ROMANIAN ACADEMY

“Sabba S.Ştefănescu” Institute of Geodynamics

- PhD Thesis -

SUMMARY

CONTRIBUTIONS REGARDING THE SEISMIC HAZARD ASSESSMENT IN VRANCEA ZONE AND THE ASSOCIATED PHENOMENA (LANDSLIDES) BY ELECTROMAGNETIC STUDIES

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CONTENTS

INTRODUCTION

The subject of this thesis is keeping with the actual tendency to identify viable solutions concerning seismic hazard assessment, based on a continuous monitoring, in an observation point (test zone), of some electromagnetic (EM) parameters able to emphasize the electrical conductivity changes at lithospheric level, produced by physical and chimical processes associated to the intermediate depth earthquakes.

By this thesis, it was tried to get some new elements regarding the application of an EM methodology to the seismic hazard assessment and the associated landslides generated by the intermediate geodynamic activity of Vrancea zone.

By using this methodology, the aim is not to solve some problems related to the prediction of these events, at least in the actual stage of knowledge, but to reveal how the EQ-s are emphasized in the EM parameters.

To develop more clearly and more completely the subject of the thesis, this paper includes two parts, the first one named "The actual stage at national and international level", and the second one being titled „Original contributions".

Thus, after a reviewof of the most known EM techniques for seismic hazard and induced landslides assessment, especially of the those developed in the last decade, it is pointed out the necessity of a specific approach, from a methodological point of view, regarding the identification of possible precursors, depending on the geotectonic setting and seismological characteristics of the studied zone (magnitude, periodicity and epicentral depth).

At the same time, it was taking into account the fact that, for a more correct assessment of the seismic hazard, the electromagnetic phenomena occuring in the Earth and the relation between them and the seismic events must be understood.

The electromagnetic studies accomplished in the frame of this thesis are centered on a continuos monitoring of some EM parameters having an evident potential in pre-seismic assessment process, the anomalous variations of which, correlated with characteristics of the seismic events, may supply information with precursor character on short term.

The EM methodology used to make an assessment for the seismic hazard and associated events (landslides) was based, firstly, on some adequated techniques and methodology to monitorize the EM field in certain circumstances specific to the Vrancea zone, what made possible that acquired information may be correlated with the specific depth of generation of the analysed geodynamic processes.

The main key in the frame of the EM studies related to the seismic hazard assessment is represented by the distribution of the anomalous values of the Bzn parameter ($Bzn(f) = Bz(f)/B\perp(f)$) recorded on a 2D structure – identified by means of skew and strike parameters and emphasized as a conducting chanel up to the seismogenic volume zone Vrancea, as a result of the analysis of Wiese induction arrows distribution.

The development of the EM methodology related to the natural hazard in the Vrancea seismic zone had as premise the fact that the electrical conductivity changes, before a seismic event occured, could be emphasized by means of Bzn parameter owing his invariant character in seismic calm circumstances (Stănică şi Stănică, 2007; Stănică şi Stănică, 2009, 2010).

Data analysis (time series reflecting the anomalous distributions of the Bzn are compared with intermediate depth earthquakes) carried out as result of the EM monitoring at Provita Geodynamic Observatory, in the time intervals 01 Sept. - 30 Oct. 2004, 16 Jan. - 30 Sept. 2009, 01 Apr. - 31 Dec. 2010, 01 Jan. - 30 Nov. 2011 şi 01 Jan. – 30 Jun. 2012, corresponding to a more significant seismic activity, led to the identification of some correlations between the Bzn parameter (having a precursor character) anomalies and the occurence of some earthquakes, as well as to some conclusions regarding the establishment of some relations between the magnitude and the mentioned EM parameter anomaly amplitude, for various circumstances, such as: one or more earthquakes at large time intervals, or more earthquakes at very short time interval.

PART I.

THE ACTUAL NATIONAL AND INTERNATIONAL STAGE

The first part of the thesis offers a general image on the actual stage of knowledge in the EM research range, on ground and by satellites, concerning the seismic hazard study. În this context, in **Chapter 1**. the results of some EM studies accomplished by researchers of Greece, USA, Japan, China, France and India, based on various parameters with a potential precursory character, depending on the applied method, are presented. It is also pointed out that the problem of the seismic hazard evaluation for a certain zone may be approached taking into account the folowing aspects: the specific geotectonic setting of the investigated zone, the distribution in space and time of the earthquakes, as well as the aim.

Among the most known studies, those accomplished by Varotsos and the team, centered on the seismo-electric anomalies extracted from the monitoring data of the geoelectric potential variations, have been presented. Although there are numberless controverses (Wang et al., 2009; Uyeda, 1996) concerning various aspects of the VAN method, this made possible the prediction of some earthquakes for long time, over ten years.

The information supplied by Miyakoshi (1986) after measurements of natural potential, by using two parallel dipoles with different length, before and after EQ (M=5.6), are based also on significant differences of potential. It must be mentioned that the shorter dipole, crossing a fault, registered stronger signals, what suggests the role of the geotectonic factor.

A relevant example regarding the manner of using the electric resistivity as a precursor is represented by the results carried out by Zhang and Shen (2011), related to its analysis before the devastating EQ of Wenchuan/ 12 mai, 2008. The authors ascertained that the resistivity becomes a very sensitive indicator for tectonic changes, and, at the same time, it may be influenced by a lot of factors, what makes necessary to correlate it with other data categories.

Related to the seismic events, the geomagnetic field anomalies are emphasized among the most investigated phenomena, being interpreted in terms of many physical processes, depending on their relevance level. Such an example, regarding the Loma Prieta earthquake, is offered in the lower figure:

Loma Prieta EQ , M 6,9 ↓ 1989,18 Oct., ora:00:04 UT

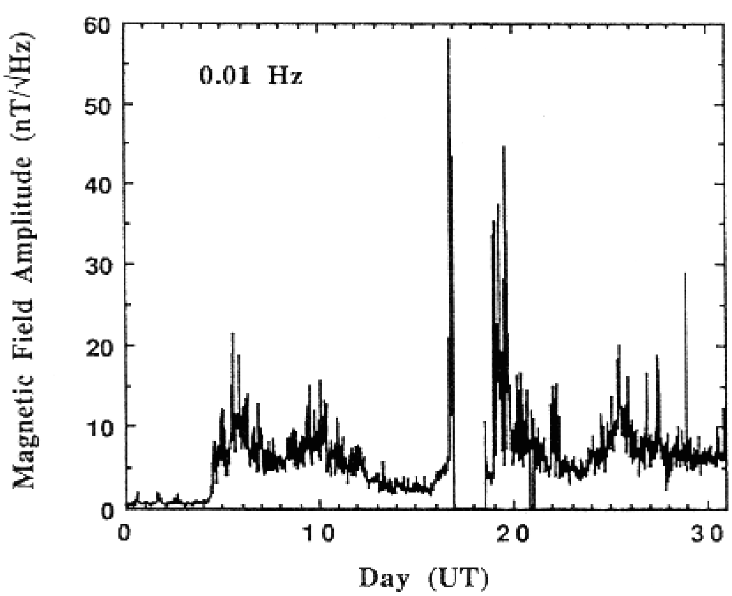

Fig. 1-1. Anomalous geomagnetic variations associated with the Loma Prieta earthquake. Narrow band signal dissapears beginning with 5 October, and the anomalous signals are emphasized at 0,01Hz frequency band, registering a sudden increase of the values. Fraser-Smith et al. (1990)

The anomalous geomagnetic changes related to earthquakes are also presented in Fig.1-2:

