VRANCEA SEISMICITY ANALYSIS BASED ON CUMULATIVE SEISMIC ENERGY

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Vrancea's seismicity (Curvature Carpathian mountains) recorded in 2013 an energy discontinuity preceded by the highest seismic inactivity according to the Romanian National Institute for Earth Physics. The energy is calculated based on the local magnitude (Richter), and is cumulative. Vrancea is the most important seismic region from Eastern Europe through its intermediate depth earthquakes. Energy variations can be linearly approximated due to the constant rate of earthquake occurrences. This allows to forecast the magnitude using the inverse energy-magnitude relationship. Periods longer than 5-8 days without earthquakes are followed by a more intense seismic activity. This paper analyses the evolution of seismicity in several Romanian regions that have similar energy deviations. The analysis was performed using a software tool developed by the authors of this paper. Energy discontinuity can be precursors to earthquakes greater than 7R. The analysis used information from NIEP and the European-Mediterranean Seismological Centre (EMSC) database.

Keywords: Seismic energy, earthquake forecast, seismic precursors, intermediary earthquake, hypocenter distribution, b Gutenberg-Richter

1. Introduction

The conversion of magnitude into seismic energy is a well-known method described by Thanassoulas C [1] and Tselentis, G.A [2]. We developed the software tool called 'Report_Energy' for this analysis. Bulletins generated by software Antelope (http://ds.iris.edu/ds/nodes/dmc/software/downloads/Antelope) and Hypoplus (ftp://www.orfeus-eu.org/pub/software/conversion/.../manual.doc) are used for the input information. The software could be adapted to any bulletins format and it does not depend on the analyzed area.

The paper presents seismic sequences starting from 2013 for regions in Bulgaria, Serbia, and Romania (Southeastern Carpathians and Balkan Mountains). In this time interval we had two important inactivity periods for Vrancea

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seismicity (10.6 and 9 days). Two earthquakes with local magnitudes 5.5R and 4.9R produced in a short interval and generated the biggest energy release step. Another 3 similar examples are presented with the same energy discontinuity: Hateg (Carpathian area), Galati (a Romanian port on the Danube - a special case with high shallow depth seismic activities), and Marasesti - Tecuci (5.7R, located next to eastern limit of the Vrancea area).

Constantine Thanassoulas [1] describes 'Lithospheric Seismic Energy Flow Model (LSEFM)' and presents many examples using cumulative seismic energy. We evaluate a future magnitude using Vrancea seismic energy linearity approximation but we cannot say how the energy will release (a larger earthquake or several smaller ones). Every area has a different geological structure but the methods could be adapted and applied to any zone. Thanassoulas uses mainly crustal seismicity from Greece, but the Vrancea area has intermediate earthquakes.

For a better geophysical knowledge of a given zone, seismic monitoring has to be completed with other multidisciplinary activities. NIEP develops a specialized network (which will be a part of EPOS – European Plate Observation System infrastructure) that measure the geomagnetic and electric fields induced in the lithosphere, local magnetic field variations, infrasound (ground, air), seismic-acoustic noise, air ionization, radon concentration, and radio wave perturbations in epicentral regions.

Vrancea's last important seismic event was in 1977, Mw = 7.4. Currently, the digital NIEP seismic network has over 120 stations, two seismic early warning systems that work in parallel and transmit information for Romanian authorities involved in risk management. The seismic energy analysis is a part of this system and helps perfecting risk evaluation, seismic forecast, and informing the decision factors regarding the impact minimization of natural disasters and the education of the general population.

Energy discontinuity can be considered as a precursor factor.

