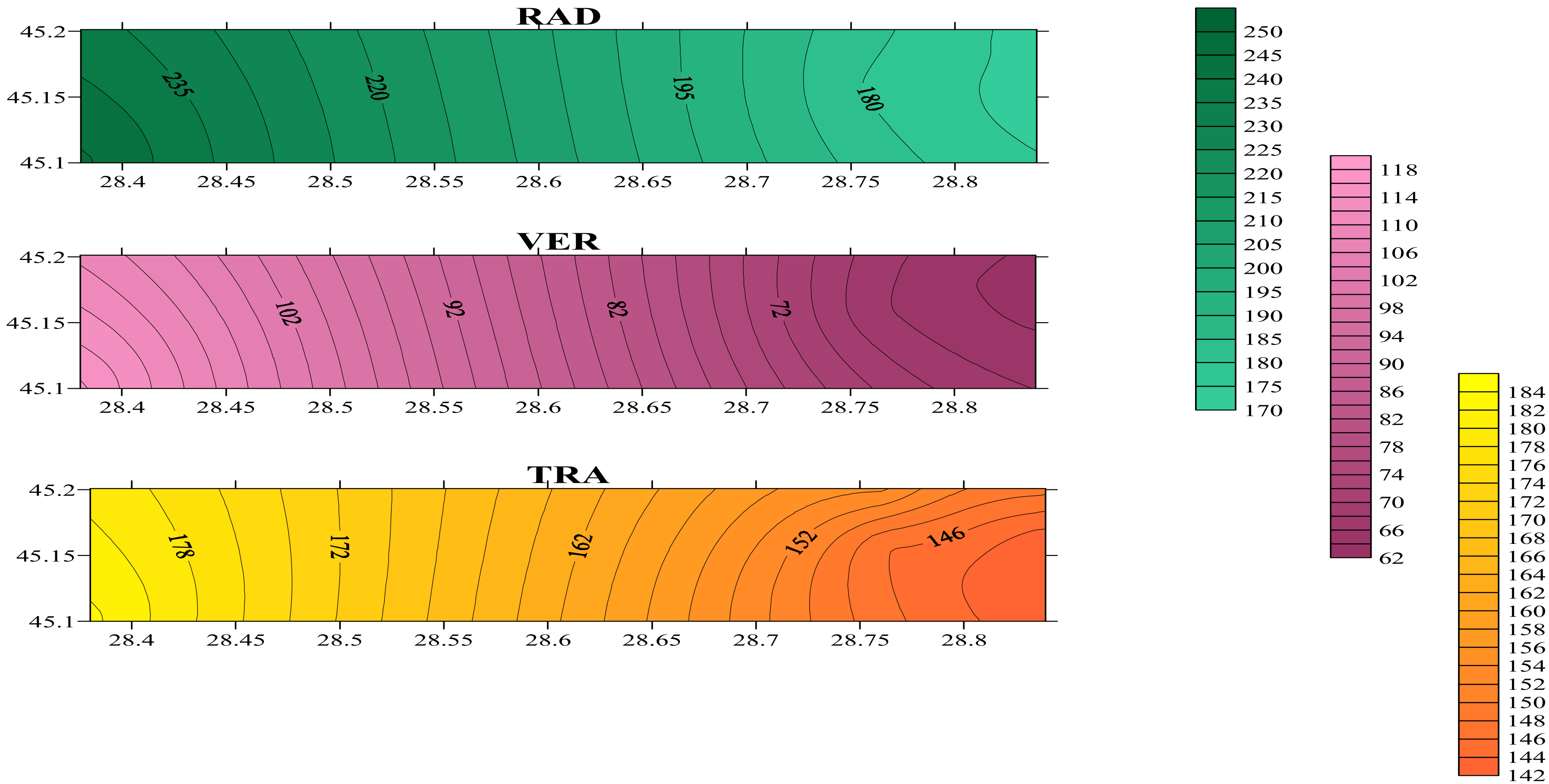

Local seismic hazard map with space distribution of PGA in Tulcea City and surroundings to strong deep Vrancea earthquake of magnitude Mw =7.5. Deterministic analysis.