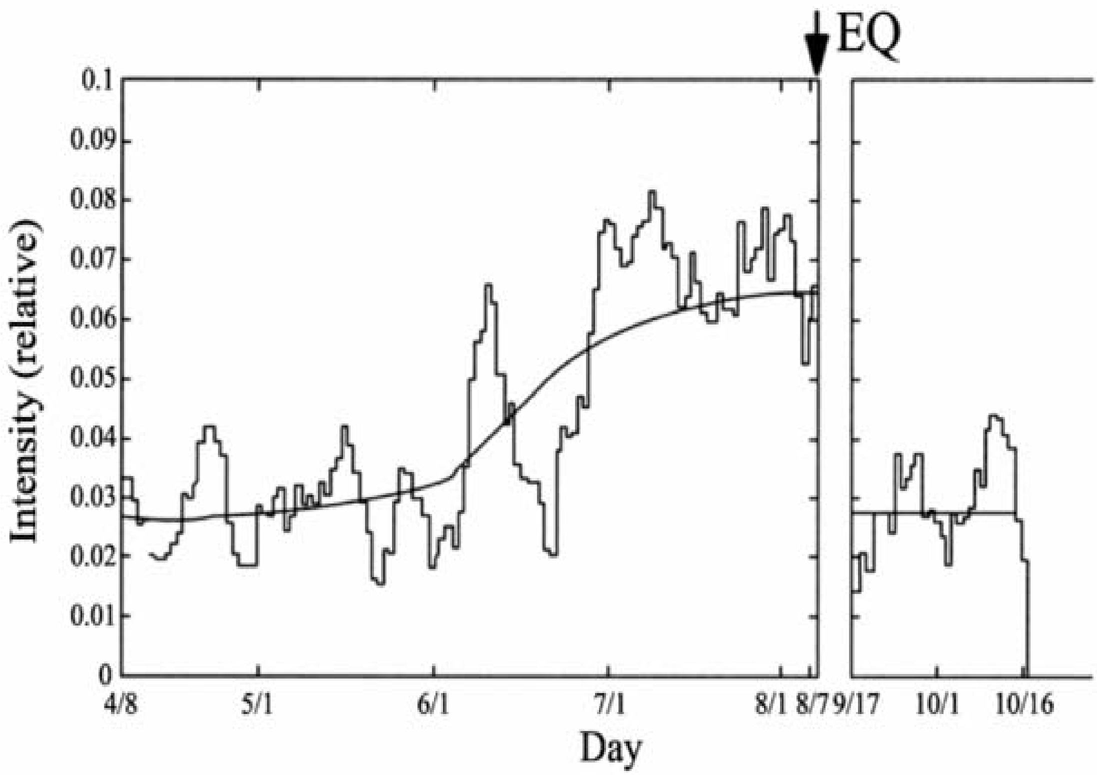

Fig.1-2. Anomalous geomagnetic changes associated with the Guam EQ/ 8 august,1993, recorded on the time interval 8 aprilie- 16 Oct., with a interruption between 8 August and 17 September, when the field comes to the previous values. (Hayakawa et al., 1996)

Starting from the data and the method initiated by Hayakawa, Jeremy N.Thomas et al., 2009, performed a complex study on the geomagnetic field anomalies precursory to the Mw 7.7 /Guam, 1993, accomplishing two sets of data for GAM and Kakioka stations: some reffering to the time series registered for the vertical (Z) and horizontal (H) components, according to the figure 1-3, others emphasizing the magnetic polarization ratio Z/H , according to the figure 1-4, both of them being compared with Hayakawa's data.

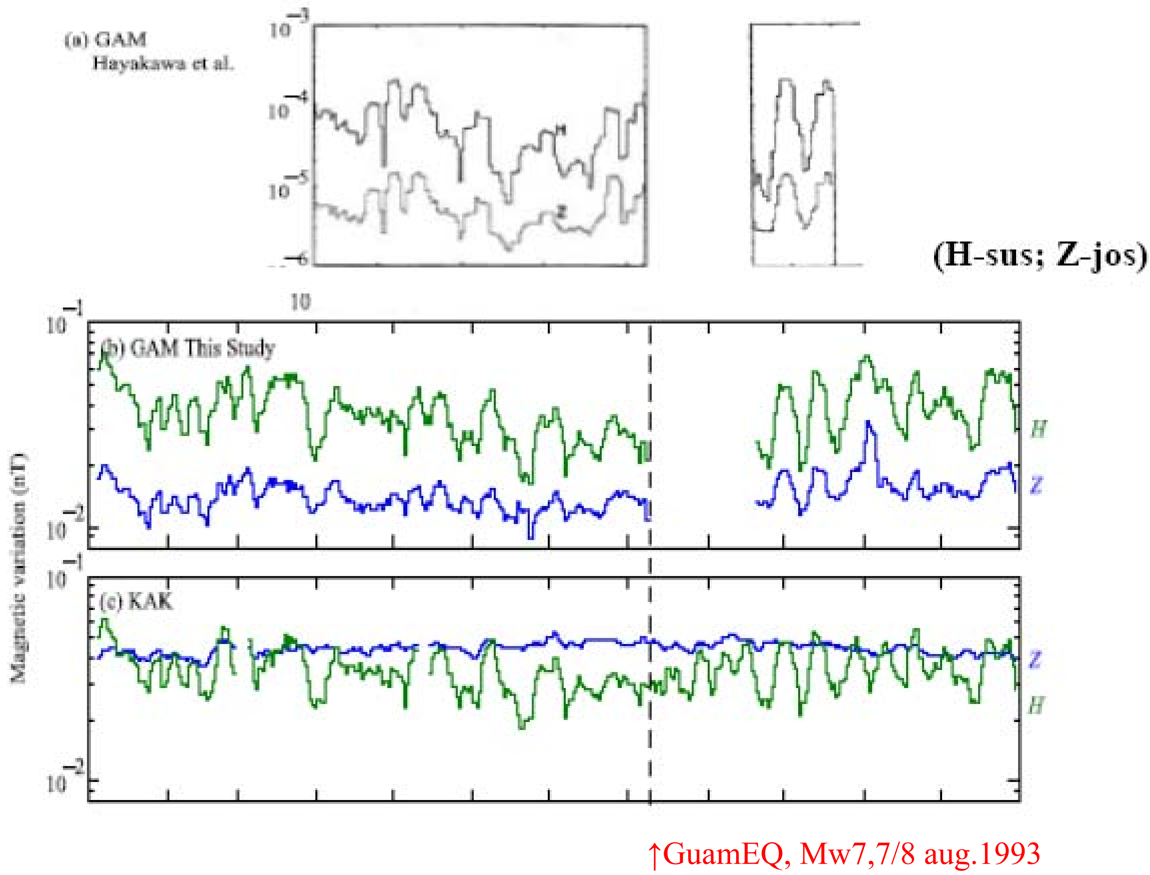

Fig. 1-3 . Representation of the geomagnetic field variations (Z vertical component and H horizontal component) during 1993 year, as against the EQ occurence moment (Thomas et al., 2009)

To make comparison, the polarization ratio values are presented in figure 1-4, for the folowing data:

a. Data recorded at Guam, by magnetic station GAM, processed by Hayakawa et al., 1996;

b. Data recorded at USGS Guam Observatory, placed 67 km away from epicentre, by magnetic station GAM, processed by Thomas et al, 2009, in conformity with relation established by Hayakawa et al., 1996;

c. Data recorded at Kakioka Observatory and processed by Thomas et al. (2009);

d. Amplitude difference between polarization ratio computed for Guam Observatory and that determined for Kakioka Observatory.

