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An Assessment on Correlations of Seismotectonic Parameters Preceding and Following Roudbar-Manjil Earthquake (Gilan, North of Iran)

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Abstract: An assessment on fractal dimensions and seismic attributes of areas displaying seismic activity provides insights into the area activity. The present study is conducted on seismic potential parameters in Roudbar, located in north of Iran, preceding and following an earthquake occurred in the area in 1990. A study of fractal dimensions of seismic distribution over time and their relationship with seismotectonic parameter of an earthquake occurred in 1990 showed that the relationship between seismotectonic parameter and fractal distribution dimension had been changing during 1990s before the occurrence of the earthquake and positive after that, both including decreasing trend. An assessment on changes of seismotectonic parameter over time represents its decrease in 10 yrs after the earthquake occurrence, suggesting a decrease in seismotectonic activity and the beginning of energy concentration in area. The relationship between fractal dimension of local fracture and local seismic distribution is not clear.

Key word: Roudbar – Manjil, fault ,fractal dimension ,Iran,seismotectonic

INTRODUCTION

Until 1986, when Mandelbrot introduced the concept of fractal and its applications in numerous branches of natural sciences and fractal began to be applied considerably in different sciences, a lot of natural phenomena were regarded irregular and unpredictable. Examples of which include medicine, biology and geology. Fractal, in particular, opened a way to access tectonic processes which generally posses fractal properties (Gilbert, 1989) and involve discrete activities such as movement on faults and continuous activities like folding. These extremely complicated processes, however, include convincing fractal statistics (Turcotte, 1992). Among all influential tectonic activities, earthquakes are particularly important since they follow no serious danger for human being. Seismic potential – an example of a complex phenomenon- can be examined by fractal concepts (Turcotte, 1992).

Using global seismographic network and recording earthquakes of 4-Richter magnitude, it would be possible to study seismic distribution and to discover relations for seismic potential properties in different regions, the most important of which between frequency of the occurrence of earthquakes and their magnitude is commonly called Gutenberg-Richter (Gutenberg and Richter, 1952).

$$\log N = -bm + \log a \tag{1}$$

where a and b are constants. N is different time period ranging from 10 to 90 yrs. m is earthquake magnitude and is defined as the range of ground movement in a certain distance from earthquake center. Magnitude is of various kind: surface wave magnitude and body wave magnitude. The former is defined in terms of movements resulted from Love and Raleigh surface waves at 20 seconds; the latter is computed in terms of those movements occurred by body waves. There is also moment magnitude which is widely used for maximum magnitude earthquakes based on energy released from earthquakes as shown in equations 2, 4 and 6.

W_0 refers to the energy released from an earthquake. $\Delta\sigma$ is stress drop and μ equals rock shear module where fault has influenced. D is mean movement or fault slip and M_0 is moment or seismic moment.

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$$\log W_0 = 1.5M_W + 11.8 \tag{2}$$

$$W_0 = (\Delta\sigma / 2\mu)M_0 \tag{3}$$

$$M_0 = \mu\overline{D}S \tag{4}$$

Overall, a seismic moment of an earthquake can be related to its magnitude through the following equation:

$$\log W_0 = CM + d \tag{5}$$

Where C and d are constants.

According to Kanamouri and Anderson (Kanamori and Anderson, 1975), C and d equal 1.5 and 9.1 respectively.

On the other hand, considering the equation (6) and the equation (7), (Turcotte, 1992)

$$N = \beta A^{-3b/2c} \tag{6}$$

$$N = C / r^D \tag{7}$$

Where D refers to scattered fractal dimension of seismic potential and is computed as follows (Aki, 1981)

$$D = 3b/c \tag{8}$$

Using theoretical relation of c= 1.5 Kanamori and Anderson, (1975), D= 2b is derived.

It follows that global fractal dimension of seismic potential is simply twice bigger than b (Turcotte, 1992). In addition, according to the equation (9)

$$N = C / r^D \tag{9}$$

and its comparison with Gutenberg – Richter relationship, equation (9) will become equal to fractal distribution (Aki, 1981).