2. Report_Energy Software and method for evaluate the seismic cumulative energy

The first step is to select a seismic area (figure 2.1 - 1). This is not a simple task, because there should be a correlation between earthquakes. For example, Vrancea has its own rhythm, 'music' through the sequence of epicenters: Nereju and Gura Teghii areas, 3-5 days period. Next, select the time period (2), depth – magnitude intervals (3), (4) and the seismic bulletins (5). Finally, run 'Report_Energy' software (6) and you will get information about cumulative energy, b parameter from Gutenberg – Richter's law, magnitude and depth evolution, time intervals between earthquakes.
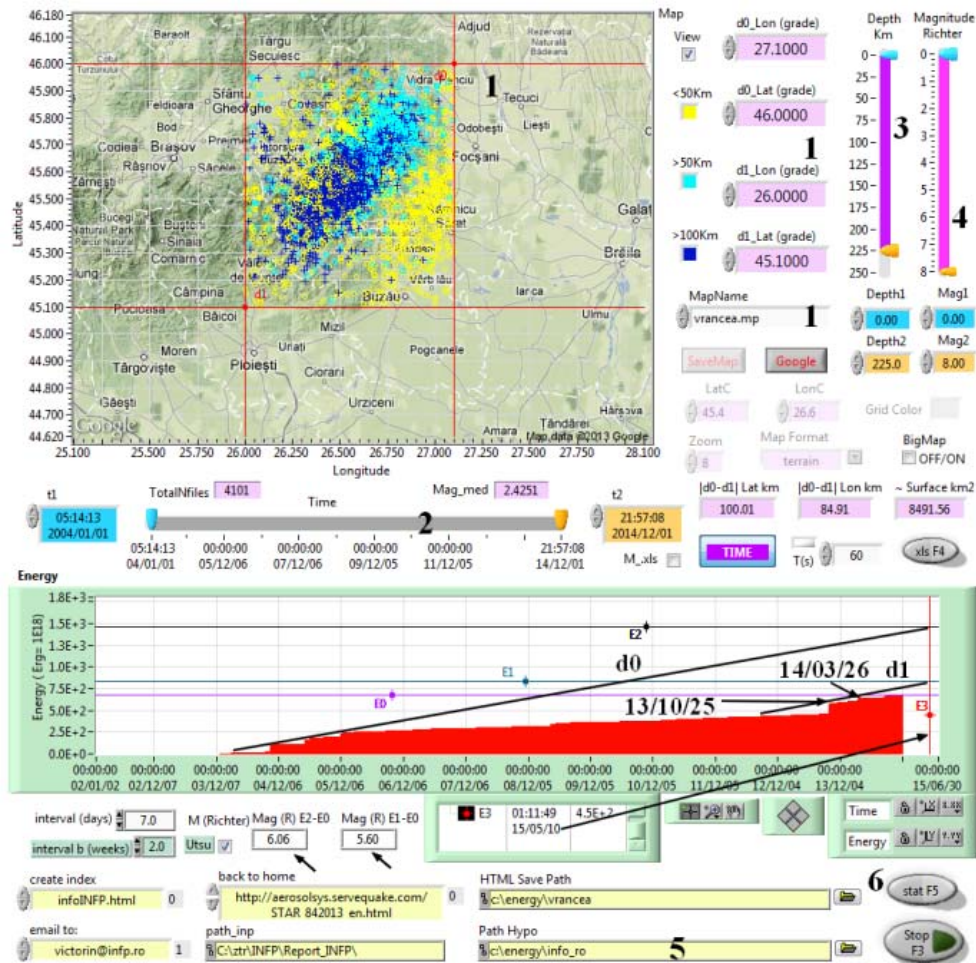
Fig. 2.1 Main panel Report_Energy software, Vrancea seismicity - energy 2004 - 2014

The next picture represents an example of Vrancea energy estimated from Antelope bulletins used by NIEP. A linear interpolation is possible (d0 and d1).
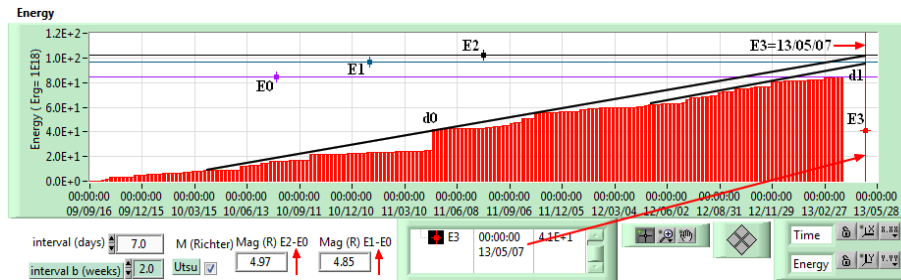