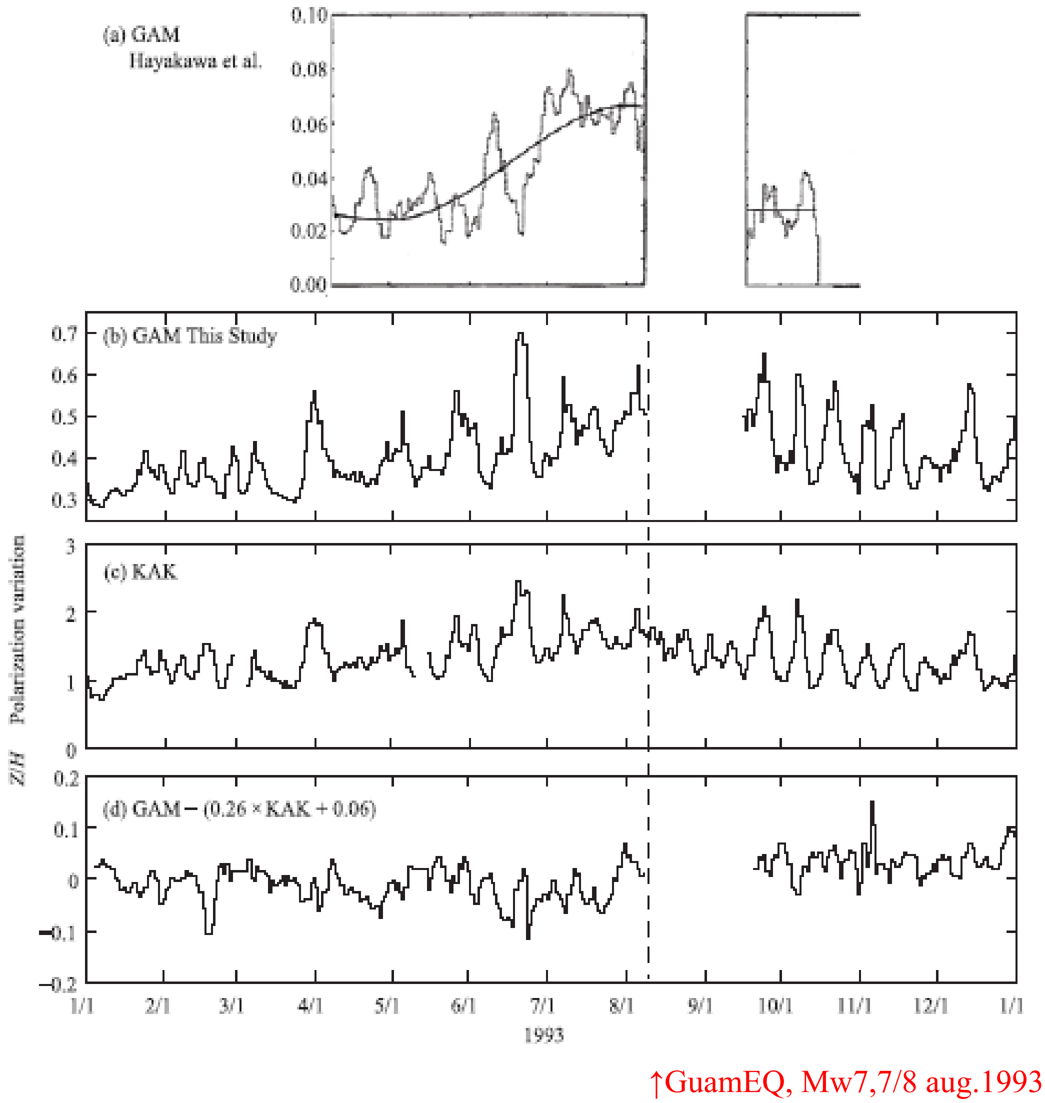

Fig. 1-4**.**Variation of the Z/H ratio in the range 0,01-0,05Hz (Thomas et al., 2009)

Studies regarding the EM phenomena related to the seismic events, by means of the magnetic polarization values, were also performed by Hattori et al. (2002), on the base of the data recorded in ULF domain, at 3 geomagnetic stations. From these data, it is clearly observed that the polarization value shows an obvious increase before earthquake on the curve obtained at Tarumizu, the nearest station from epicentre.

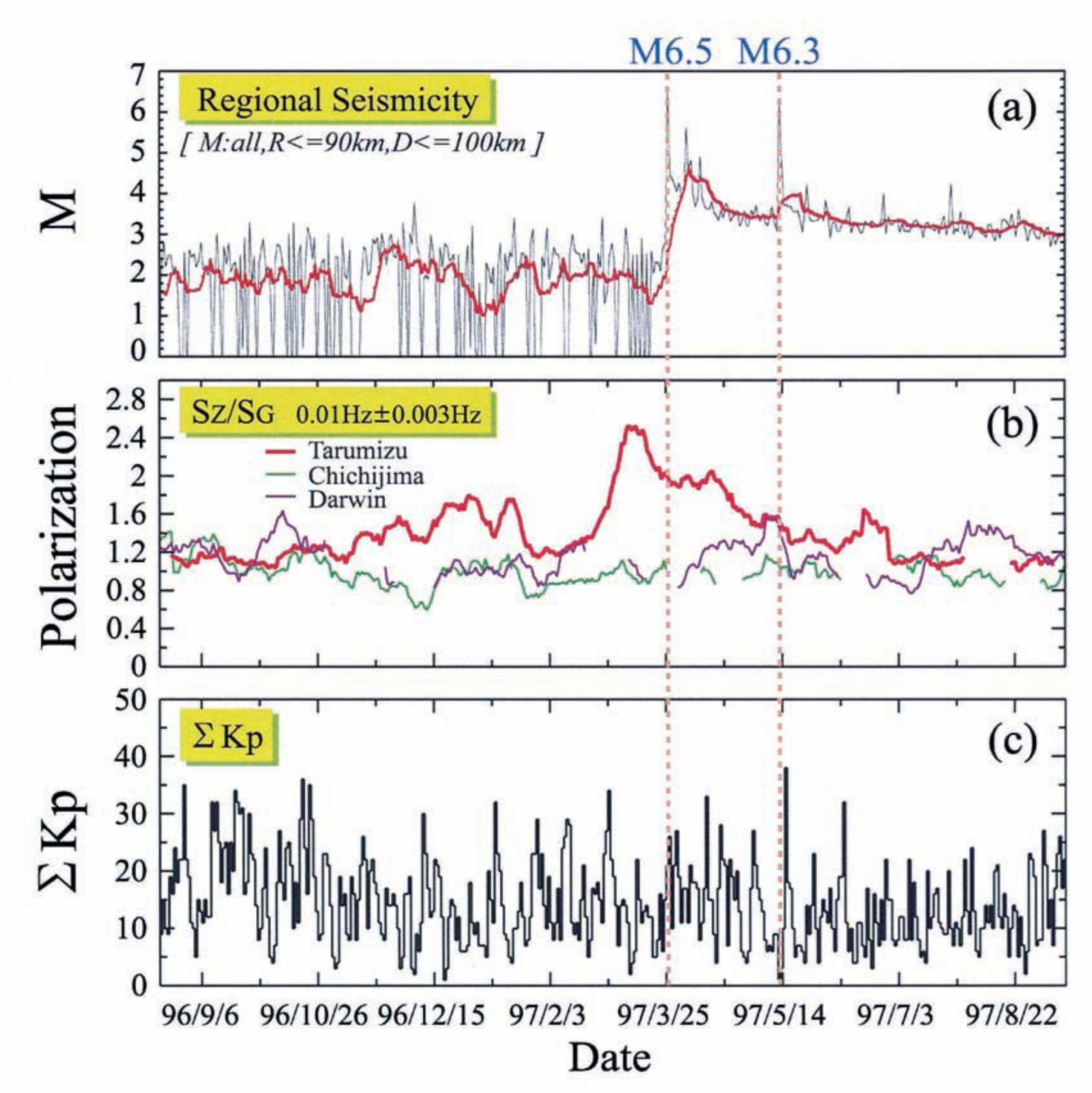

Fig. 1-5. Anomalous geomagnetic variations associated with the Kagoshima EQ (after Hattori et al., 2002)

(a) The regional daily seismicity in terms of total horizontal magnitudine, at 0,01 Hz frequency band;
(b) The polarization variations S_Z/S_G (Z- vertical component and G- total horizontal) at 0,01 Hz frequency band, ;
(c) Global magnetic activity Kp indices values.

Some satellitar studies are also presented, as these got a larger and larger use owing to their posibilities of covering ample areas and to get important quantities of data, under the circumstances in which the measurements are not inflenced by various factors.

Thus, a conclusive example is offered by the satellitar studies performed by Parrot et al. (2006) and Bhattacharya et al.(2009), based on the spectral density analysis, in the frame of the

DEMETER program, accomplished by means of the Franch satellite with the same name, launched in 2002 year.

The landslides associated with major earthquakes represent the subject of the **Chapter 2**., where some of the most usual satellitar electromagnetic techiques are presented.