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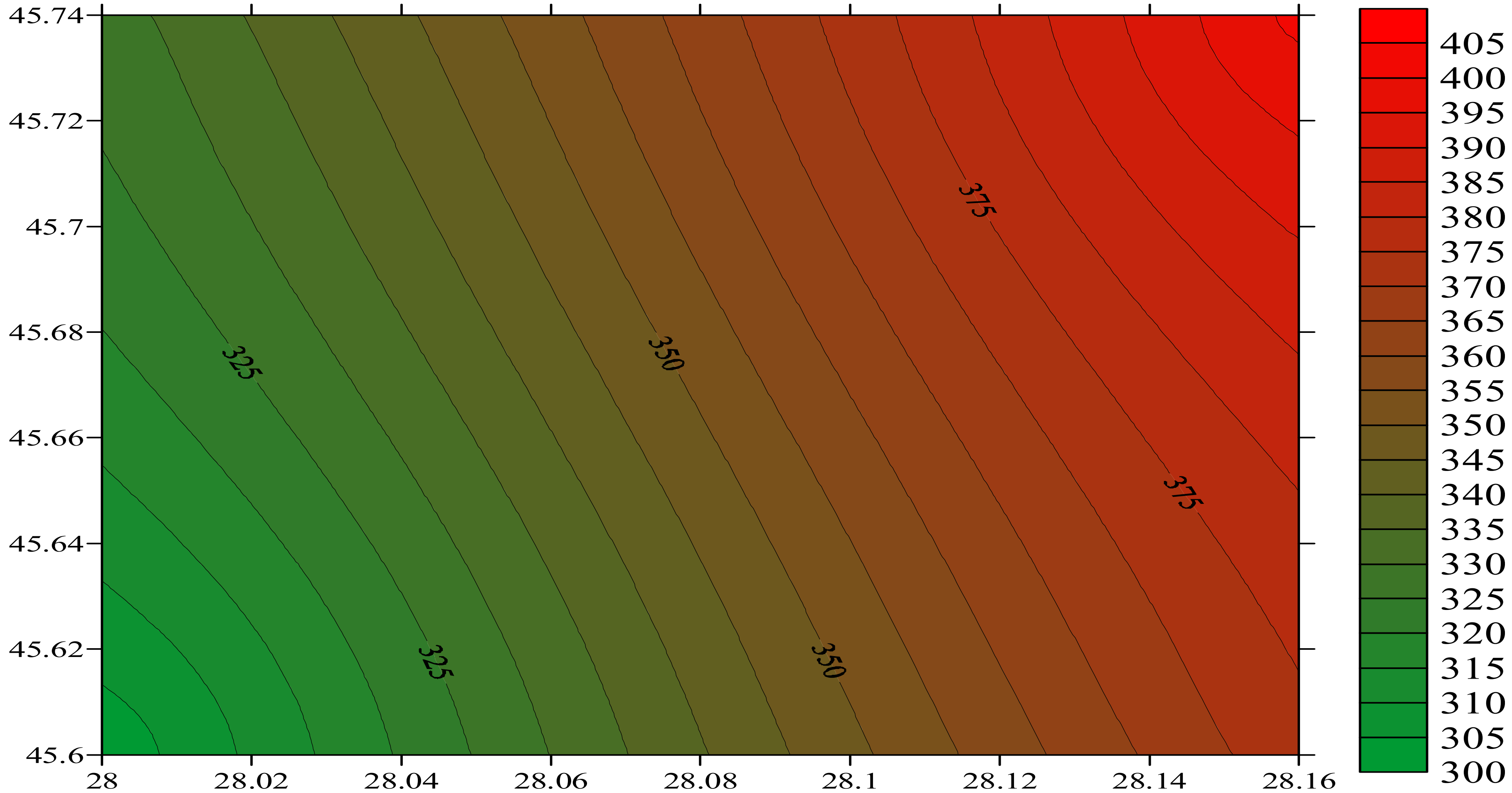
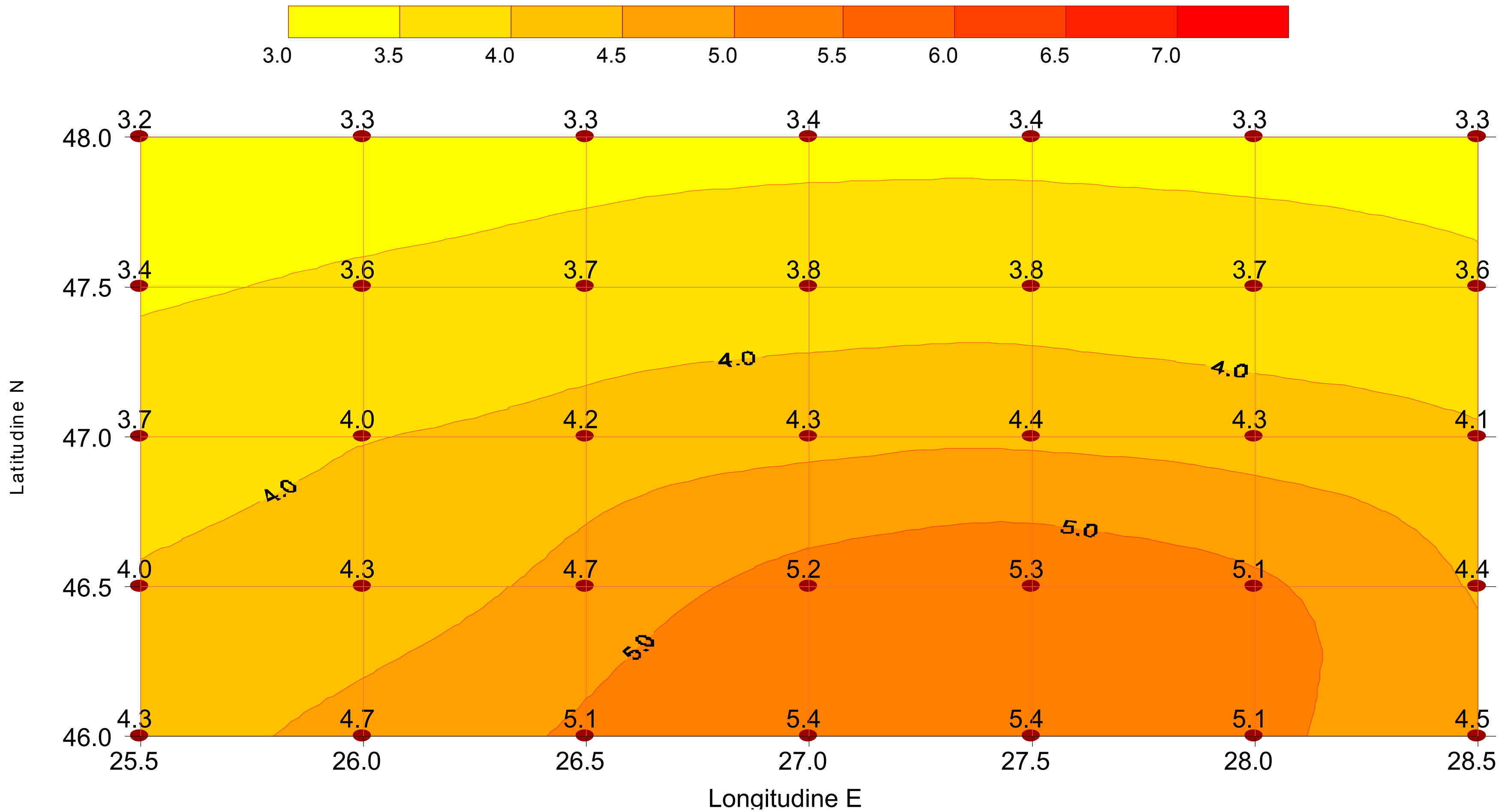