Fig. 2.2 Energy analysis for Vrancea region, time window 7 days

Each earthquake from a selected area (figure 2.1 - 1) is converted in energy and cumulated in a time interval ('interval (days)', figure 2.2). This time window is moving and covers the whole period. The seismic cumulative energy is calculated with formulas mentioned in [1], [2], [3], and [4]:

$$\lg(E) = 11.8 + 1.5 * M_s \qquad\qquad\qquad (1)$$

$$M_s = -2.14 + 1.43 * M_l - 0.018 * M_l^2 \quad , \text{Antelope} \qquad (2)$$

$$\lg(E) = 11.1 + 1.65 * M_d \text{ , intermediary earthquake, Hypoplus (3)}$$

E   = energy expressed 1Erg = 1E+18
M_l = local magnitude, Richter, Antelope bulletins
M_d = duration magnitude, Richter, Hypoplus bulletins
M_s = surface magnitude, Richter
Mag(R) E_2-E_0 = equivalent magnitude for $E_2 - E_0$
Mag(R) E_1-E_0 = equivalent magnitude for $E_1 - E_0$
interval (days) = time window for energy evaluation
interval b (weeks) = time window for b evaluation using Utsu
relation or Gutenberg – Richter law

We approximate the energy evolution drawing d0 and d1 and selecting a target time E_3 (13/05/07, Fig. 2.2). E_0 is the last energy level, while E_1 and E_2 are the intersection points of lines d0, d1 with time E_3. The special software 'Report_Antelope' makes all these analyses. The National Institute for Earth Physics (NIEP) uses the Antelope software for seismic acquisition and analysis. The newer version of 'Report_Energy' accepts inputs from the Antelope and Hypoplus software tools. A bulletin example is presented in figure 2.3. 'Report_Energy' reads these files and saves all information in a HTML page (Fig. 2.4).

Fig. 2.3 ANTELOPE bulletin

Fig. 2.4 HTML 'Report_Energy' page

Each DATE is a link to the seismic solution (example, figure 2.5).

Earthquake Arrival Times (UTC, Manual)

BISRR	0.13	145.3	P	20:43:01.166	-0.4	T__			md__			425
PLOR	0.20	9.0	P	20:43:01.920	0.3	T__			md__ ml	2.5		420
VRI	0.23	22.0	P	20:43:01.929	0.2	T__		0.1	mc__ ml	2.7		422
MLR	0.49	250.8	P	20:43:03.778	0.5	T__			md__ ml	2.4		416
CFR	1.18	113.3	P	20:43:09.547	0.0	T__			mc__ ml	2.6		413
BISRR	0.13	145.3	S	20:43:12.004	-0.7	T__			md__			426
PLOR	0.20	9.0	S	20:43:12.796	-0.2	T__			mc__ ml	2.5		421
VRI	0.23	22.0	S	20:43:12.838	-0.3	T__		0.1	md__ ml	2.7		423