Recent studies show that the relationship between fractal dimension of earthquakes' distribution and seismic potential parameter of the area can be equally varied depending on faults, natural fracture systems, earthquake distribution and temporary patterns of the occurrence of earthquake (Mandelbort, 1982).

Using two-point correlation dimension, Dc, it was proved that spatial patterns of earthquake distribution epicentrals also have fractal nature. Assessments suggest that parameter b changes systematically (Smit, 1986) due to stones heterogeneity and heterogeneous distribution (Scholz, 1968). Some examples of fractal dimension include capacity dimension, D_0 and correlation dimension, Dc. It's possible to examine their relationship with seismic potential parameter. Capacity dimension of space filling attributes measures a set of fractures on changes in network size (Hirata, 1989). It also enables researchers to relate fault linear dimension and b-value. Correlation provides a method to measure distance attributes of a set of points. Correlation is often used to measure distribution attributes of earthquake epicenters and hypocenter distribution of acoustic explosion occurring in laboratories (Hirara *et al.,* 1987).

The present study tries to examine the relationship between b -parameter and capacity dimension of local fractures in Manjiil- Roudbar, and to discover the relationship between correlation dimension of earthquakes ocurred in the area displaying seismic potential parameter preceding and following Roudbar – Manjil Earthquake in 1990.

Local description:

Iran, southwestern part of Asia, is situated in Alp-Himalaya earthquake belt (Aganabati, 2004). The country has gone under Iran's plate through the influence of subduction Arabian plate in the Southwest, Suture strike of Zagros in the northeast, and under Alborz through the influence of southern Caspian plate in the north (Pourkermani and Aryan, 2007). Pressure resulting from the two opposite sides and boundedness between neighboring regions have produced many faults and fractures on the plate.

Regarding existing faults and geographical distribution of earthquakes, Iran is divided into 4 basic seismotectonic zone including Alborz, Central Iran, Zagros and Coppe-Dagh (Berberian, 1977). Mount Alborz, extended in southern Caspian Sea in north of Iran, is 600 km long and 100 - 300 km wide.

Active dextral strike faults parallel with eastern Alborz mountain have shown ENE trend and WNW trend in western Alborz (Berberian, 1992). Of the most important faults of the zone are Northern Alborz fault, Khazar fault and Astara fault. Thrusting from the two opposite sides of the north and south was followed by north - south shortening. Recorded activity for 1990 Roudbar – Manjil earthquake shows pressure activity with sisnstral strike – slip component (Berberian, 1992). A multi – segment fault has frequently been considered the cause of 1990 Roudbar – Manjil earthquake (Kabate, Zardgoli,…). Since this article is focused on Roudbar 1/100000 geographical map, Kabate fault as one of those segments is to be studied too.

Previous studies:

After a disastrous earthquake, Mb=6.4 and Ms= 7.7, occurred in Roudbar – Manjil and over 35000 people were killed and 3 towns of Roudbar, Manjil and Loushan and 300 villages were destroyed, field studies started to be conducted in order to identify the fault underlying the earthquake and its mechanism.

After the main earthquakes, some aftershocks took place, the strongest of which happened hours after the main earthquake. Most aftershocks were reported differently ranging from 10 to 20 km deep (Tavakkoli and Ramzi, 1991). The earthquakes' center was 49.41 E and 36.96 N (ISCS).

Manjil – Roudbar earthquake was accompanied with seismic fault in 3 separate segments arranged in the form of en-echelon. The fault is about 80 km wide in the main shock belt. The pieces stretch on the ground in the form of en-echelon toward each other with N095˚ – N 120˚ trend, suggesting sinstral strike-slip and pressure activity. Each segment is along the fault with sinstral strike slip (more or less vertical inclining toward south, southwest).

An approximately 95-centimeter movement and sinstral strike –slip movement for about 60 centimeters were measured along the fault (Berberian *et al.,* 1992). Deep mechanism of this earthquake's fault (Berberian *et al.,* 1992) does not match with the earthquake's fault on the ground. The difference might suggest that fault on the field is comparable with other secondary structures.

Huge shocks of the earthquake in high slopes of Alborz mountain caused some spread land sliding and mountain falls, great gaps, a change in the level of underground water, liquefaction phenomenon along Sepidroud River and its delta (Astaneh Ashrafiyeh region) (Pourkermani and Aryan, 1998).

