This is an extended version of the paper presented in SEE7 conference, peer-reviewed again and approved by the JSEE editorial board.

Identification of Vrancea Earthquake Prone Zones Based on Seismic Energy Discontinuity Using Empirical Analysis and Analytical Tools

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Received: 25/08/2015
Accepted: 16/12/2015

ABSTRACT

The need for evaluation of a sound earthquake disaster mitigation and critical assessment of the detailed cumulative seismic energy dissipated in the Vrancea Region in Romania is required to identify the active seismogenic activity for the last 12 years associated within the seismotectonic zone of Vrancea Region of Romania. The seismogenic behaviour observed by the recent strain energy release from 2004 to 2016 in Vrancea by processing the energy bulletin of the seismic energy discontinuity gives new results. Vrancea is the most critical seismo-tectonic region in Eastern Europe prone to earthquakes and suffer seismic energy variations that can be linearly approximated due to the constant rate of earthquake occurrences. This allows to forecast the magnitude using iso-contour plotting and analysis of the energy-magnitude relationship. The study shows that there is an immediate need to diagnose for a unifying slip-dependent law determined from strain energy bearing capacity of the region. In this study, the average moment release rate and strain release pattern within time frame 2004-2016 for the region have been examined by analysing the updated Romplus Catalog from the Vrancea region of Romania. The study shows that if strain energy released by a tectonic block is large it might affect the stress building process in the rocks of adjacent tectonic blocks. A zone of future earthquake activity in the Vrancea based on the study is also identified and an integrated functional block diagrams as part of the activity in any geotectonic region incorporating pre-earthquake parameter assessment is developed.

Keywords:
Geotectonic block; Seismicity; Strain energy; Earthquake forecast; Seismic precursors; Intermediary earthquake

1. Introduction

The proneness of a region to earthquake occurrence and seismicity on the basis of temporal and spatial distribution can be measured empirically using well-defined, measurable quantities and diagnostic precursory analysis. It is observed in many studies [1-2] that understanding the nature of nucleation and strain energy released in earthquakes and eruptions for "remote triggering" of earthquakes is a difficult proposition. Moreover, the newly discovered episodic tremor and slip (ETS) [3-4] that may lead to success in the future indicates robust areas of elevated strain rates where data coverage is strong. The proposed study is a novel method for the observation of seismicity rate changes for a seismogenic source [5-6] based on the seismic energy discontinuity in the rupture process. In this method, spatial clustering is done by studying the recurrence period of seismic occurrences in rupture zones of intermediate depth earthquakes. The nucleation, slip and arrest phases of earthquakes result from the interplay of stress perturbations and grain-scale deformation processes in the rock strata. In the last ten years, there has been a virtual explosion in the number of laboratory-based studies [2] aimed at understanding the physical and chemical deformation processes by studying the dynamic parameters that control the onset of earthquake ruptures based on fault mapping and geotectonic analysis. The seismic moment is an empirical parameter related to the area of the fault rupture for the average displacement or slip during the rupture that provides quantitative measure for integrated earthquake warning methodology. Earthquake genesis is constrained by scaling laws of rupture along fault planes related to rupture length, seismogenic layer depth, stress drop and slip per event. Secondly, it is needed to identify the historical data based on the data set, time period and rise of earthquake correlation strain accumulation rates inferred from aftershocks, limited length of the fault and the maximum strain energy that can be stored in different types of rocks before reaching their failure points. A portion of the energy released by an earthquake can alter the state of stress, thus there is a need to re-look and analyze the existing epicenter data developing a characteristic simulation model. Static triggering occurs within a few fault lengths of the mainshock rupture that results from changes in the local stress field induced by the earthquake slip [7]. Longer instantaneous fault ruptures release more energy in one shock and thus generate a larger earthquake of greater magnitude. Based on the study conducted by Dutta et al. [8], the pressure increases with increasing depth from the surface affecting the strain energy release pattern for a tectonic earthquake on a fault where pore pressure is affected by compressive stress. When this strength is exceeded, a rupture is produced and an earthquake is triggered. The upper bound of energy that can be stored depending on seismic moment can define the rock strength that is extracted from the different earthquake magnitudes. The most imminent method to determine the physical quantities related to the rupture for the size of the nucleation zone and the slip acceleration is found to be scale-dependent with the shear rupture energy where the square root of the energy 'E' is proportional to the strain rebounded during an earthquake that generates the earthquake. The part of the elastic energy 'E' is considered to be stored up during the earthquake preparation stage affecting causal nature of the residual strain release pattern. There is a well-known relation between the Gutenberg-Richter magnitude (M_S) and the seismic energy 'E', which can be used for finding the relationship with moment magnitude (M_W):

$$\log E = 11.8 + 1.5 M_S \tag{1}$$

It is also known that M_S = (M_W - 0.81)/0.92 = 1.087 M_W- 0.88, where the moment magnitude M_W is known. Then, by putting it in Eq. (1), it is found that:

$$\begin{aligned} &\log E_S = 11.8 + 1.5(1.087 M_W - 0.88) = \\ &11.8 + 1.63 M_W - 1.32; \\ &\log E_S^{0.5} = 0.815 M_W + 5.24 \end{aligned} \tag{2}$$

where $E_S^{0.5}$ is the equivalent to the strain release due to the elastic forces during the preparation stage of the earthquake. Thus, we have:

$$E_S = 10(1.63 M_W + 10.48) \tag{3}$$

Once the derivation for the energy release is found in Eq. (2), we can estimate a linear relationship of the magnitude with rupture length (L_m) identification, which has been established by Kasahara [9] as shown in Eq. (3) to identify the affected source zone where the nucleation had taken place.

$$\begin{aligned} &LogL_m = 3.2 + 0.5 M_S \quad [9] \\ &LogL_m = 3.2 + 0.5(1.087 M_W - 0.88) \end{aligned} \tag{4}$$

$$\begin{aligned} &LogL_m = 1.76 + 0.5435 M_W \\ &LogL_m = 10(0.5435 M_W + 2.76) \end{aligned} \tag{5}$$