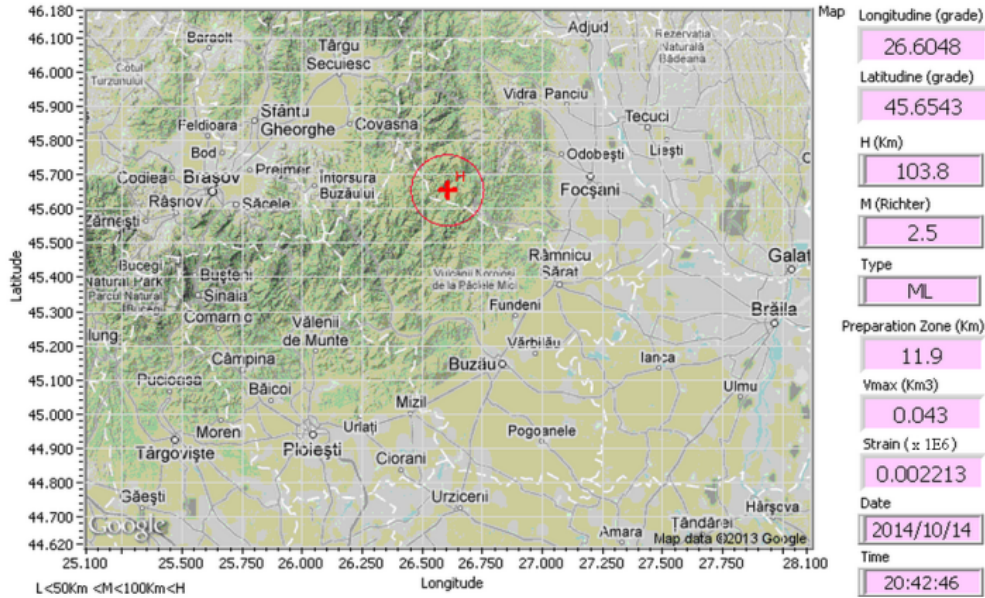back to list   home

Fig. 2.5 Seismic solution, preparation zone, strain

Using the 'Report_Energy' program, the operator has the base information about an earthquake (P-S times, latitude, longitude, depth, local, global magnitude). Dobrovolsky et al. [5] estimated the zone where the earthquake has effects, and Vittorio Sgrigna et al. [7] use these equations (figure 2.5) to estimate the pre-seismic strain:

$$V\text{max} = 10^{(1.24M-4.47)} \qquad \text{Km}^3 \qquad (3)$$

$$R = 10^{0.43M} \qquad \text{Km} \qquad (4)$$

R = 'preparation zone' from epicenter (red circle in figure 2.5)
V = spherical volume
Strain (x10^6) = pre-seismic strain ε, (Vittorio Sgrigna at al. [7]):

$$\varepsilon = \frac{10^{1.5M-9.18}}{R^3} \qquad M < 5.0, \qquad (5)$$

$$\varepsilon = \frac{10^{1.3M-8.19}}{R^3} \qquad\qquad M \geq 5.0, \qquad\qquad (6)$$

'Report_Energy' calculates 'b' using Gutenberg – Richter's law or Utsu's method, the time interval between successive earthquakes, hypocenter depth distribution, and number of earthquakes direct and cumulative in a time interval. The software uses Gutenberg – Richter's law:

$$lgN_m = a - b * m \qquad\qquad\qquad (7)$$

Where N is the number of earthquakes over minimum magnitude m. Utsu's formula [8] is more useful (figure 2.6):

$$b = \lg(e)/(M - m) \qquad\qquad\qquad (8)$$

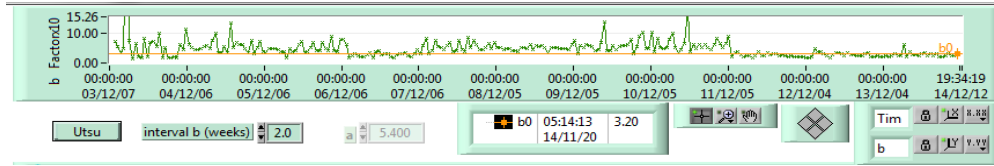M is average magnitudes over minimum m. Ardeleanu, L and Bazacliu ,O do a similar analysis [6].

Fig. 2.6   'b' evolution for Vrancea seismicity 2004 – 2014 using Utsu's formula

'Report_Energy' also generates hypocenter distributions in time, horizontal, and vertical views, and interactive 3D representations (figures 2.7, 2.8). Vrancea has two important intermediate earthquake zones (A and B, figures 2.1, 2.7).
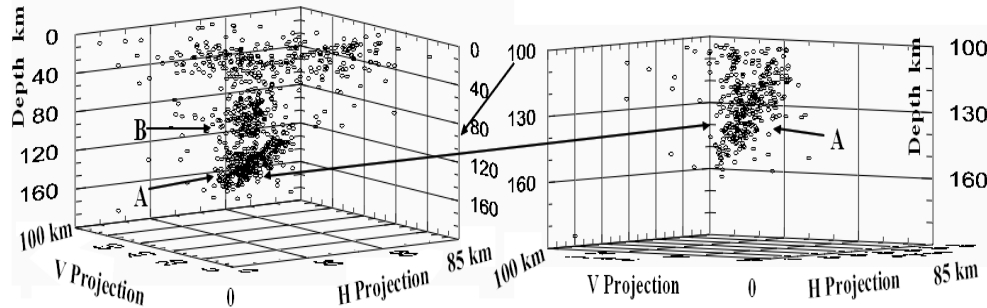