Yet, there have been no studies on the comparability of fractal dimension of regional active faults and seismic potential parameter value in terms of Gutenberg-Richter. In this study, we explore, for the first time, the relationship between seismotectonic variables and fractal attributes in order to be able to understand the way this seismic potential area works.

Analysis method:

Seismic b-value:

Where b is measured using likelihood method via the equation (10). b in the following equation represents quantitative deviation (Aki, 1965).

$$b = \log e / (\overline{m} - m_0 + 0.05) \qquad (10)$$

Where $\overline{m}$ is mean magnitude of events of M> m_0 and m_0 is threshold magnitude for the area under study.

B-value is negatively related with mean magnitude and mean crack length Main, (1992). 0.05 value is correlation constant capacity dimension (D).

Studies on Rudbar- manjil area have applied box-counting method to evaluate the detailed lineament properties of fault network and local fractures. The method required that lineament map and fractures of Roudbar 1/100000 area were first prepared based on Roudbar geological 1/100000 map (Nazari and Salamati, 1998).

Local fractures were drawn with the help of ArcGIS. In order to prevent making any errors, comparisons were made between a set of regional lands and between and drainage fractures using satellite images and determining drainage line layers and the location of the area under study on the early map of local fractures respectively. Finally, map's accuracy was increased through a digital elevation rnodel. After the map of fractures was prepared, capacity dimension was determined. For this reason, the map of fractures was covered by squares with sizes of length (r). The number of squares covering part of faults' fractures pattern, (N), was counted in different steps and after changes of the length of box side (r). As the length of box side raised, the number of squares including fractures' pattern was decreased. At the final step, fractal dimension, sometimes referred to capacity dimension, is calculated using the following equation (Addison, 2005).

$$N = Cr^{-D} \quad (11)$$

Where D is fractal dimension and C is a constant.

Correlation Dimension (Dc):

In case one seeks to carefully evaluate the distribution of points such as earthquake epicenters in one area, integral correlation method is preferred. The method gives a real estimate of fractal properties of points distribution (Kegan and Knopoff, 1980). Correlation Dimension is realized by the following equation:

$$\underrightarrow{D_C} = \lim(\log C(r) / \log(r)) \quad (12)$$

Where C(r) – integral correlation – is calculated through the following equation :

$$C(r) = \frac{1}{N(N-1)} \sum_{i=1}^{N} \sum_{j=1; j \neq i}^{N} \theta(r - |X_i - X_j|) \quad (13)$$

In above equation, X_i and X_j represent points on reference trajectory and on attractor nearby X_i respectively.

The present study, correlation integral is determined via the equation (14).

$$C\ (r) = N / n \quad (14)$$

N is the number of a pair of earthquakes in analytical window separated by a gap of less than r. n is total sum of seismic events analyzed. Standard deviation is estimated using logarithm linear regression C (r) versus logarithm r.

Discussion:

By mentioned above methods and by assistance of some special software such as ArcGIS, Benoit ,Fractalysc and so on ,we achieved to results that are considered in following.

Relationship Between Fractal Dimension of Seismic Distribution and Seismic Parameter:

To determine fractal dimension of seismic distribution, the first epicenter points identified through site was plotted on local map by ArcGIS software so that the location of epicenter points are specified in terms of fractures. Epicenter points, then, is converted into a exported file in different time periods. Finally, fractal dimension of distribution is determined via Fractalysc software.

Correlation Dimension is calculated based on epicenter distribution in the period 1964-2008 in different time intervals. To determine fractal dimension, local seismic distribution was considered from the center of Roudbar 1/100000 map, 36.45° N and 49.15° E toward 150km around the center. Seismic data used in the present study had been derived from USGS site. Note that seismic data used for the period 1964-1967 had been taken from ISC site since there has been no data available for this time period in USGS site. Data used include geographical longitude and altitude and earthquakes' epicenter depth, earthquake magnitude and the time of the occurrence of earthquake. The number of data was totally 173.