As the approach of the problem regarding the seismic hazard evaluation is directly related to the geotectonic characteristics of the investigated seismic zone, the particularities of the seismogene Vrancea zone and the most reprezentative geotectonic models proposed for it are presented in the frame of the **Chapter 3.**

PART II.

THE ORIGINAL CONTRIBUTIONS

The recent studies and researches, performed in the geodynamics domain, emphasized that the main difficulty to achieve a supervision system around the area characterized by a high natural hazard (seismic events and seismic induced landslides) is represented by the implementation of the observation systems specific to the investigated domain, and the accumulation of information carried out by monitoring and continuous and complete processing of the geodynamic parameters. For this reason, to delimit the active zones, it is imposed to use some adequate methodologies and techniques allowing the acquisition, store and complex processing of the information concerning spatio-temporal distribution of some parameters associated with geodynamic activity.

In this contex, in **Chapter 1/Part II,** the achievement and implementation of an adapted system for the monitoring (Stanica D.A. & Stanica D., 2010) and real time transmission of data (Stanica D.A. et al, 2008) to the central computer is presented as an important contribution.

To elaborate an electromagnetic methodology for the seismic hazard and associated landslides assessment of Vrancea zone, the development of some adequate methodologies and techniques has taken priority.

The physico-chimical and stress changes appearing at subcrustal level (intermediate depth EQ), or subsurface (seismic induced landslides), which may represent the possible cause for an instability state around the seismic-activ Vrancea zone, may be emphasized by the anomalous behaviour of the EM parameters continuously recorded in the frame of the geodynamic observatories and/or in discret points placed on the surface of the landslide. For this reason, a test zone was choosen (Provita de Sus Observatory) where a specific equipment (Fig.2.1), able to get necessary data for seismic hazard (Stanica D.A. et al., 2009; Stanica D. & Stanica D.A., 2010; Stanica D. & Stănică D.A., 2011) and associated landslides evaluation (Stanica D.A. et al., 2008; Stanica D.A. & Stanica D., 2010; Stanica D.A. & Stănică D., 2011) was installed for the multiparametric EM monitoring.

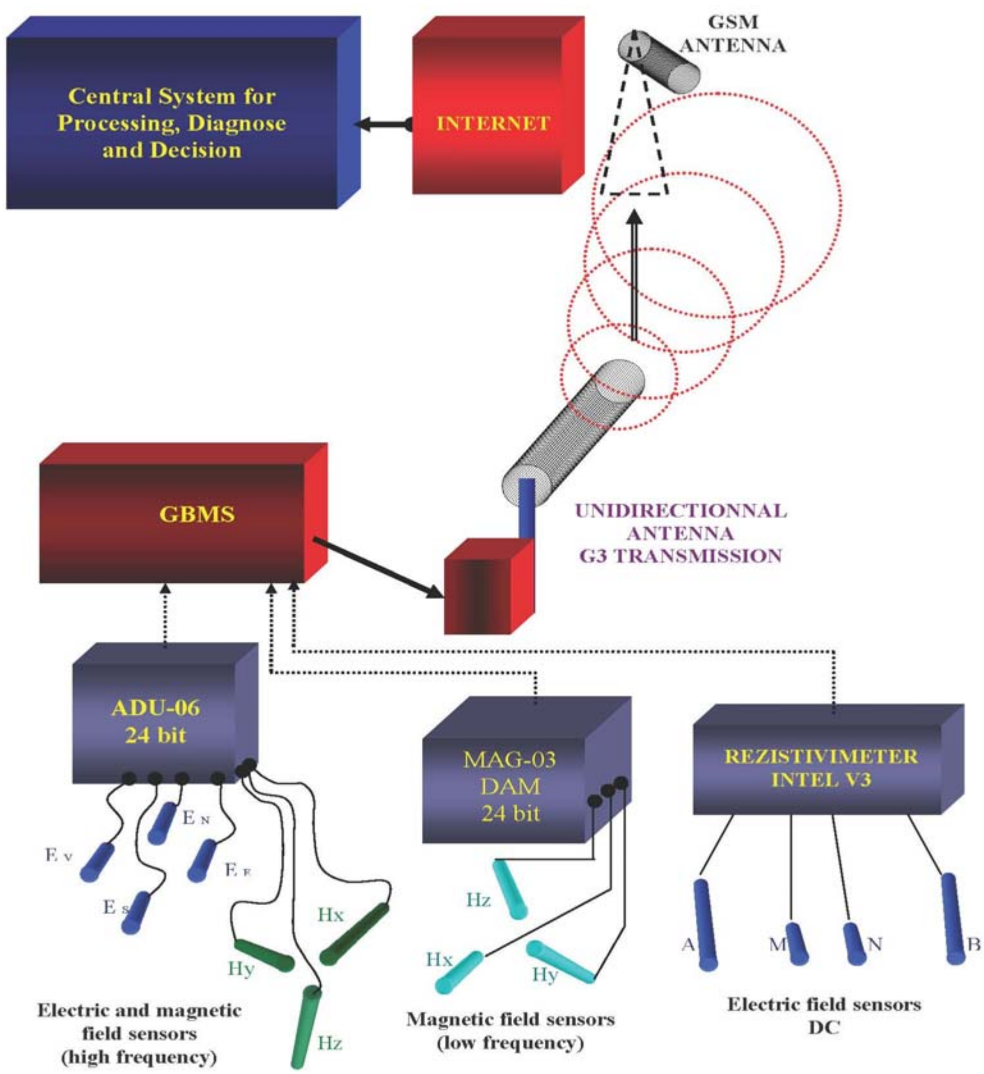

Fig. 2-1. Configuration of the continuous and in discret points monitoring system.

EW, EE, ES and EN - electric sensors on the four directions.

The structure of the sensors system, their placement mode and geoelectric pattern determined for normal circumstances, as well as the involved time constants, must be well established, for any kind of hazard, by means of specific electromagnetic research.

The advantage of the EM methodologies and techniques is derived from their posibility to be adapted, so that the information supplied by multiparametric monitoring may be correlated with depths specific for the generation of the analized geodynamic processes. Thus, the carried out results must contribute to the folowing:

- Determination of the dimensionality characteristics of the tectonic compartments getting in contact, begining from surface (some meters for landslides) up to lithospheric depth (about 180km, for intermediate depth seismicity of Vrancea zone);
- Determination of the geoelectric pattern for zones selected to be multiparametric monitorized, with implications in the characterization of the natural hazard generated by the two types of geodynamic processes;
- Elaboration of spatio-temporal distributions of the parameters affected by accumulation/release of energy associated with geodynamic processes;
- Elaboration of new concepts regarding the connection among various types of hazard indicators (earthquakes and seismic induced landslides) and the factors triggering the mentioned phenomena.

Monitoring program used in the frame of the Provita de Sus Geodynamic Observatory provides the time series corresponding to the geomagnetic components $B_{\perp}$, By and Bz, with a sampling rate $\Delta t = 5$ seconds, and information is stocked every 60 sec. on a HDD, as „*.txt ." file. The files are transmitted daily to the Center, by means of the STDE (Transmission System of Electromagnetic Data), wireless, integrated to the acquisition, store and transmission system (Fig.2-2.), where these are received and processed in order to get Bzn parameter – with a seismic precursory character.

Fig. 2-2**.** Monitoring and transmission data system (wireless)
at Provita de Sus Geodynamic Observatory

To give an example, geomagnetic time series and carried out results for a 32 min. time interval/April 2, 2010 are presented in Table 2.1.

Chap.2/ Part II is devoted to the contributions to the methodology and procedures of results evaluation. So, in order to verify the reliability level of the methodology of making evident electromagnetic precursors, correlations of the Bzn anomalous distribution with intermediate depth earthquakes ($M \geq 3.0$) of Vrancea zone were done for different years, on time intervals with more significant seismic activity.

The Bzn is determined by relation 2.1.:

$$Bzn(f) = \frac{Bz(f)}{B_{\perp}(f)} \tag{2.1.}$$

All the earthquakes were taken over from the National Institute for Earth Physics - Magurele(INFP) catalogue.