2. Material and Methods

2.1. Seismic Evaluation and Prediction of the Tectonic Behavior in Vrancea, Romania

The evolution of seismicity in several regions having similar tectonic behavior and seismic inactivity in the Vrancea region is done using both empirical calculations and geo-scientific tools and observations. The analysis was performed using Matlab to perform geo-scientific modelling and analysis and has been developed to analyze both the spatial and temporal variations of the energy discontinuity in the Vrancea region. The first step is to select a seismic area (Figure 1) to identify the region of seismic correlation between earthquakes. For example, Vrancea has its own seismic signature and seismic energy discontinuity identified through the sequence of epicenters and magnitude and depth in Nereju and Gura Teghii areas. The next step is to select the time window, depth-magnitude intervals (3), (4) and the seismic bulletins (5). Finally, apply the proposed geoscientific methodology and also the Antelope software to get information about cumulative energy, b parameter from Gutenberg-Richter's law, magnitude and depth evolution, time intervals between earthquakes. Research being conducted in Seismic Network, National Institute for Earth Physics, Magurele, Romania termed as the AeroSolSys located in Vrancea (Curvature Carpathian Mountains) [11] includes radon concentration monitoring in five stations. We focus on lithosphere energy transfer using some critical geoscientific tools proposed as part of the integrated methodology to identify low atmosphere phenomena using real-time information about seismicity, +/- ions, clouds, solar radiation, temperature (air, ground), humidity, atmospheric pressure, wind speed and direction, telluric currents, variations of the local magnetic field, infrasound, variations of the atmospheric electrostatic field, variations in the earth crust with inclinometers, electromagnetic activity, CO2 concentration, ULF radio wave propagation, seismo-acoustic emission, and animal behavior. The main purpose is to inform the authorities about risk situation and update hazard scenarios. The earthquake occurrence based on geological data and tectonic history all has close correlation, and many geophysical and other parameters show anomalous changes in the wake of earthquakes. However, based on this study, it can be said that a single precursor cannot explain the entire earthquake process as shown in Figure (2).

2.2. Romania Seismicity

The seismicity of Romania is generated mainly by the Vrancea sub-crustal source, which has caused, over time, several destructive events. The first strong earthquake for which accelerometer records were obtained was that on March 4, 1977 (moment magnitude M = 7.4, focal depth h = 94 km), which the years that followed, three more earthquakes with $M_W > 6$ were generated by the same source. Due to the progressive extension of

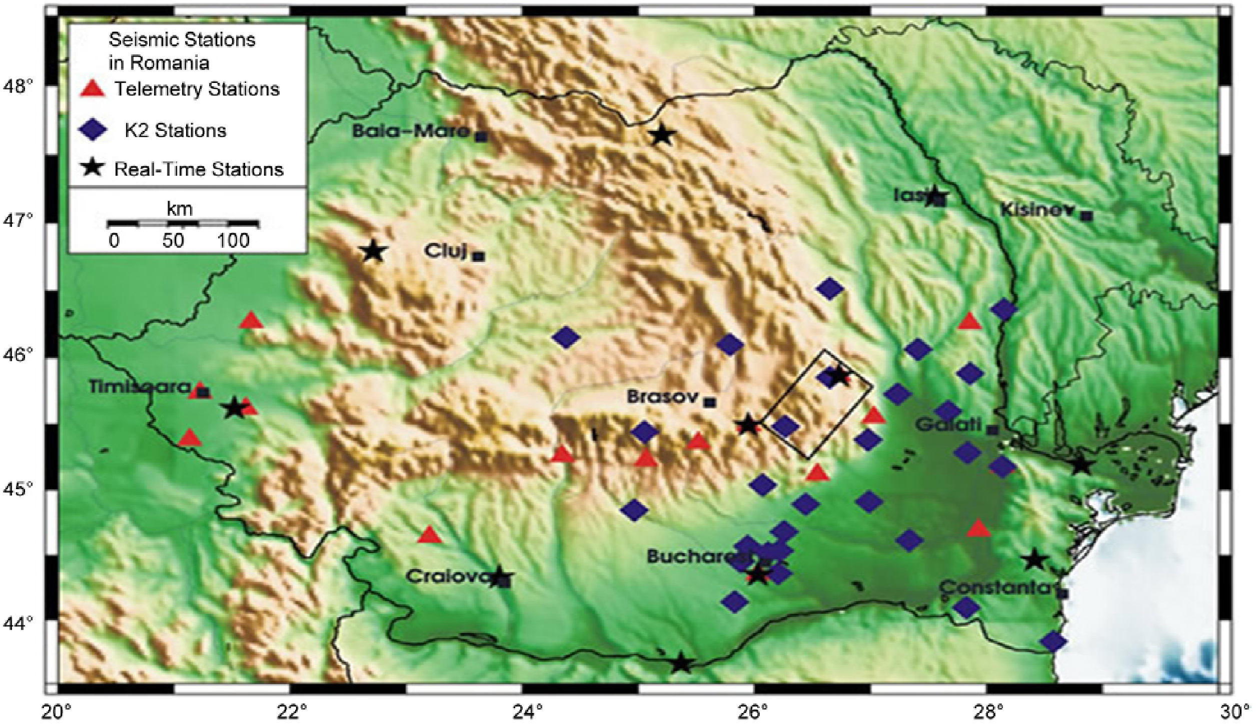


Figure 1. Analysis of the Telemetry. Accelerometer and Real-time Monitoring stations for Vrancea Earthquake Monitoring (taken from Radulian et al. [10]).