Fig. 2.7 Complexity of Vrancea hypocenters distribution, 2013 seismicity

The number of earthquakes in 'interval Energy (days)", 'N/t' and 'Ncum/t', are calculated as well (figure 3.3). The linearity of the slope indicates a seismic rhythm that allows a linear approximation of the energy evolution.
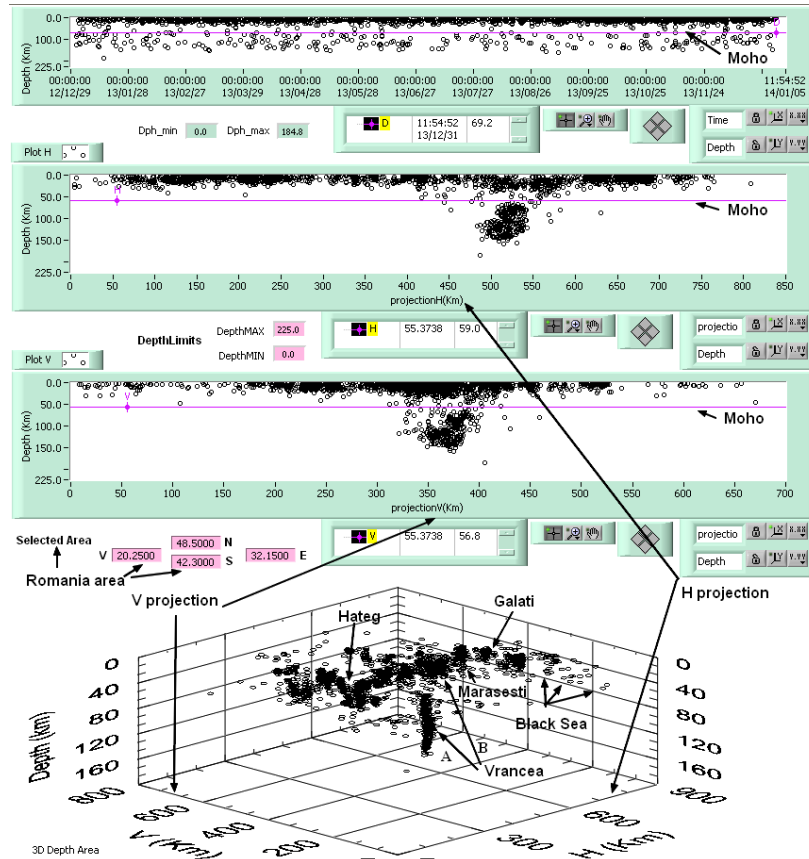
Fig. 2.8 Hypocenter distribution for the Romanian area, 2013 seismicity

3. Regional and local seismic energy analysis

Sometimes there are seismic sequences on a large zone. Our analysis starts with a general view of seismicity from Bulgaria (Balkan mountains), Romania and Serbia (East). Figure 3.1 shows the important seismic regions (marked 1, 2, 3, 4, 5, 6, 7). The period seleted 2013/06 – 2013/12 includes energy discontinuity in regions 1 to 5. The 6th recorded an energy discontinuity after an earthquake with 5.7R magnitude in 2014/11/22. We define the areas (figure 3.1):