The use of Bzn parameter to emphasize seismic precursors is based on the concept according to which the geomagnetic component of extern origin (magnetosphere-ionosphere) is constant, in conformity with relation (2.1), and that of intern origin,in conformity with relation (2.8), may be produced by the change of the electrical conductivity in litosphere due to the stress increase of the seismogen volume, associated with cracking/fracture processes of the rocks and release of fluides that migrate along the faults system extended between seismic-active Vrancea zone and Provita de Sus Geodynamic Observatory (OGPS).

As between the electric components (Ex şi Ey) and magnetic components (Bx şi By) of the natural electromagnetic field there is the interdependence relation:

$$\begin{pmatrix} Ex \\ Ey \end{pmatrix} = \begin{pmatrix} Zxx & Zxy \\ Zyx & Zyy \end{pmatrix} \begin{pmatrix} Bx \\ By \end{pmatrix}, \tag{2.2}$$

where : Zxx, Zxy, Zyx, Zyy tensor impedance elements expressed in $[VA^{-1}]$, then for a 2D geoelectric structure, where the electric conductivity varies after 2 directions (horizontal and vertical), the conditions:

$$\begin{aligned} Zxx &= -Zyy = 0 \\ Zxy &\neq -Zyx \end{aligned} \tag{2.3}$$

must be fulfiled.

Taking into account that the dimensionality parameter skew may be expressed as :

$$Skew = \left\| \frac{|Zxx + Zyy|}{|Zxy + Zyx|} \right\|, \tag{2.4}$$

then, for a 2D geoelectric structure its value must be less than 0.3 .

SERII DE TIMP GEOMAGNETICE (B⊥, By , Bz , Bzn, Bzn med, ρn, ρn med şi STDEV)									TABEL 2.1.	
Data	Ora	B⊥ [μT]	By[μT]	Bz[μT]	**Bzn**	**Bzn med**	**STDEV**	**ρn**	**ρn med**	**STDEV**
2/4/2010	6:02:31	22.989	0.233	42.315	1.840663	1.840107	0.000302	3.38804	3.385993	0.001113
2/4/2010	6:03:31	22.989	0.233	42.316	1.840706			3.3882		
2/4/2010	6:04:31	22.989	0.233	42.316	1.840706			3.3882		
2/4/2010	6:05:31	22.99	0.234	42.316	1.840626			3.387905		
2/4/2010	6:06:31	22.989	0.234	42.316	1.840706			3.3882		
2/4/2010	6:07:31	22.989	0.234	42.316	1.840706			3.3882		
2/4/2010	6:08:31	22.989	0.234	42.316	1.840706			3.3882		
2/4/2010	6:09:31	22.988	0.235	42.316	1.840786			3.388495		
2/4/2010	6:10:31	22.988	0.235	42.316	1.840786			3.388495		
2/4/2010	6:11:31	22.987	0.236	42.316	1.840867			3.38879		
2/4/2010	6:12:31	22.987	0.236	42.316	1.840867			3.38879		
2/4/2010	6:13:31	22.987	0.236	42.316	1.840867			3.38879		
2/4/2010	6:14:31	22.988	0.236	42.316	1.840786			3.388495		
2/4/2010	6:15:31	22.988	0.237	42.316	1.840786			3.388495		
2/4/2010	6:16:31	22.988	0.237	42.316	1.840786			3.388495		
2/4/2010	6:17:31	22.989	0.237	42.316	1.840706			3.3882		
2/4/2010	6:18:31	22.989	0.237	42.316	1.840706			3.3882		
2/4/2010	6:19:31	22.989	0.238	42.316	1.840706			3.3882		
2/4/2010	6:20:31	22.99	0.238	42.316	1.840626			3.387905		
2/4/2010	6:21:31	22.99	0.238	42.316	1.840626			3.387905		
2/4/2010	6:22:31	22.991	0.238	42.316	1.840546			3.387611		
2/4/2010	6:23:31	22.991	0.238	42.316	1.840546			3.387611		
2/4/2010	6:24:31	22.992	0.237	42.316	1.840466			3.387316		
2/4/2010	6:25:31	22.992	0.237	42.316	1.840466			3.387316		
2/4/2010	6:26:31	22.992	0.237	42.316	1.840466			3.387316		
2/4/2010	6:27:31	22.992	0.237	42.316	1.840466			3.387316		
2/4/2010	6:28:31	22.992	0.236	42.316	1.840466			3.387316		
2/4/2010	6:29:31	22.992	0.236	42.316	1.840466			3.387316		
2/4/2010	6:30:31	22.992	0.236	42.316	1.840466			3.387316		
/4/2010	6:31:31	22.992	0.235	42.316	1.840466			3.387316		
2/4/2010	6:32:31	22.992	0.235	42.316	1.840466			3.387316		
2/4/2010	6:33:31	22.992	0.235	42.316	1.840466			3.387316		
2/4/2010	6:34:31	22.992	0.235	42.316	1.840466			3.387316		

The theoretical basis of this methodology consists in the fact that, at Earth' surface, the vertical geomagnetic component (Bz) totally expresses a secondary field, and its existence represents an immediate indicator of the lateral inhomogeneities (Word et al., 1970). Furthermore, for a 2D structure, (Bz) is essentially produced by the horizontal component perpendicular to the geoelectric structure orientation ($B\perp$) and, as a sequence, the normalized function Bzn having the form of the relation (2.1) must be invariable in time (Word et al., 1970), under the geodynamic calm circumstances, but it becomes unstable because of some geodynamic processes that may generate changes in the electric conductivity values. Therefore, Bzn may be considered an invariant, then an EM parameter with a precursory character of the intermediate depth seismic activity. (Stanica D.& Stănică D.A., 2010; Stănică D.& Stănică D.A., 2012). To explain the connection between an earthquake occurence and the anomalous values of the Bzn(f) , the following relations that allow its assessment in terms of resistivity are introduced:

$$\rho z\,(f) = \frac{0.2}{f}\left|\frac{E_{||}(f)}{Bz(f)}\right|^2 \tag{2.5}$$

where: ρz = vertical resistivity [$\Omega m = VmA^{-1}$], (f) = frecquency [Hz], $E_{\|}$= electric field paralel to the direction of the structure [Vm^{-1}], and Bz = vertical component of the magnetic induction [Tesla (T) = $Vs\ m^{-2}$],

and

$$\rho_{||}(f) = \frac{0.2}{f}\left|\frac{E_{||}(f)}{B_{\perp}(f)}\right|^2 , \tag{2.6}$$

where: $\rho_{\|}$ = the resistivity paralel to the direction of the structure, $B\perp$ = magnetic induction component perpendicular to structure.

On the basis of the last two relations, Bzn may be written in terms of resistivity:

$$\left|Bzn\,(f)\right| = \sqrt{\frac{\rho_{||}(f)}{\rho z\,(f)}} \qquad (2.7)$$

By relation (2.7) it is demonstrated that normalized function Bzn may be associated with the electric resistivity variation along the fault system developed at lithospheric level, what may be expressed by means of the normalized resistivity (**ρ_n**) :

$$\rho n(f) = \frac{\rho_{||}(f)}{\rho z(f)} \qquad (2.8)$$

Electromagnetic parameters **Bzn (f)** şi **ρ_n** may be used to evaluate the seismic hazard, taking into account their precursor quality of the seismic activity at intermediate depth around Vrancea zone (Stanica and Stanica, 2007), only when the observation point is placed on a 2D structure, because only in this case the parameters determined by relations (2.1) and (2.8) are invariable in time, in normal (non-seismic) circumstances, and become instable some days before a seismic event (Stanica D.& Stănică D.A., 2011, Stănică D.& Stănică D.A, 2012).

In this context, to identify a 2 D structure, in order to install the recording station of the data, an electromagnetic sounding (magnetotelluric) was made. The results showed a 2D geoelectric structure (skew ≤ 0.3) and an orientation about E-W(strike = $96{,}5^0$), for the frequency range of 0.1 – 0.001 Hz.