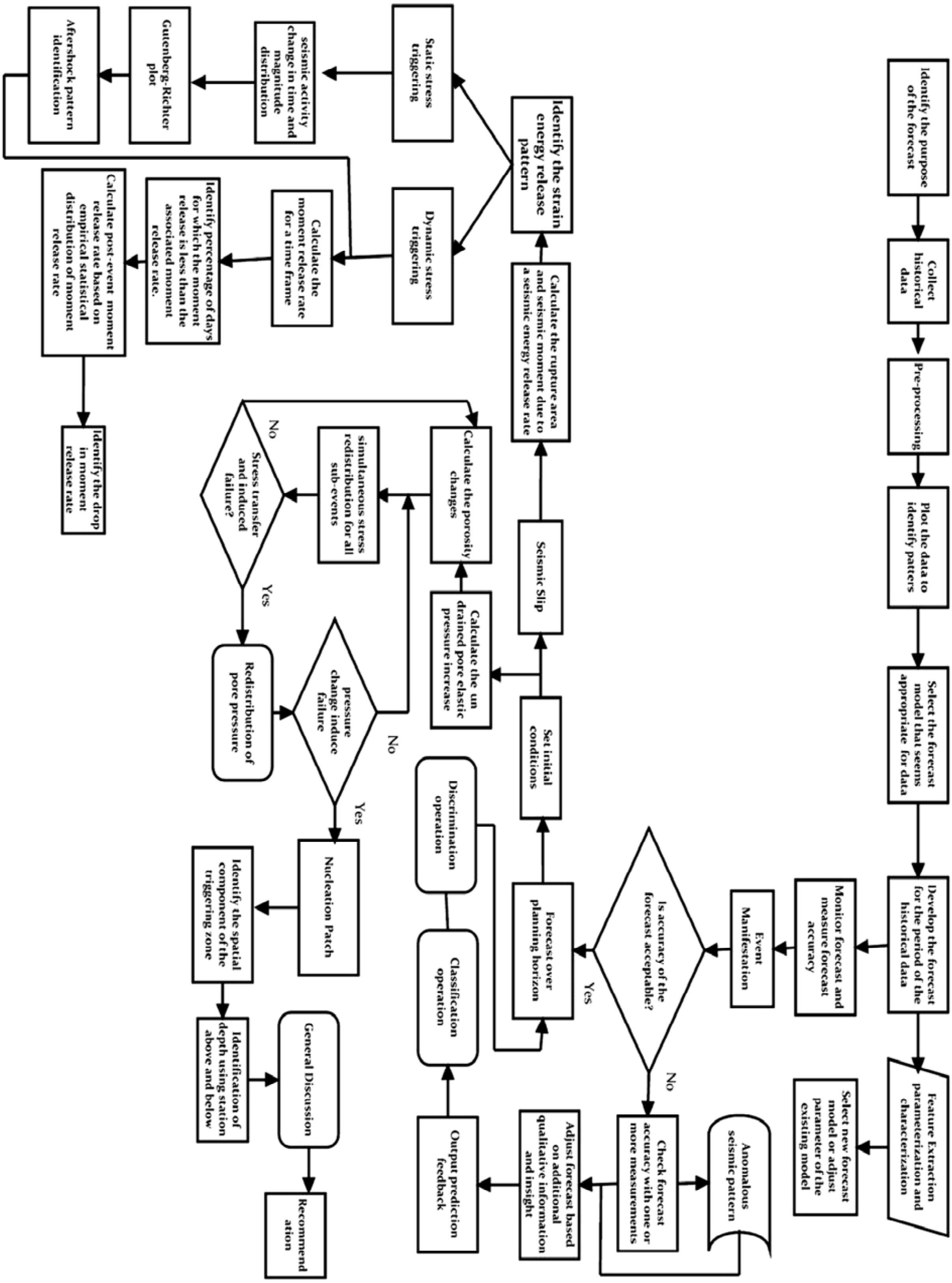
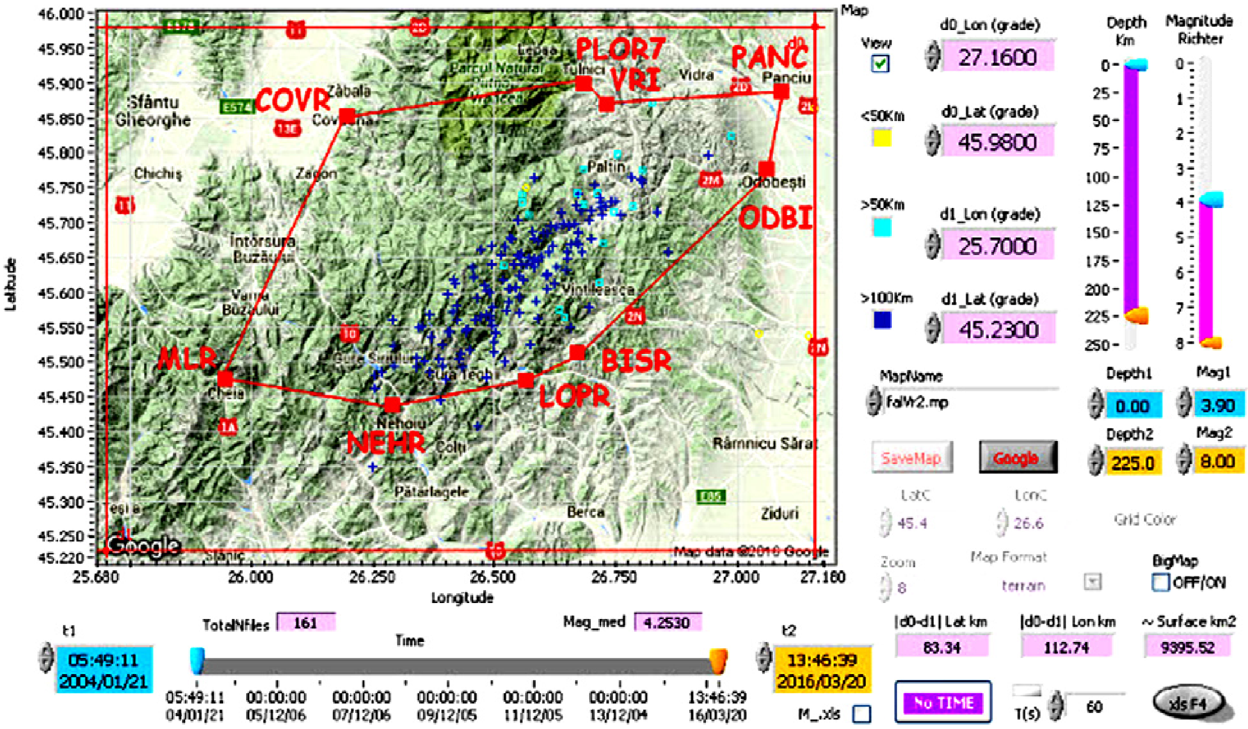