Using that data and the base earthquake identified (Turcotte, 1992), b-value was first calculated for different time periods in Alborz seismotectonic zone for the period 1964-2008 (equation 10). Then, the relationship between correlation dimension and b parameter shows changes preceding and following Manjil – roudbar earthquake. For this reason, first b changes are examined: b parameter reflects two stages of trend changes before 1990 earthquake (from 1967 to 1990). The first trend was decreasing (from 1964 to 1984) whereas the second one was increasing.. Increasing trend of b parameter represents an increase in area seismic potential, thereby increased potential of the occurrence of earthquake preceding 1990 earthquake. The trend was decreasing following the earthquake so that b parameter has reached 1.17 in the 1990s from 1.23 in 1985-1989. b- parameter remained decreasing until 2008 so that it reached 0.989 in the period 2005-2008 from 1.03 in the period 2000-2004. This decreasing trend can be attributed to strain reconcentration along main faults of the area as well as decreased local seismic activity and the possibility of increased seismic activity in future.

After studying the relationship between calculated Dc for mentioned time periods and seismic potential parameter, it was concluded that seismic distribution of epicenters is correlated positively with seismic potential parameter (Fig.2)from 2000 on so that a decrease in b-value is followed by a decrease in Dc. This, in turn, suggests increased seismic activity and decreased local epicenter distribution, implying that strain release results from seismic activity in a specific area as is explained in later section.

However, for the time period 1964-2000, Dc and b-parameter have shown to be negatively correlated, that is, they are divergently related (refer to Fig. 2). As is shown in the picture, in the time period 1980 - 1985 seismic potential parameter was decreasing whereas fractal dimension of seismic distribution was increasing, suggesting little and scattered seismic potential activity. In the next 5 yrs, seismic potential parameter was increasing whereas fractal dimension of seismic distribution was decreasing. The recent observation can be regarded as an alarm for the occurrence of a big earthquake, given that seismic potential activity in the area has shown a sudden increase and earthquake distribution was observed in a limited area (near the area where a great earthquake is likely to occur in future) followed by a decrease in seismic distribution. After the occurrence of 1990 earthquake, fractal dimension of seismic distribution has considerably increased from 0.065 to 1.708 but seismic potential parameter value has been slightly decreasing. Negative correlation between Dc and b implies a strain concentration in such great extent that is not limited to an area or along active fault zone after the earthquake occurrence but in the whole region. A general relationship between b and Dc is shown in figure 3a. The relationship for the time period 1964 – 1999 and 2000- 2008 is given in figures 3b and 3c respectively.

An important point about epicenter distribution is the location of seismic distribution in the area. The location is shown for different ears in figure 4. During 9 yrs, most earthquakes took place in northeastern part and were distributed near active seismic zone but earthquake epicenter changed southwestwards from 2000. one reason could be that seismic potential of the area decreased after 1990 as a result of many earthquakes happening in 10 yrs. It's worth noting that new seismic activities began in another part of the area. This could mean that another main earthquake will occur in future in that area. As mentioned above on the relationship between seismic potential parameter and fractal dimension of seismic distribution, the relationship has been convergent from 2000 on, both showing decreasing trend. Decrease in fractal dimension parameter can be attributed to seismic activity concentration in the southwest of the area rather than to the activation of seismic potential zone in the northestern part.

D0 (Capacity Dimension of Active Fault System) Local Fractures:

Using fault map and fractures along Roudbar-Manjil 1/100000 area (Fig.5), where the fault responsible for 1990 earthquake is located, applying Benoit software and D_B method, capacity dimension of active fault system for the area was measured. Understanding the way earthquakes are distributed in the area enables us to divide the area into two northern and southern regions based on seismic distribution.