The reliability level of the evaluation methodology of the seismic hazard was verified by analysis of the daily mean distribution of the Bzn and Bzn* corelated with intermediate depth earthquakes ($M \geq 3.0$) for the folowing five time intervals:

1). 01 Sept. –30 Oct. 2004; **2).** 16 Jan.-30 Sept. 2009; **3).** 01 April 2010 -31 Dec. 2010;
4). 01 Jan. 2011 - 30 Nov. 2011; **5)** 01 Jan. - 30 June 2012.

For a clear evidence of the pre-seismic anomalies emphasized in the Bzn time series, a relation of statistical analysis based on standardized random variables was introduced:

$$Bzn^* = \frac{X - \overline{X}}{\overline{Y}} \qquad (2.9)$$

where:

- Bzn* is the parameter taking into account the presence of the geomagnetic noise and that emphasizes the presence of the preseismic anomalous intervals, using standard deviation;
- X is the mean value of the Bzn parameter determined for anomalous intervals of 1, 5 or 9 consecutive days, and taken before every day of the next new time serie;
- $\overline{X}$ is the mean value of the Bzn parameter determined for a 30 consecutive days interval, taken before every day of the next new time serie;
- $\overline{Y}$ is the mean value of the standard deviation determined for 30 consecutive days interval, taken every day of the next new time serie;

To illustrate it, in Fig.2-3, the daily mean distribution of the Bzn parameter and of the standard deviation (STDEV) obtained for the interval 01 April 2010-31 Dec. 2010, in order to identify the pre-seismic signals associated with the eight intermediate depth EQ (M>3.5) produced in this period, in Vrancea zone (Tabelul 2.2).

TABELUL 2.2.

Data	Lat.	Long.	Adâncime [km]	Magnitudine	Zona
08-06.2010	45.57 N	26.42 E	110	4.5	Vrancea
12-07-2010	45.66 N	26.49 E	103	3.8	Vrancea
21-07-2010	45.53 N	26.39 E	110	3.6	Vrancea
30-08-2010	45.68 N	26.54 E	143	3.7	Vrancea
30-09-2010	45.50 N	26.31 E	135	4.7	Vrancea
25-11-2010	45.59 N	26.36 E	120	3.8	Vrancea
02-12-2010	45.68 N	26.52 E	106	3.8	Vrancea
05-12-2010	45.68 N	26.54 E	146	3.9	Vrancea

Although, to emphasize the pre-seismic anomalies (Fig.2-3) and to eliminate the possible effects generated by seasonal variations or geomagnetic storms, that are observable by the STDEV ≥ 0.002, for the time series of Bzn it was applied the above mentioned statistical analysis procedure (relation 2.9), where:

- X represents the mean value of the Bzn determined for a 5 consecutive days, taken before every day of the next new serie (in this case starting with 01 May, 2010);
- $\overline{X}$ is the mean value of the Bzn determined for a 30 consecutive days interval, taken before every day of the next new serie;
- $\overline{Y}$ is the mean value of the standard deviation determined for a 30 consecutive days interval, taken before every day of the next new serie;
- Bzn* represents the separation limit between the pre-seismic anomalous domain and those with a normal trend, by using the standard deviation.

The distribution of the Bzn* time serie (Fig. 2-4.) emphasizes more anomalous intervals of maximum values that may be most probably associated with the intermediate depth EQ-s of Table 2.2., as follows:

a) 2 May - 15 May 2010, with a maximum on 11 May (Bzn* = 3.237), that could represent a precursor of the earthquake M= 4.5/ 08.06.2010 ;

b) 31 May – 27 June, with a maximum on 20 May (Bzn* = 3.2595), that may be a possible precursor of the two EQ-s : M= 3.8/12 July and M= 3.6/21 July;

c) 23 Aug. - 23 Sept., where two maximum values are presented: Bzn* = 5.741 / 26 August and Bzn* = 4.789/ 4 Sept. associated with the two EQ-s: M= 3.7/30 Aug., and M= 4.7/30 Sept., respectively;

d) 12 Nov. – 3 Dec., characterized by a maximum value Bzn* = 2.180, on 17 Nov., associated with a cumulated effect of the three EQ-s: M= 3.8 /25 Nov., M= 3.8 /2 Dec. and M= 3.9/ Dec.

Finally, the analysis of the Bzn* time series accomplished on the interval 01 May –31 Dec. 2010, to evaluate the seismic hazard related to the intermediate depth EQ-s having the magnitude (M) > 3.6, of Vrancea zone, leads to the following conclusions synthesized in Fig. 2-4:

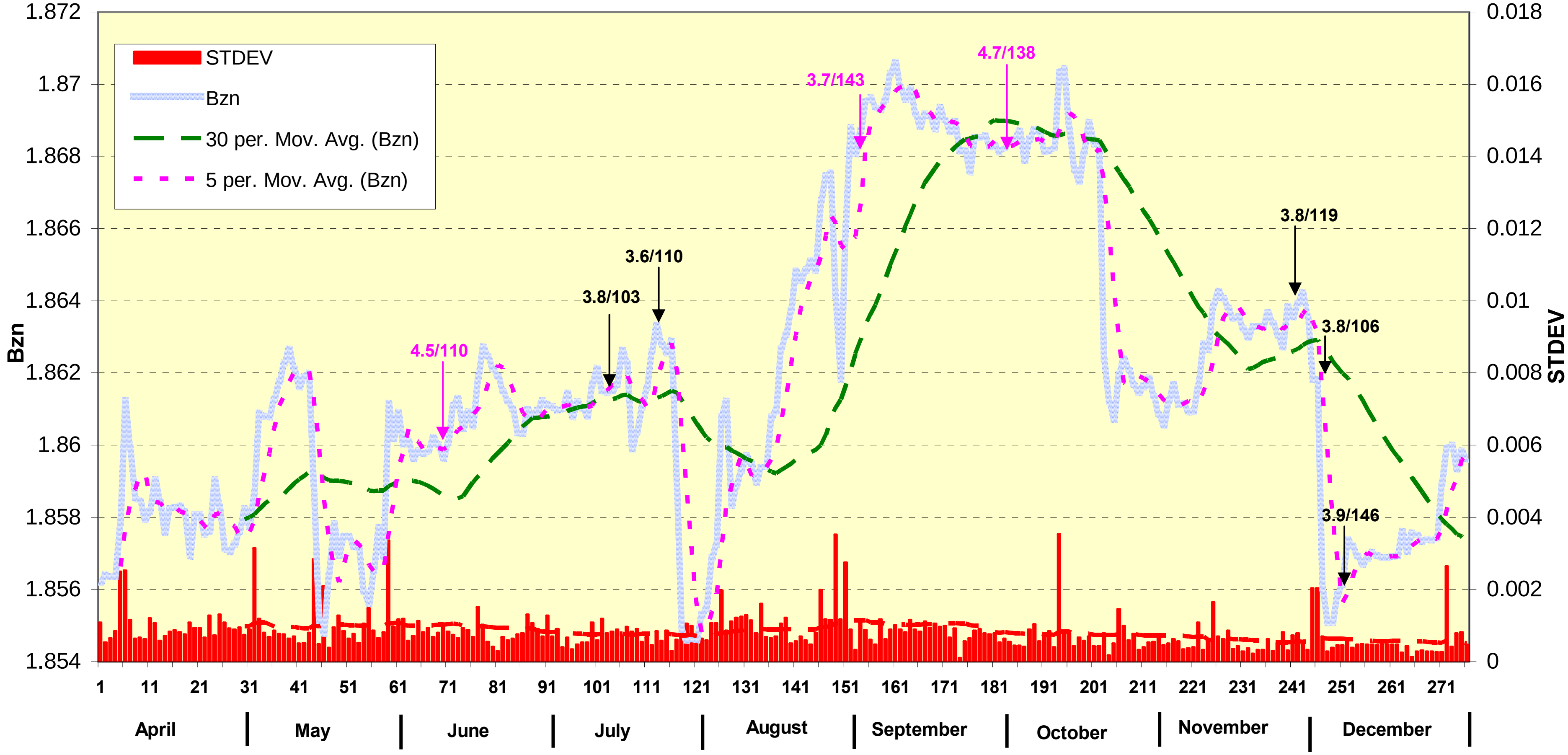

Fig. 2-3. Daily mean distributions of the Bzn parameter and standard deviation (STDEV) correlated with the eight EQ-s appearing on the interval 01 April, 2010-31 Dec., 2010.