Figure 2. An Integrated model for earthquake genesis pattern analysis for the Earthquake Forecast Problem.

the seismic networks in Romania during this period, hundreds of accelerometric records were obtained for these strong earthquakes. It has been observed that the subduction zone bedrock in Vrancea is very steep and various probabilistic approaches have been applied so far including PRESTo [12] to identify the bed rock for the seismogenic mechanism to take place. In the study conducted for tracing seismic and geophysical precursors that has been in existence in INFP at the National observatory at Magurelle, Bucharest for identification of the plausible geoscientific signatures and collective geo-information related to earthquake early warning scenarios in Vrancea, Romania has been collected with seismo-geo observations and instruments as shown in Figure (3). It has been observed by studying the past history of the seismic nature of the Vrancea region of Romania by many scientists from different fields that the Vrancea is a highly sensitive tectonic zone having seismically active geodynamic features and has faced a number of seismic shaking in the past seismic time cycle for the heterogeneity scale [13]. The seismic behavior of the rock pattern shows that the earthquakes occurring in Vrancea are clustered in a confined volume at intermediate depths beneath the Vrancea (Romania) seismic region forming an intermediate seismic fracture network with the Carpathanian Mountains that forms an extended area of Romania and its neighboring countries of Europe. Many database patterns and geo-scientific tools used to monitor the epicenter catalog for Romania and the nearby regions are transferred to the seismic observatory to gather consequent information about the seismo-geoscientific anomalous changes that occur in this region as shown in Figure (3).

We inferred that if the magnitudes of all earthquakes occurring in any fault system over a period are known, then a plot of the fault displacement (strain) during that time period gives strain release characteristics and their corresponding rupture length behavior patterns. If we restrict our goal to find an analytical expression capable of representing the traction evolution within the cohesive zone during the dynamic earthquake propagation, then a slip-dependent law is a candid solution for earthquake forecast. The analysis carried out in the present study provides a clear information on the issue of earthquake genesis with greater rupture length for a smaller release of strain for the Vrancea region from 2004-2016 by recording all earthquakes and seismo-tectonic events during this period. The study shows that if strain energy released by a tectonic block is large it might affect the stress building



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Mag2 8.00

LatC 45.4

LonC 26.6

Zoom 8

Map Format terrain

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t2 13:46:39 2016/03/20

|d0-d1| Lat km 83.34

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~ Surface km2 9395.52

T(s) 60

Figure 3. Multi-disciplinary monitoring network in romania for earthquake studies.

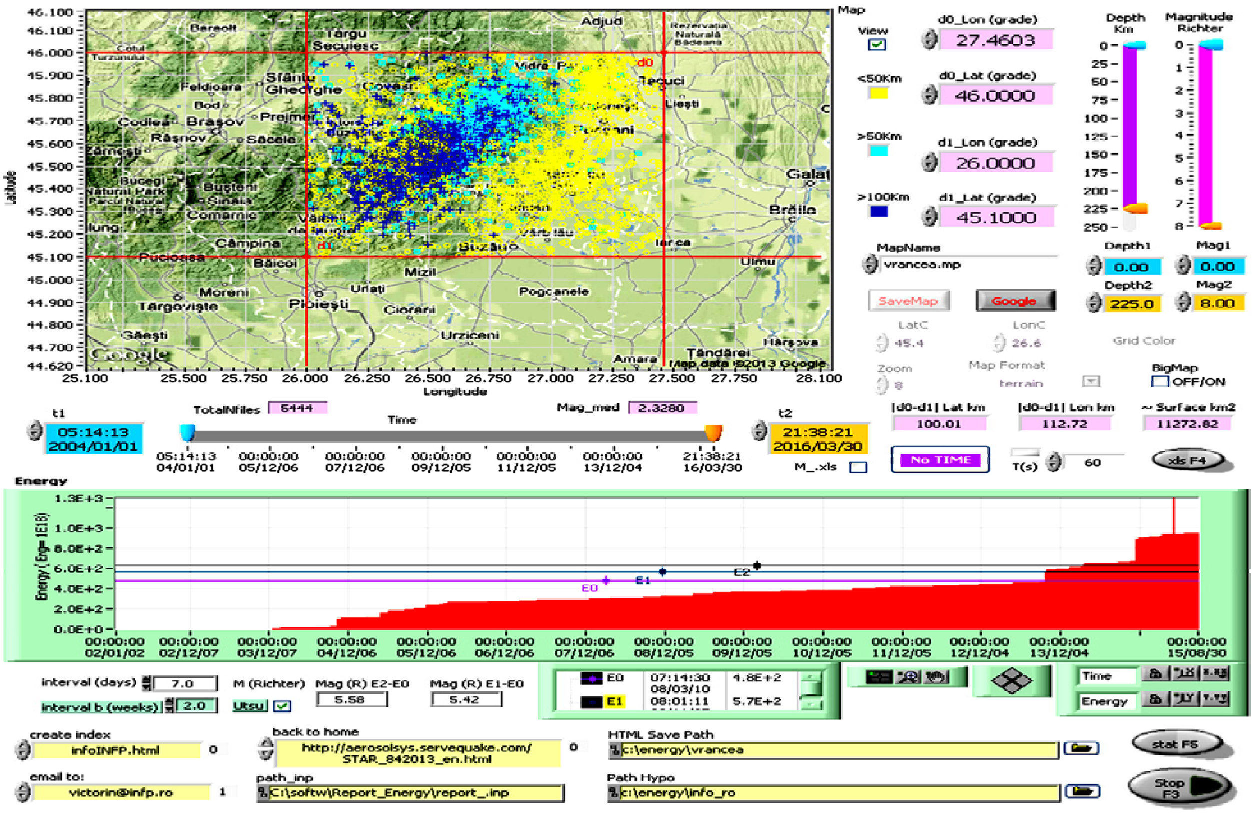
process in the rocks of adjacent tectonic blocks. In order to draw a conclusion for determination whether a larger earthquake will occur in the near future along the Vrancea range, we have used iso-contour mapping and we found that the 27.4591 E - 46N and 26E - 45.1N are the plausible zone for future earthquake vulnerability as found by INFP for future correlation of earthquake rate changes where seismic activity in the Vrancea region are the likely seismogenic zones that has generated a lot of strain energy in the past 12 years due to intense accumulation of strain energy and susceptible for release of strain as found based on the rupture length. The proneness of a region to earthquake occurrence and seismicity on the basis of temporal and spatial distribution can be measured empirically using well-defined, measurable quantities and diagnostic precursory analysis as identified using the earthquake IRIS earthquake browser [14]. The problem with seismic pre-earthquake signals is that, in order to produce any reasonably detectable seismic signal, catastrophic ruptures have to take place in the crust [15]. The seismic moment depends on the average slip (displacement at rupture) and rupture area, as well as the driving shear stress (roughly stress drop) during the earthquake. The maximum rupture area relates to the strike dimension ('length') and dip dimension ('height' or 'width') of the rupture (slip) plane, and so does the slip. There are certainly limits to how large a rock body - seismogenic fault zone or part of it - can develop stresses. Thus, the dimensions of the rock body/fault zone with favorable stresses for a particular earthquake at a particular time put limits on the maximum rupture area and slip and thus the moment (and the moment magnitude) of the earthquakes generated [16]. Due to the limited length of the fault and the maximum strain energy that can be stored in the different types of rocks before reaching their failure points. However, physically speaking, it is constrained by scaling laws of rupture along fault planes, relating, length, seismo-genic layer depth, stress drop and slip per event. The rupture length is increasing with the rise in seismic energy during the preparation of the earthquake by generating changes in stress in the aftershock zone and near-fields. The triggering of new earthquakes is the result from the change in state of stress. An integrated model for measurement of the energy release by tectonic slip can be used to quantify and analyze any seismic behavior and slip change.