1- Vrancea: 27.1E/46.0N, 26.0E/45.1N
2- Galati: 28.5E/45.87N, 27.5E/45.13N
3- Hateg-Hunedoara: 23.46E/45.97N, 22.16E/45.23N
4- Serbia: 22.458E/45.22N , 19.826E/42.35N
5- Bulgaria: 28.35E/43.47N , 22.476E/41.95N
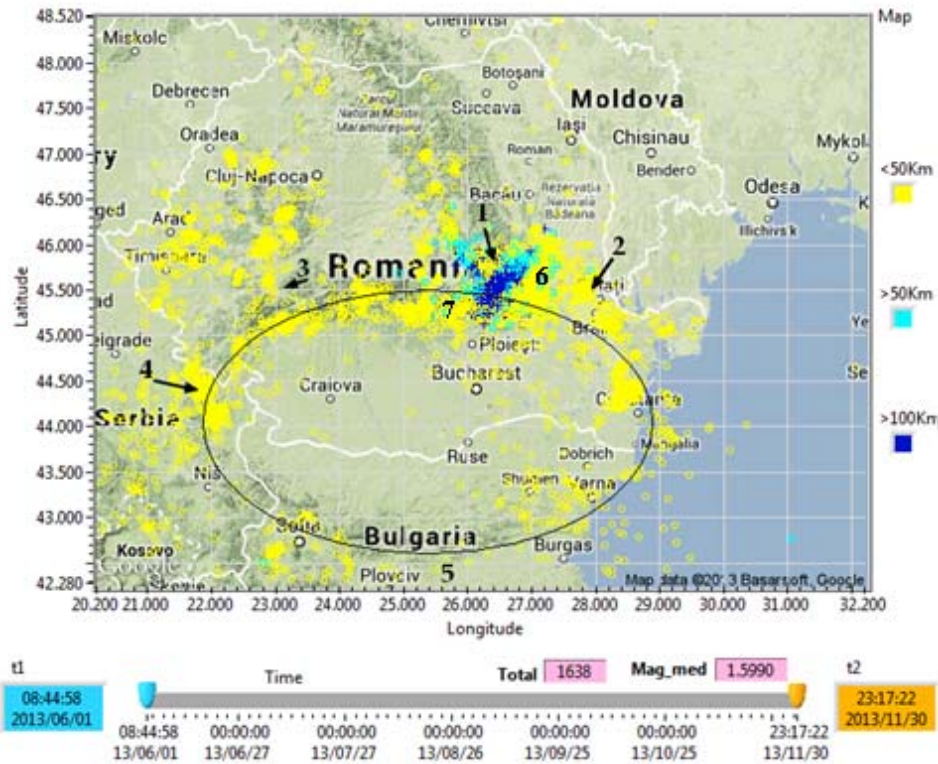6- Marasesti-Tecuci: 27.1E/46.37N, 27.5E/45.63N

Fig. 3.1 Seismicity sequence Bulgaria, Romania and Serbia

Every high magnitude from each region (1 to 5) means an energy jump (Vrancea 5.5R, Galati 3.9R, Hunedoara-Hateg 4.7R, Serbia 4.7R and Bulgaria 4.3R).

Seismic detection depends on the capacity of the network (number of stations, their location and type of sensors). When the energy slope data does not fit in a line, we verify the localization. A real increase of magnitude beside the theoretical position could be a precursor situation. A global seismicity view for the Vrancea zone (map of epicenters and seismic energy slope) is presented in figure 2.1. The study area is defined by the red square. The 'd0' and 'd1' lines (from the 'Energy' graph figure 2.1) are the principal evolutions of energy and '*Mag(R) E2-E0*' and '*Mag(R) E1-E0*' represent the equivalent cumulative magnitudes for the 2015/05/10 time moment. The energy jump is at 2013/10/05 due to the earthquake with magnitude 5.5R. Before this we have two inactivity periods, 10.6 and 9 days (figure 3.2). The analysis of the Vrancea seismic activity is presented in figure 3.2. The first graph plots the 'b' parameter from Gutenberg – Richter's law. The second is the time interval between earthquakes (2013/07/05 – 10.6 days, 13/10/05 – 9 days). The next are the magnitude ('Mag (Richter)') and seismic energy ('Energy').
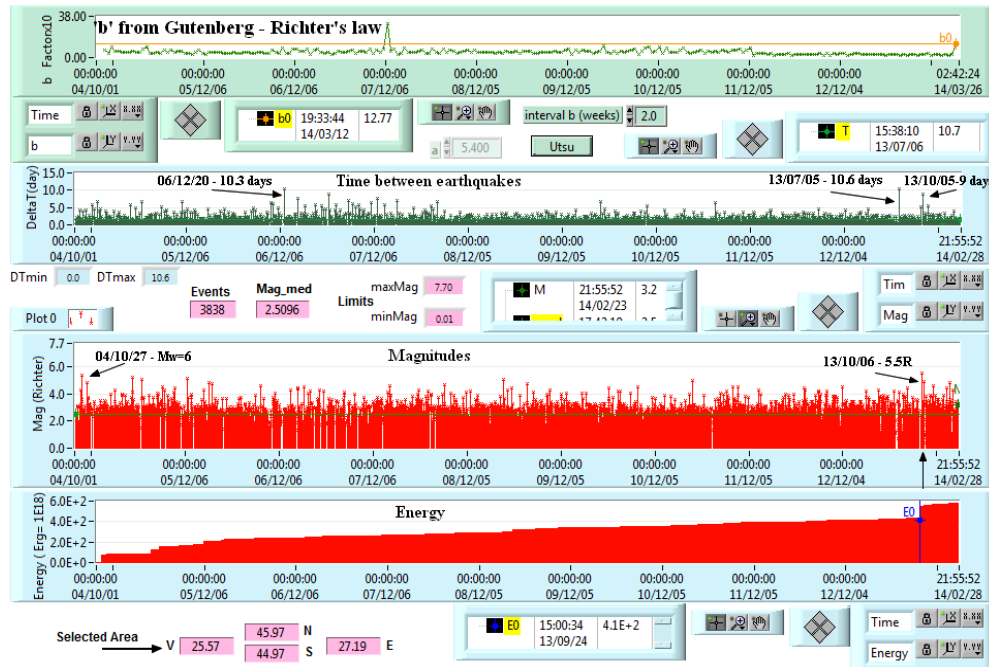
Fig 3.2 Vrancea seismicity evolution since 2004 – 2014/02/28