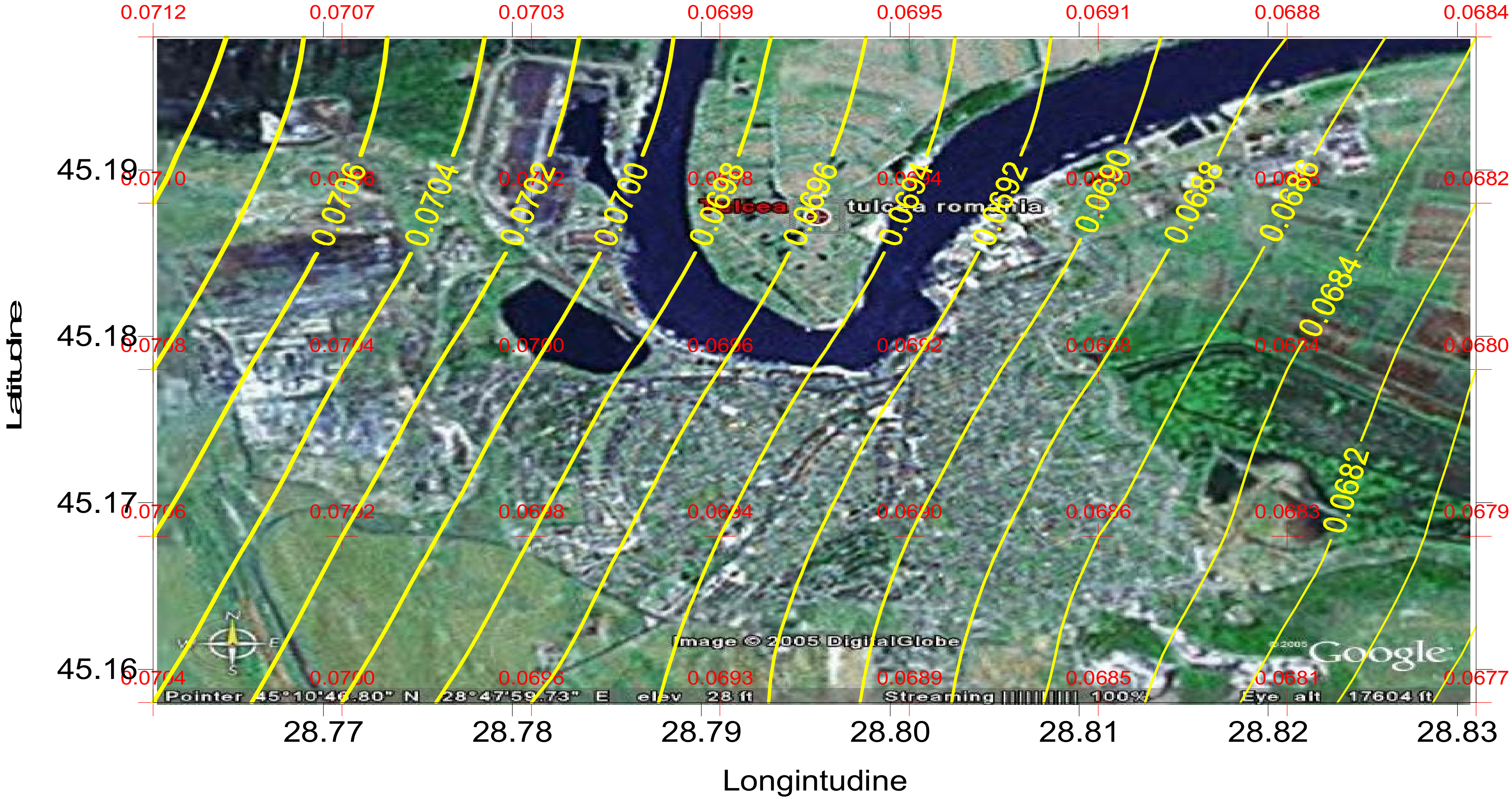