2.3. Spatio-Temporal Variation

The epicentral distribution of the earthquake events considered is given in Figure (1). The last big event in terms of size that occurred in the Panchu Earthquake had been recorded on November, 22, 2014 was of M5.7 earthquakes at a depth of 39 km located that had its epicenter at 27.15N and 45.86E at November 22, 2014. The time series plots calculated seismic moment for any event that occurred from January 1, 2004 to March 31, 2016 for examining average moment release rate and strain energy release rate within a certain time frame. We prepare the seismic solution for the strain preparation zone for the energy report software prepared using Antelope bulletin used by INFP as shown in Figure (4) as applying the study [17]. Earthquake mapping has been done by measuring the energy cumulated in a time interval for the estimated cumulative energy content and seismicity features for the Vrancea region. This time window is moving and covers the whole period. The seismic cumulative energy of each earthquake has been determined in the study using Matlab and iso-strain release map that can be further enhanced using the Moving average Strain graph. It is also identified that temporal variation of the nucleation event for any thrust fault earthquake can establish a relation with crustal seismicity [18] as:

$$Logt_a = 0.06 + M_p \tag{6}$$

where t_a is the nucleation period and M_p is the magnitude of the preceding foreshock. A portion of the energy released by an earthquake altered the state of stress and induced damage in regions that surround the earthquake source. An integrated model for measurement of the energy release by tectonic slip can be used to quantify and analyze any seismic mass. The focal depth of the major earthquakes has been determined using IRIS [13] catalogue and iso-strain release map has been prepared. For this, the whole study region is divided into small grids having dimension 10 by 10. The sum total of the energy released by all the earthquakes occurred in a particular grid are computed out and plotted at the center of the grid. Then the isolines of energy have been drawn to prepare the iso-strain release map as shown in Figure (4). In terms of



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interval b (weeks) 2.0
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Figure 4. Vrancea seismicity evolution from 2004 to March 31, 2016 (Antelope energy bulletin).

regional events separate formulas are suitable whereby the use of the relation *Mb* (body wave magnitude) = $0.56M_S + 2.9$ as per Baths formula as in [19]. Besides, the relation $E_S = 1.44\,M_S + 12.24$ is used to calculate the radiated seismic energy from the surface wave magnitude [19]. This has also been used for calculating the seismic cumulative energy based on energy evolution of the period using antelope software [20] as done by Toader et al. [17] for calculating the energy discontinuity preceding the seismic inactivity for the Vrancea and adjoining curvature of the Carpathanian Mountains in 2013.

3. Results and Discussion

3.1. Effect of Release of Strain Energy by a Tectonic Block on Nearby Blocks

The Vrancea Region in the South East Carpathanian Mountains in Romania is an active seismogenic area characterized by frequent seismic activities. Using Eq. (6), the total strain energy released by earthquakes in each year by each tectonic zone is determined and is represented together graphically. Next, correlation co-efficient of the total strain energy released is computed between the six tectonic zones. The seismic events of Vrancea region has deep focus due to subduction and almost perpendicular dip. Based on this analysis, we evaluate the causal period of a predominant earthquake, which seems evident in the near future. It is found that nucleation of strong events around 90 km depth released high amount of energy. The rupture patterns show that they are clustered in the region 26.5-27 N and 45.6-46 E, the other region being closely clustered at a depth. The energy of each earthquake has been determined using the Eq. (6) and iso-strain release map that can be further enhanced using the Moving average Strain graph. The iso-lines of energy computed according to Eq. (4) have been drawn to prepare the iso-strain release map for showing the crustal structure of the Vrancea region. It is found that areas of different rupture activity [21-22] derived from Eq. (6) are found to have coincided reveal that the spatial projection of the seismogenic basin is prone for earthquake activity where the rupture is likely to occur. Although, this study specifies that the Vrancea region is accumulating strain, there is still a limitation to work on a model that identifies that strain accumulation in any region can lead to larger earthquakes. A novel method has been applied for the observation of seismicity rate changes magnitudes events that would be expected to occur depending on the recurrence time of the recent events based on the size analyzed by the seismic moment and the effect of the dynamic strains associated with the passage of earthquake wave. The plot that was generated shows the history of seismicity during the time span of the catalogue for identifying the distribution of seismic moment derived as an expression from moment magnitude and strain release energy is found as heterogeneous and that the source time function is quite complex. Since each event is a point without duration, there is no possibility to define a moment release rate for each individual event. To define the moment release rate, the moving time window is used to smooth out the time series and remove some of the noise related to the randomness of individual events. The seismic release rate is an empirical variable U_r calculated by the sum of the moments or strain energy release occurring within is time window divided by variable number of days in the window, L that in our case is static and can be calculated based on Eq. (7).