The Galati area is a complex case. The high crustal seismicity period was preceded by flooding. The area includes several active faults and oil exploitation. There were similar meteorological conditions in the past but never such number of earthquakes concentrated in a small region, a part of the Izvoarele village – Galati (figure 3.3). A 3.9 R earthquake (2013/09/30) generated the energy discontinuity. Figure 3.3 shows the seismic evolution of this area.
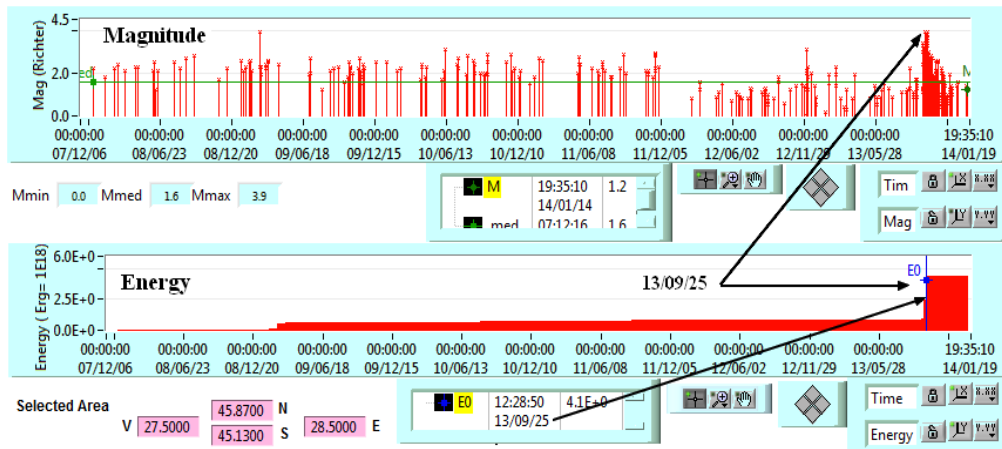

Fig 3.3 Galati area, 2008-2014/01 period

The same energy jump was evaluated in the same period in Hunedoara – Hateg area (figure 3.4). An earthquake with 4.7R magnitude was recorded next to Hateg, 2013/09/08.
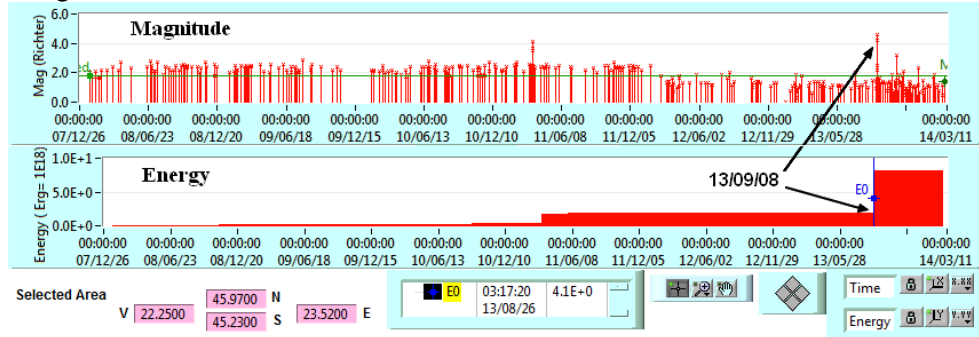