Seismic hazard map –*Galati City* in accelerations to Vrancea deep earthquakes with magnitude MW =7.7 .Deterministic analysis



Seismic hazard map –*Moldova county* to crustal earthquakes and recurrence period, T=100 years (Intensities MMI)

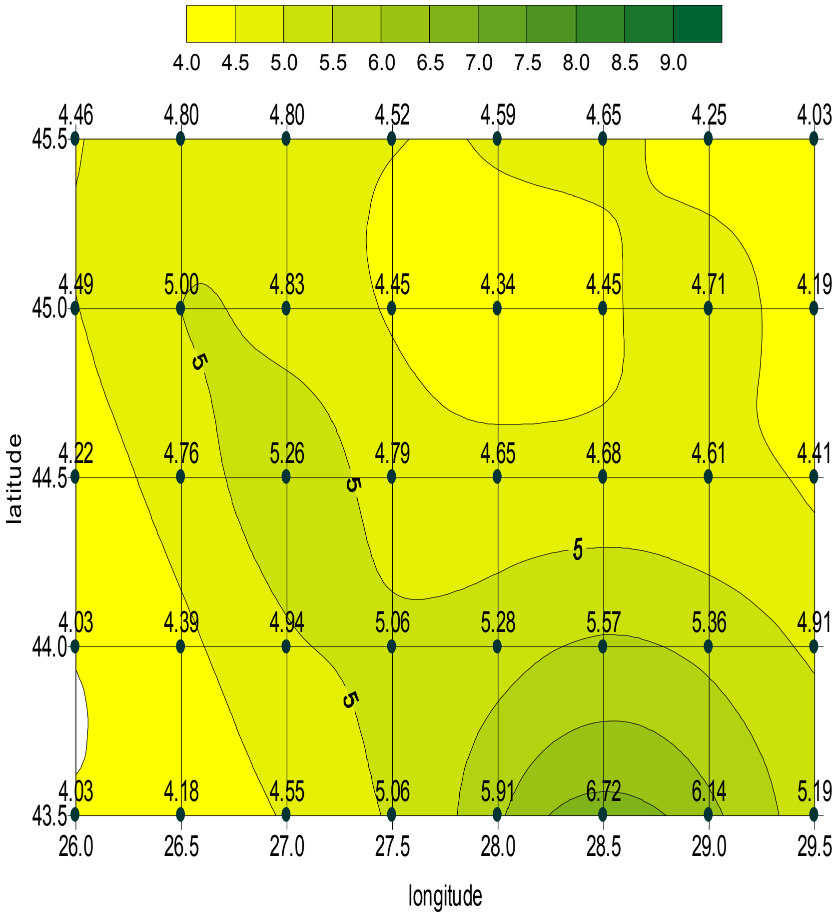
ICTP Advanced Conference on Seismic Risk Mitigation and Sustainable Development



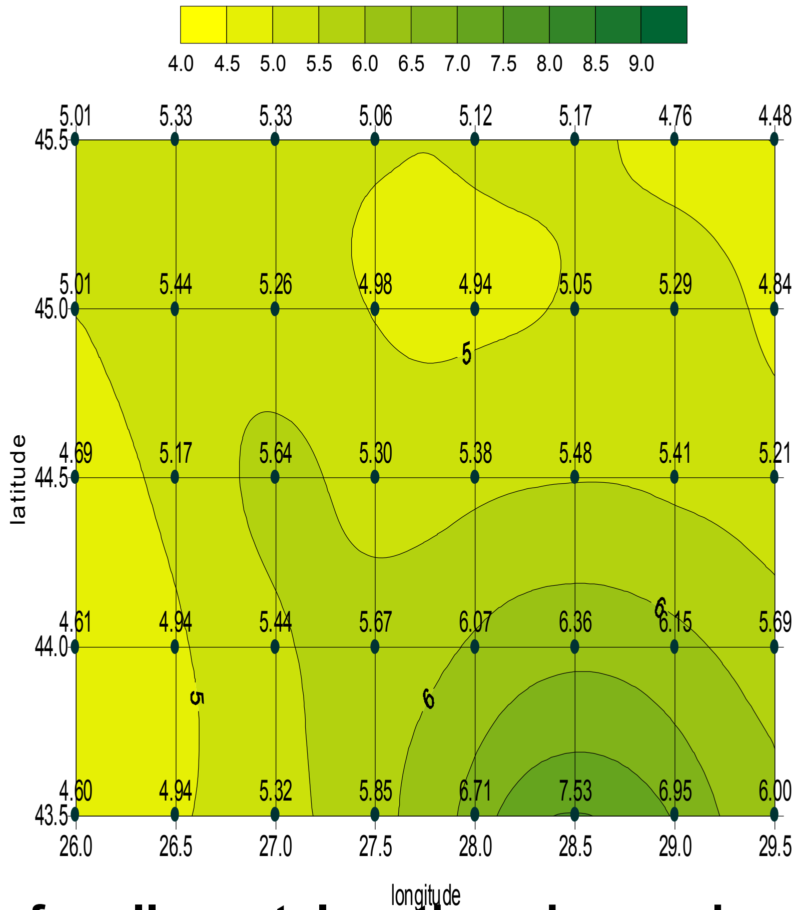
Local probabilistic hazard map –Tulcea City. Exceed probabilities - I=VII

Trieste-Italy. May 10-14,2010

H1 an =0.005; Tr=200 ani



H1 an =0.002; Tr=500 ani



Seismic hazard maps –*Dobrogea county-* for all crustal earthquakes and recurrence periods: T=200 and 500 years (Intensities MMI).