$$U_r = \frac{1}{L}\sum_{d}^{d+L} U_0 \tag{7}$$

As we can calculate the average of the moment and strain energy associated with the earthquakes within that time frame. The process is repeated for the next "start day" and is continued until the end of the time series plot. Then the averaging scheme restarts for a different time window size. The moment release rate and the strain energy release rate is plotted within the time series plot as a logarithmic value to show the average of the energy released from the earthquake source depending on the length of time as shown in Figures (5) and (6) respectively. We thereafter record all seismic

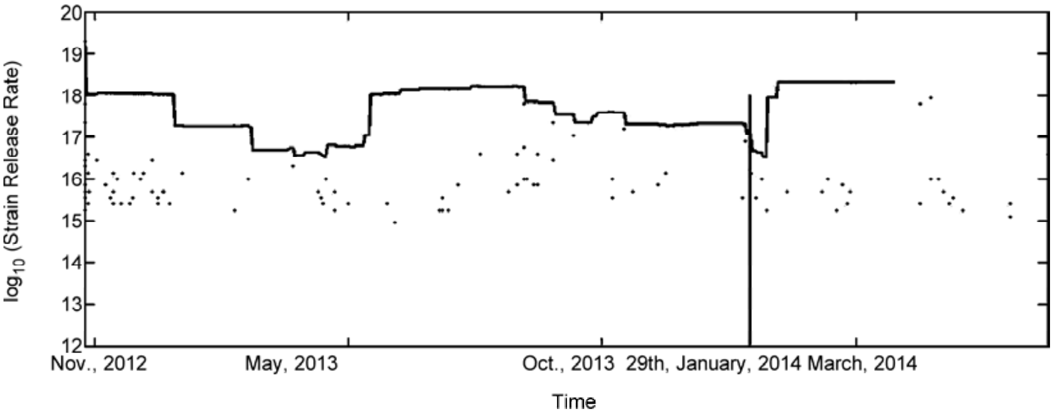

Figure 5. Strain energy release and window moving averages in two-year duration from November, 2012 to December, 2014 for all events of M 3.6 or greater in Shillong Basin and the Indo-Myanmar Region. The red line denotes the M5.7 event in Panchu with highly variability observed in the average strain energy release pattern.

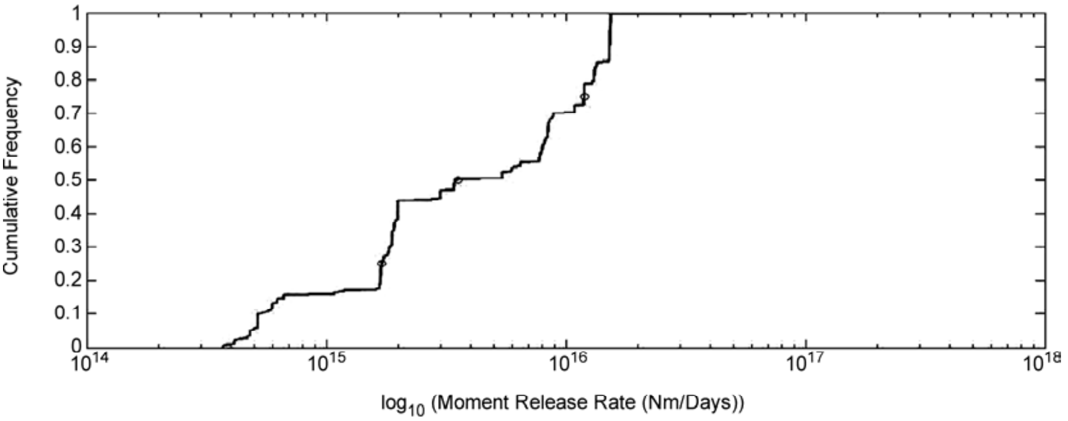

Figure 6. Cumulative Histograms of the moment release rates associated with the window sizes throughout the two-year period.

activities and use a contour mapping function of the form contourm, whereby vector inputs are allowed only if the lengths of latitude and longitude correspond to the number of rows and columns of Z whereby lat, lon, and Z must be matrices that represent a grid. The function plot is of the form contourm (lat, lon, Z) displays a contour plot of the geolocated M-by-N data grid, Z. lat and lon can be the size of Z or can specify the corresponding row and column dimensions for Z. Similarly it can be found that contourm (Z, R, n) or contourm (lat, lon, Z, n) where n is a scalar, draws n contour levels and contourm (Z, R, V) or contourm (lat, lon, Z, V) where V is a vector, draws contours at the levels specified by the input vector v. In order to implement real time strain analysis whereby we have different strain maps for depth, energy and strain deformation we put $V = [v\ v]$ to compute a single contour at level v. This is then superimposed on each other to reveal a spot of iso-contour plot as shown in the Figure (7) to reveal the time series expresses the date on the x-axis and the seismic moment on the y-axis. The plot that was generated shows the history of seismicity during the time span of the catalogue for identifying the distribution of seismic moment derived as an expression from moment magnitude and strain release energy is found as heterogeneous and that the source time function is quite complex. The energy rate variability over a period of two years has been found in Figure (8). We identify the seismic rate to define the temporal variation for large earthquakes to occur in the close vicinity of the