Fig 3.4 Seismicity-Energy for Petrosani - Hunedoara – Hateg region, 2008-2014/03 period

Serbia and Bulgaria recorded high seismicity in the same period. The next pictures show the energy evolution.
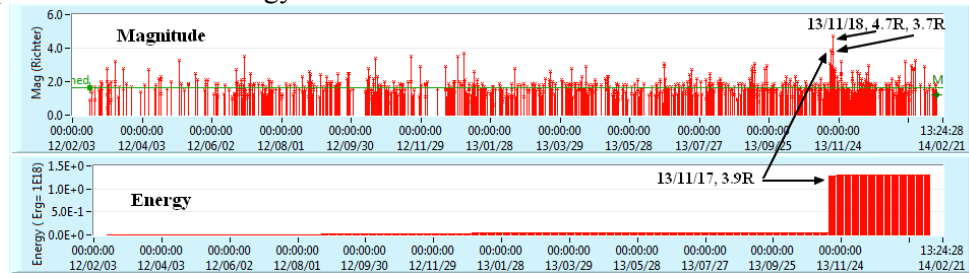

Figure 3.5 Seismicity-Energy for Serbia, 2012- 2014/01 period
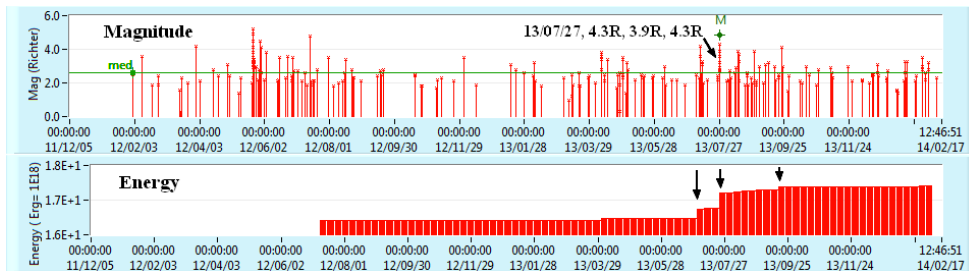
Figure 3.6 Seismicity-Energy for Bulgaria 2012- 2014/01 period

The Marasesti-Tecuci area (figure 3.1 – 6) recorded two important earthquakes: 5.7R in 2014/11/22, and 4.6R in 2014/12/07, at 38 Km – 40 Km on the edge of the Moho region (figure 2.8). These earthquakes were accompanied by several aftershocks. The area is located at the eastern limit of the Vrancea region. Figure 2.8 shows a general view of the hypocenter distribution for Romania, and the particularity of the Vrancea area.

4. Conclusions

The cumulative seismic energy method depends on the selected region. First we chose a large area, then we identify the epicenters, and define either the portions of interest or alternatively we use a geological map. The 'Cumulative' term implies a time window, and a time origin. When using 7 and 60 day intervals the conclusions are the same. The time origin is important because we could have two earthquakes in the same window or in successive time intervals but the total energy is the same. A correct energy analysis needs to use the same start time and window size across all data sets. The factors from equations (1) and (3) affect the value of energy but the reverse calculation of magnitude $(E_1\text{-}E_0 \text{ and } E_2\text{-}E_0)$ is independent because it uses the same relations. The cumulative energy is not absolute and it is based on relative variations $(E_1\text{-}E_0$, figure 2.2). The relations (3), (4), (5) and (6) use only the M variable but the crustal and intermediate earthquakes have different effects at the same magnitude. The method does not predict the 'jumps'. The inactivity period is uncertain in our case. Utsu's relationship had better results for 'b' determination.

Our analysis covers a short time period (2004-2014), and follows recent energy jumps that have occurred in several regions of Romania during the same period of time. They can be seismic precursors but a multidisciplinary analysis is necessary in order to make a short-term forecast.

R E F E R E N C E S

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