The vertical arrows indicate the EQ occurence date; 4.7 / 138km indicates : magnitudine / hipocentru;

Pink and green dashed lines represent the mean values of the Bzn on 5 and 30 days;

Red dashed line represents the mean values of the STDEV on 30 days.

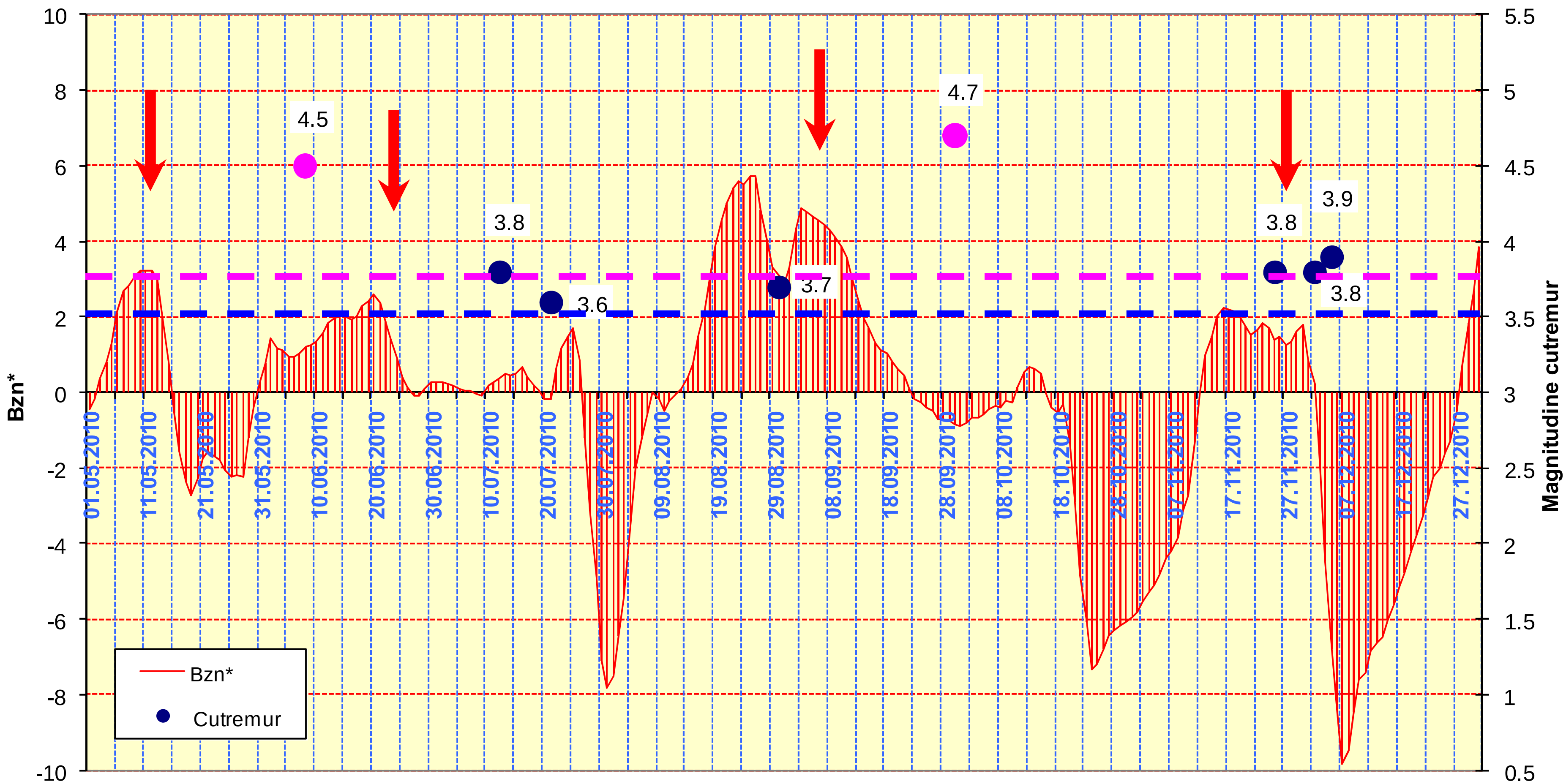

Fig. 2-4. The pre-seismic anomalies emphasized on the basis of the Bzn*distribution obtained by appying the statistic analysis relation (2.1) on the time series Bzn şi STDEV carried out in the period 01 May-31Dec., 2010.
The full circles represent earthquakes; Red vectors indicate the possible precursors for the eight EQ-s (Table 2.3); Blue dashed line (Bzn*=2•STDEV) and pink dashed line (Bzn*=3•STDEV) represent the separation limits between the normal trend and anomalous zones by using the STDEV.

- Separation limit between the normal trend and the precursory anomalous domains associated with the EQ-s having M>3.6 is represented by Bzn* = 2•STDEV (blue dashed line);
- Anomalous domains of maximum (Bzn* ≥ 3•STDEV) are most probably associated with seismic events of $M \geq 4$.

For making the induced landslides evaluation, it was selected the Provita de Sus landslide zone as it was mainly reactivated along the Provita de Sus Fault by the earthquake Mw=6/27 Oct. 2004. The landslide has been developed in a flysh area, what means a very complicated geotectonic sitting (Tatu et al., 2005).

In the frame of the performed studies a high frequency EM methodology (Stanica &, Stanica, 2011) was used and the skew, strike and anisotropy parameters were determined in order to correlate them with the changes of the geoelectric structure resulted as a consequence of the cracking/fracture processes.

A post-seismic evaluation of the landslide hazard, related to its level (H) was approached by using Mora and Vahrson's methodology (Mora and Vahrson, 1994), according to which

$$H = (Sr * Sl * Sh) * (Ts); \qquad (2.10)$$

Where : Sr = 3 ;

Sl = 4 (lithologic factor for hazard susceptibility evaluation);

Sh = 4 (humidification factor – correlated with the low resistivity values, cca. 7-8 ohm.m, corresponding to the landslide surface interval);

Ts = 1 (Indicator of seismicity triggering, determined in conformity with the methodology previously mentioned, on the basis of peak-ground acceleration PGA - de 25 cm/s^2, supplied by INFP-Magurele.

Substituting these values in ec.2.10, the landslide hazard level is obtained**:**

$$H = (3.4.4).1 = 48, \qquad (2.11)$$

which, according to the clasification presented in the frame of Mora and Vahrson's methodology (Tabel 2.3.) indicates for the Provita de Sus landslide a landslide hazard potential corresponding to the "class 3" – namely a moderate level.

TABEL 2.3

Valoarea lui H	Clasa	Gradul potenţialului de hazard de alunecări de teren
< 6	1	Neglijabil
7-32	2	Scăzut
33-162	3	Moderat
163-512	4	Mediu
513-1250	5	Înalt
> 1250	6	Foarte înalt

CONCLUSIONS

The assessment of the seismic hazard involves a multitude of factors variable in time, what make this equation to be hardly solved. In spite of this, a very ample research activity is developed, especially in the countries where these kind of events may have dramatic consequences, by trying to identify some elements/phenomena/parameters with a certain relevance for the geodynamic changes, and possible seismic events ocurences, respectively.