Conclusions

1.The Carpathians- great variations in lithosphere structure have led to pronounced weakness and the localization of strains in adjacent basins. The strong deep Vrancea earthquakes are localized to a restricted area in the bending zone between the Eastern and Southern Carpathians at least three units in contact: the East European plate, Intra- Alpine and Moesian sub-plates. The strain transfer path is coming from the active Adriatic, Aegean and Vrancea deformation fronts through the ALCADI-Pannonian System;

2.The seismicity of Romania comes from the energy that is released by **crustal** earthquakes , which have a depth not more than 40 km, and by the **intermediate** earthquakes coming from Vrancea region (***unique case in Europe***) with a depth between 60 and 200 km;

3.The last zonation seismic map, existing since 1993, has areas where seismic intensities are sub-evaluated (e.g. Dobrogea, Banat etc.), and other areas are over-evaluated. The chapter regarding „Seismic action" from „Norms for construction building-2004", developed by UTCB-Dept. of Concrete Structures and ***unaccepted*** by National Institute for Earth Physics, proposed design acceleration values far from credible ones;

4.The fundamental unacceptable point of view is that this design code is in peak ground accelerations (PGA) which generates a lot of drawbacks to civil structural designers and to insurance companies which are paying all damages and life loses in function of earthquake intensity;

5.National Institute for Earth Physics from Bucharest developed the concept of “***control***” earthquake. The earthquake on August 30, 1986 is used by us as “***control***” earthquake in all next studies as it fulfils the following states:

(i)-it was strong (M_{GR} =7.0);

(ii)-it was recorded in a lot of seismic station on Romanian territory;

(iii)-the fall plan solutions are very closed (almost identically) to other Vrancea stronger earthquakes (November 10,1940; M_{GR} =7.4 and March 4, 1977; M_{GR} =7.2) and with majority of earthquakes with moderate magnitudes (6.5 < M_{GR} <7.0);

(iv)-the depth of oh hypocenter (h≈135 km) is very close to medium value of all strong Vrancea earthquakes.

(v)-the shape of attenuation curves are like „***concave banana***”

6.The maximum credible Vrancea earthquake has the Richter magnitude , $M_{GR}=7.5$ and this is the magnitude used by us for our Cernavoda Nuclear Plant. The isoseismal map of the maximum possible Vrancea earthquake is obtained finally by using all data known so far and used o combination of probabalistic and deterministic approaches. Also, nonlinear amplification at sediments sites appears to be more important and any attempt at seismic zonation must take into account the local site condition and this nonlinear amplification. It is important in microzonation studies to have the space distribution of the spectral amplification factors values for each frequency domain in Bucharest area for strong Vrancea earthquakes ;

7.Site local amplifications were evaluated by using *Very Hard Rock* (VHR), *Joint Source Site Determination* (JSSD) methods or by using down-hole seismic measurements performed in Bucharest, Iasi, Timisoara etc. Also, *deterministic estimation* of local effects in metro-politan area Bucharest ,Timisoara, Baia Mare, Sibiu,Tulcea, Moldova, Galati etc.were made by using *hybrid and annalytical* methods developed at University of Trieste,*Department of Earth Sciences;*

8.In the microzoning map (local seismic hazard) for Bucharest for maximum possible earthquake in Romania ($M_{GR} = 7.5$) there are 14 zones and each zone is characterized by maximum acceleration (a-max), maximum MMI intensity (I-max) and fundamental period for soil (T). Each parameter for each zone is obtained from "***reference station***" INCERC. The fundamental periods of soils in Bucharest have values between 1.3 seconds and 1.9 seconds;

9.For probabilistic seismic hazard evaluation for Crisana-Baia Mare area and Baia Mare City we used „***Fuzzy Set Theory*** “concept. The fundamental concept of the „”Fuzzy Set Theory is that it replaces the relationship of affiliation from classical theory of sets by a „***affiliation function***", and the consequences of such fundamental changes proved to be extraordinary not only on action plan of the mathematical operators but also in mathematical logic performed.

10.The unsolved problem is in connection to intensity scale for intermediary-depth Vrancea earthquakes… There is not consistency/concordance between physical parameters (PGA,PGV, PGD) of earthquake and them effects to buildings, people etc.

→MMII scale for intermediary-depth

Thank you for your attention !