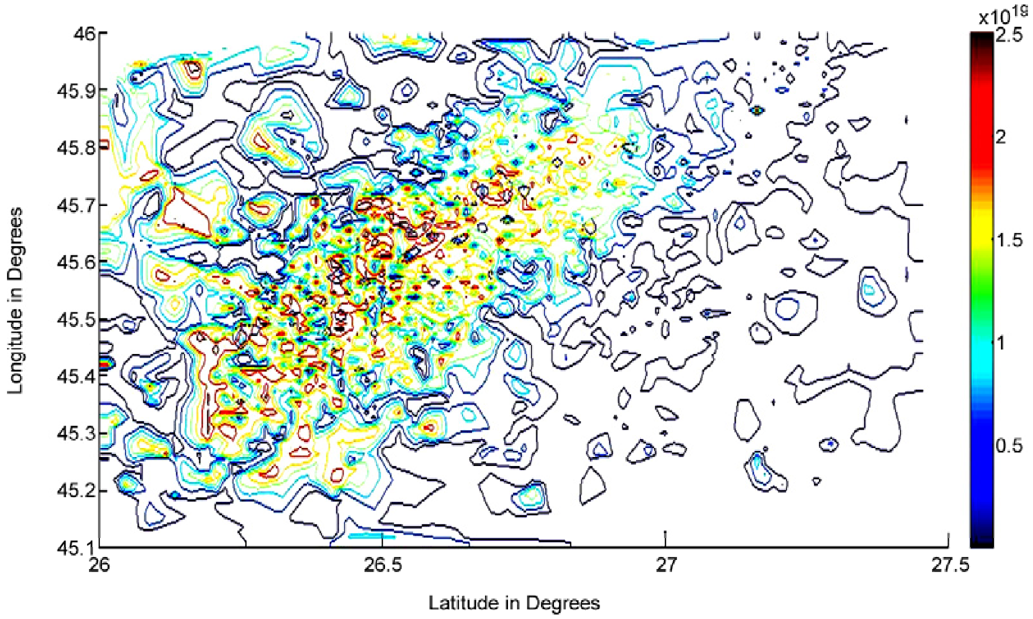

Figure 7. Identification of the Iso-strain energy (ergs), rupture change x 107 + release map of the study region.

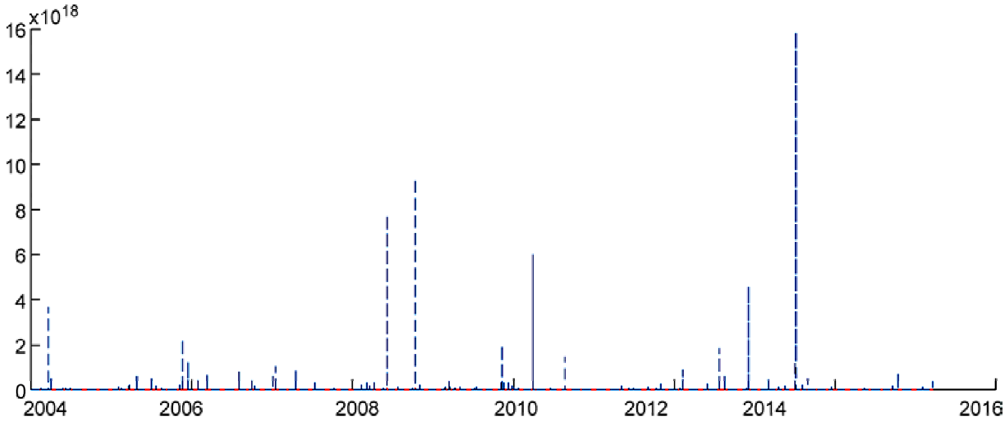

Figure 8. Temporal Release of strain $E_s^{0.5}$ shown by the unbroken blue lines and rupture patterns shown by the simple broken blue line.