The contributions to the evaluation of the two types of natural hazard, by EM studies in the frame of this thesis are developed on two directions:

*** Contributions to the data acquisition and processing :**

- The achievement and implementation of the EM data transmission system from the Geodynamic Observatory (Proviţa de Sus);
- The optimization of the data processing algorithms in the time-frequency domains (FFT şi FFT- pass band filtering), used to determinate the EM parameters Bzn and ρn, in f < 1,666E-2 Hz interval, so that 2D structure condition be fulfilled;

- The application of a statistic analysis method based on a standardized random variables equation, used for a better individualization of the pre-seismic maximum anomalous domains of the Bzn parameter, that were correlated with the intermediate depth seismicity of Vrancea zone;
- The introduction of some processing procedures of the time series related to the Bzn parameter evolution (distribution of mean values determined for various time intervals: 1, 5 and 30 days), so that the information supplied by them may allow to extract some conclusions more efficient in the seismic hazard evaluation. These procedures are usefull because, although sometimes a better correlation between the Bzn parameter amplitude and the EQ magnitude may be ascertained, on some intervals are shown more maximum anomalous domains before an earthquake, what leads to a superposition effect and makes difficult to emphasize the pre-seismic anomalies;
- The test of the two parameters Bzn şi ρn, on the same time interval (01 Jan. - 31 Dec., 2011, to verify their pre-seismic anomalous behaviour;
- The verification of the EM methodology reliability also for M>6 earthquakes, by analizing the pre-seismic anomalous distribution of the Bzn parameter associated to the M9 mega-EQ -Tohoku, Japonia/ 11 March, 2011;

*** Contributions to the data analysis and the seismic and landslides hazard evaluation:**

A.) – Data analysis on 5 time intervals (01 Sept. - 30 Oct. 2004 , 16 Jan. - 30 sept. 2009, 1 April - 31 Dec. 2010, 01 Jan. - 30 noi. 2011, 01 Jan. – 30 June, 2012), corresponding to a more significant seismic activity. The results are firstly presented as time series that reflect the anomalous distributions of Bzn compared with M ≥ 3.0 EQ-s of Vrancea zone;

B.) - The Bzn parameter evolution monitoring and comparation with the M ≥ 3.7 EQ-s led to the following aspects:

1. Many times there is a good correlation between Bzn amplitude and EQ-s magnitude (Fig.2-5), and a simultaneous decrease of amplitude and magnitude, respectivelly, may be observed;

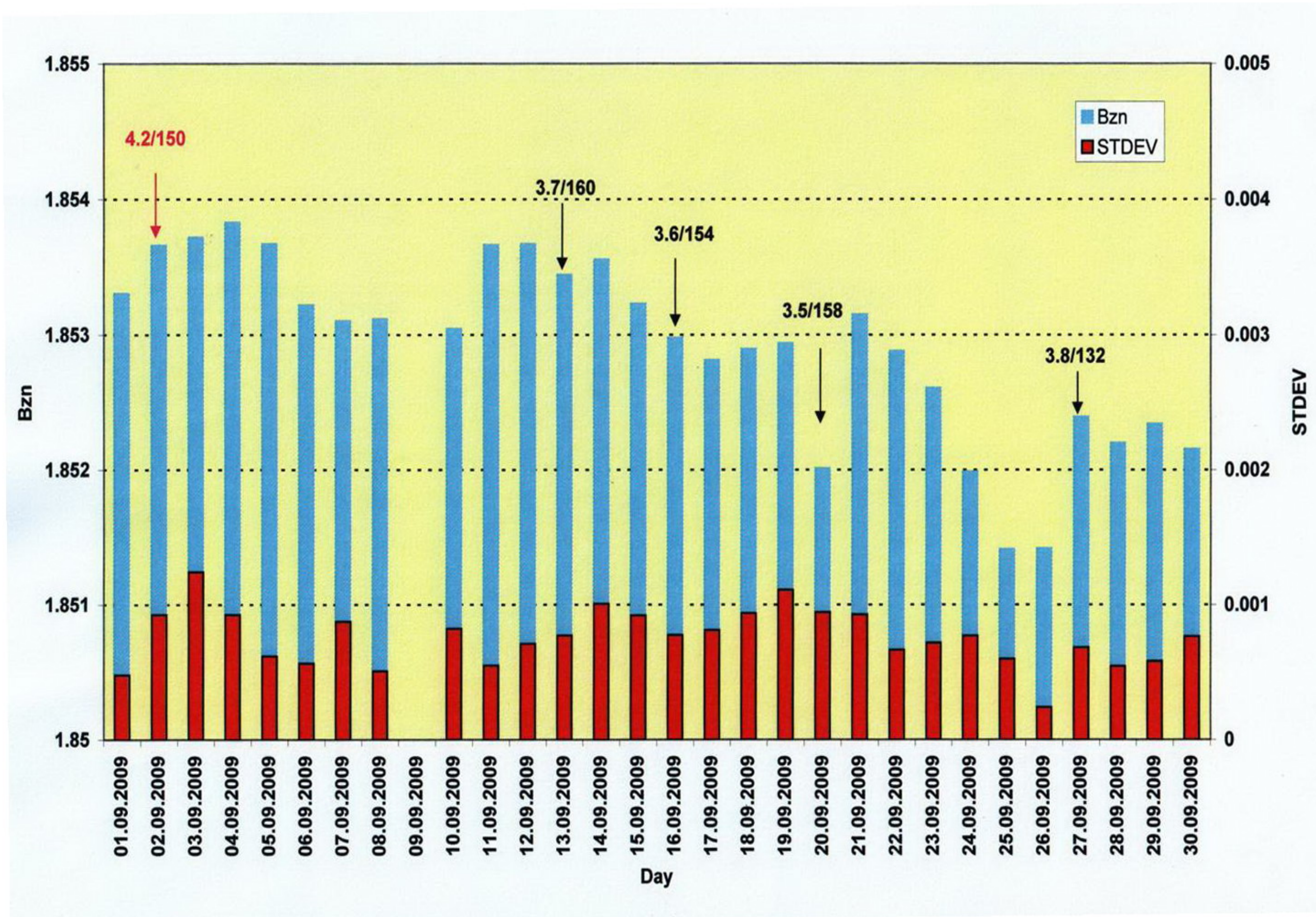

Fig. 2-5. Daily mean distribution of Bzn and (STDEV) for the interval 01.09-30.09.2009. The vertical arrows indicate the EQ occurence date; 4.2/150 represent magnitude/hipocentre (km).

2. For longer intervals more Bzn anomalies appear before an EQ (Fig.2-3/2010 year). For this reason, to select the anomalies having a precursory character, it was necessary to introduce the notion of threshold limit (Bzn*), by applying the statistic analysis formula $Bzn^* = \frac{X - \overline{X}}{\overline{Y}}$, based on standardized random variables, in order to eliminate eventual effects generated by seasonal variations or geomagnetic storms. The condition that Bzn* = 2•STDEV was

also taken into consideration, and an example for the obtained results is presented in Fig.2-3/2010.

3. It is necessary to point out that the pre-seismic maximum values of Bzn* appear owing to the electric resistivity changes which happen as a sequence of the seismic activity, at different time intervals varying from 1-3 days up to 28-32 days, even 47 days, depending on the complexity of the phenomena related to the earthquake;

4. Deviations from the mentioned rule may be exist when more seismic effects are cumullated in the anomalous Bzn variations owing to a superposition effect, as a sequence of the short time between earthquakes (Fig. 2-4.);

C.) – Owing to the significant changes asociated with EQ-s, the high frequency EM parameters monitoring (skew, strike, anisotropy) and geoelectric parameter (DC resistivity) has proved their utility in evaluating the hazard potential of the “Provita de Sus landslide”. Thus, the experimental data analysis has led to the folowing conclusions:

1. The intermediate depth EQ occured on 25 April, 2009, in Vrancea zone, was the main factor that led to the reinitiation of the landslide process ;
2. The significant post-seismic changes regarding the main morpho-geoelectric characteristics of the sliding mass, on the depth interval 0-25m, have a local character, manifested in the frontal part of the landslide;
3. Pre- and post-seismic pattern of the landslide could be quantified by means of the structural dimensionality parameters (skew and strike) and it was emphasized in the apparent resistivity tomographies;
4. Clasification of the hazard potential of the “Provita de Sus landslide”, evaluated as “moderate-class 3” by introducing the EM data in the macrozonation model (Mora and Vahrson, 1994);
5. The studies accomplished in the frame of this thesis have demonstrated the potential of this methodology applied to the landslides monitoring, due to the near real time data transfer, what assures an important role in the hazard level evaluation and, as a consequence, in a better socio-economic protection.

Data carried out up to now, for the EQ-s of relative low magnitude constitutes a chalenge to continue the electromagnetic studies by means of various methodologies and techniques, in order to make a seismic hazard evaluation.

* * *

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