region. However, the exact time period for the slip is impossible to define as the time period for the analysis of seismic moment is not the same as that of the strain energy release rate. Based on this analysis, we can say that although the total radiated energy cannot be measured, the average strain energy that causes a rupture is a very important aspect that needs to be treated in the future to find a relationship between seismic moment and magnitude, and the relationship between strain energy and seismic moment for that particular earthquake-prone region to identify the depth varying rupture properties as done in [23]. The cumulative histogram is an important tool in this aspect to find the distribution of energy release rate during the two years from 2012 to 2014 as shown in Figure (8). In the present set of data, we found that data are heavily skewed towards the larger moment release rates probably showing that the earthquake basins are clustered by nature and are not spatially clearly that the moment release rates distributed but rather occur along seismically concentrated zones. The time series output of the strain release is stationary as statistical properties remain unchanged in time. The operation for a moving window analysis for the strain release pattern is assumed to be a linear operation applied on the available information by using a linear operator that remains invariant in time. However, the exact time period for the slip is impossible to define as the time period for the analysis of seismic moment is not the same as that of the strain energy release rate. It is observed that the occurrence of this earthquake is indicated by the release of strain energy. Based on this analysis, we can say that although the total radiated energy cannot be measured, the average strain energy that causes a rupture is a very important aspect that needs to be treated in the future to find a relationship between seismic moment and magnitude, and the relationship between strain energy and seismic moment to identify the depth varying rupture properties as done in [24]. The cumulative histogram is an important tool in this aspect to find the distribution of moment release rate during the two years from 2012 to 2014 as in Figure (5). The data is heavily skewed towards the larger moment release rates probably showing that the earthquake basins are clustered by nature and are not spatially distributed but rather occur along seismically concentrated zones. Figure (5) shows clearly that the moment release rates during the two year gap for strain release rates based on empirical values associated with stress-strain relations; as shown in Figure (2) for rupture mechanisms; material science and location; the 3D geometry of all major, and possibly minor, fault zones and the distribution of stress in the lithosphere, at least close to the fault zones to link the physical characteristics of the rocks in faults (friction, brittleness, etc.). The post- M5.7 November 22, 2014 earthquake clearly shows that the moment release rate increases in small steps throughout and then increases by a large value every 50 days or so. After every 50 days, the moment release rate increases again progressively. The key to detecting a precursory signal (or in general, to isolate seismicity related to a particular event - be it in the future or the past), is in the partitioning. The trick, then, is to invert these observations to accurately model crustal deformation as shown in Figure (5) (stress/strain fields, etc.) or otherwise convolve the data into a single combined signal. The results can be interpreted with respect to the spatial (and temporal) extents over which the observation is made - an anomalous slip measurement over a region with length $L \sim 60$ km can be interpreted with respect to an incipient source earthquake. A small nucleation zone of "less than 100 m or so" (probably equivalent to 100 m^3) can turn into a large rupture of about 200 km^2, unless the stress necessary to create this large rupture had already accumulates along the much larger area/volume. As the stresses become more intense, the elastic strain energy stored in a portion of the crust (block), moving with the plate relative to a "stationary" neighboring portion of the crust, can vary only due to the random strength of the solid-solid friction between the crust and the plate. The flow diagram through an integrated earthquake model has been designed and shown in Figure (2). It is found that for a multi-geophysical approach as shown in Figure (2) that the first stage of the rock fracture begins when the stress curve deviates from linearity as differential strain variations occur at every portion of the fault due to the change of rock stiffness equivalent to the tensibility which is efficient resulting in isolated areas of stress release and strain accumulation [25]. In the second stage, strain release areas associated with quasi-static instability undergo a state of locking that initiates the early meta-instability for non-causal behavior of stress variability that initiates instable slip of fault as an independent activity for dissipation in nucleation of each fault part into a steady state evolution for stress transfer as studied by [26] in research studies. When the unstable slip function associates itself to the attractor states for the optimal state sequences, the fault enters the meta-instability stage of the rock matrix when isolated strain release areas of the fault increase and stable expansion proceeds as a distribution of the residual strain and is augmented by the sub-surface heterogeneous environment. All these observations suggest that understanding of the earthquake generating processes requires multi-disciplinary approach, which can be analyzed based on the rock properties using a reduced roughest approach for rock characterization. The energy of each earthquake has been determined using Eq. (4), and iso-strain release map has been prepared that can be further enhanced using the moving average Strain graph. The iso-lines of energy computed according to Eq. (4) have been drawn to prepare the iso-strain release map for showing the crustal structure of the Vrancea and it is found that areas of different rupture activity based on Eq. (6) are found to have coincided to reveal the spatial projection of the seismogenic basin where the rupture is likely to occur. When slips occur between the crust and the tectonic plate, the stored elastic energies are released in "bursts" which can be detected as earthquakes that can be observed as episodic tremors. As the stresses become more intense, the elastic strain energy stored in a portion of the crust (block), moving with the plate relative to a "stationary" neighboring portion of the crust, can vary only due to the random strength of the solid-solid friction between the crust and the plate. This may suggest clustering and specifically localization around planes, migration, spatio-temporal gradients of seismic parameters within a limited range. As the steady expansion is associated with quasi-dynamic instability, the interaction between the areas expands with fault linking as earthquakes are generated. However, the exact time period for the slip is impossible to define as the time period for the analysis of seismic moment is not the same as that of the strain energy release rate. The problem in earthquake forecast lies with the temporal distribution of sub-surface gas emission. This proves an important point that the rupture area and the quasi-static strain energy release is varying temporally due to the effect of the gas accumulation under the subsurface, but linearly depending on the force it exerts due to the causal forces of stress. The process of meta-stability shows that weak and strong segments associated with fault strain release and strain accumulation is found to occur successively as relatively independent and quasi-static triggering of the rock. The apparent disconnect points to the possibility that strain accumulating some 10 km deep in the crust is not faithfully transmitted to the surface, where the instruments are that can measure strain. The most likely reason is that the 10 km overlying rocks do not behave as an ideal elastic body, or even close to it, but absorb the piled-up stresses in some way that is not yet understood.

4. Conclusion

Our study shows that the seismic discontinuity is de-clustered along the Center of the Vrancea Region. The seismic energy variations and moment rate changes are clustered throughout the Vrancea Region while the presence of the rupture is centered in small linked patches as evident from the Figure (7). Second, the strain energy due to release as on November 22, 2014 indicates that there is a probability of occurrence of an earthquake of magnitude in the near future. Again, it has been observed that the strain energy bearing capacity of the rocks of the Vrancea region is high as compared to other regions. Moreover, the amount of strain energy due is comparable with the estimated strain bearing capacity of the rocks of the region. Hence the probability of occurrence of earthquake in that region in the near future is greater than the other regions. Third, the examination of seismicity rate changes in the Panchu earthquake reveals the conclusion that the moment release rates without the aftershocks in the Vrancea region exceed the 95th percentile confidence level as shown in Figure (6). We get some idea about the crustal structure of the study region iso-strain release map and also areas of different seismic activity could be identified.

The present study has great significance as a number of devastating earthquakes have occurred in this region. The method identifies the predict of the 'jumps' associated with the change of seismic energy, moment and rupture and finds the relationship between all the three from 2004-2016. The inactivity period is uncertain in our case. Our analysis covers a short time period (2004-2016), and follows recent energy jumps that have occurred in several regions of Romania during the same period of time. Again, knowledge of the size of the most probable earthquake that might occur in the region as shown in Figure (2) will help the structural and architect engineers while designing buildings. Thus, a detailed analysis of strain energy release pattern of the region would be very useful in minimizing the loss of life and property due to a seismic event.

Acknowledgement

This research was partially supported through data acquired from Romplus Catalog acquired from the National Center of Earth Physics, Bucharest, Romania. I would like to thank the scientists in National Center of Earthquake Physics as Victorin Toader, Ionescu Constantin, Alexandru Marmaneu, Irina Moldovan and Mircea Radulian in National Institute for Earth Physics, Romania for providing me the data to analyze the Romplus Catalog as part of my study as an Erasmus Post-Doctoral Fellow in Romania and the Risk Management Research Center, International Institute of Earthquake Engineering and Seismology (IIEES), Iran for acceptance of research and insight and expertise through SEE7, 2015 conference presentation in Iran in May, 2015 and publication in the conference proceedings of SEE7, 2015.

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