After dividing the area into two boundaries, capacity fractal dimension was calculated for individual region in order to discover the relationship between fractal dimension and seismic distribution. Calculated values yield no significant difference, i.e. the values 1.91219 and 1.91837 were obtained for northern and southern regions respectively. In contrast, a tangible difference was observed for fractal dimension of seismic distribution. There are different reasons for the difference, one to mention here is released energy concentration both during and after 1990. It should be noted here that northern region is situated near the fault responsible for Manjil-Roudbar earthquake so that strain concentration and its final release on surrounding faults. As is shown in the figure 5, these active faults are located in northern part whereas faults and fractures situated in southern part remained inactive because of the large distance from Manjil- Roudbar earthquake center and lack of al energy. Lithologic difference in northern and southern boundaries could be another reason difference in activity. In southern part, Paleocene Granitites, Tarom Granite set (which had shaped Mount Changal highlands, Shame Dasht and Mount Sepid) and generally magmatic set of Alborz arc can be found. The magmatic set, dating back to Paleocene were formed as a result of thrusting of an oceanic segment under an Alborz continental segment. In northern boundary, volcanic or less deformed rocks are hardly found certain faults and fractures are observed in less deformed rocks set of southern part, their activity could be continuous because of their influence in rocks which bear deformations as creep. Besides, energy is not so much concentrated along the fault able to cause many earthquakes after sudden release. A clear example of this latter fact is creeping changes in Sanandaj-Sirjan zone.

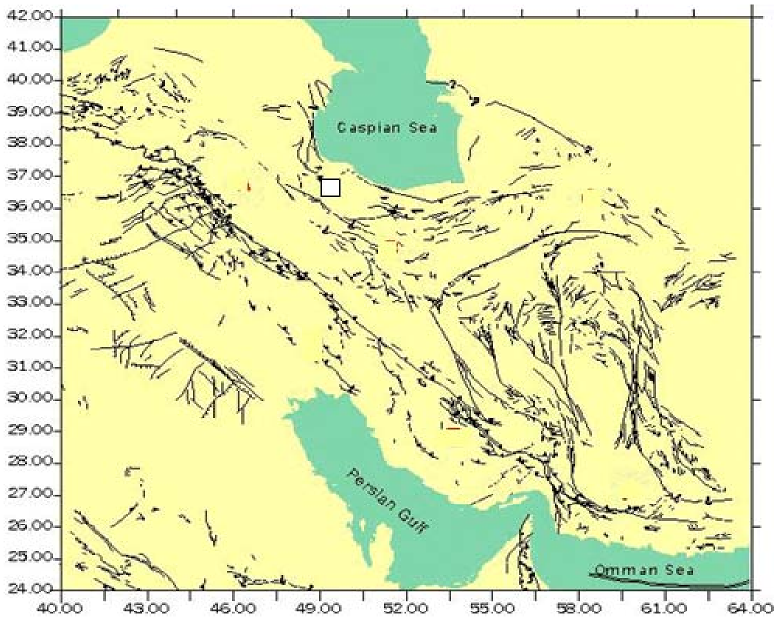

Fig. 1: Map of main faults of Iran. The study area is shown by white rectangle. (Derived from NGDIR Site, 2009)

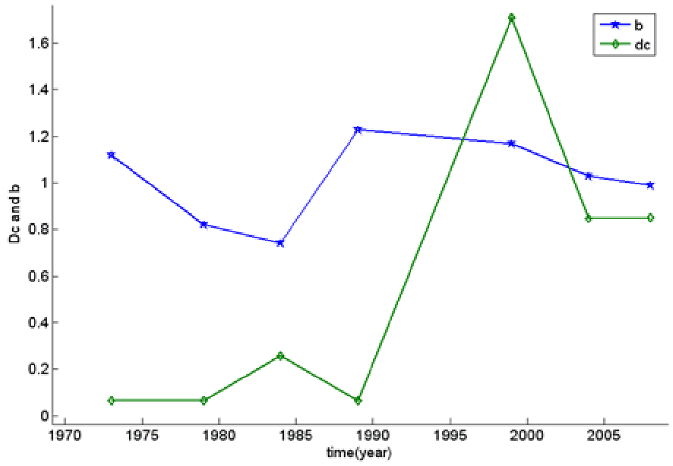

Fig. 2: Change in seismic parameter and fractal dimension of seismic distribution in the period 1964- 2008.

Conclusion:

Studying the relationship between fractal dimension of seismic distribution in the area near Roudbar-Manjil preceding and following 1990 earthquake along with the area seismic potential parameter, certain changes can be discovered in these two parameters before and after the earthquake occurrence. In the ti1964-1999, fractal dimension of seismic distribution and seismic potential parameter have shown to be negative.

Using seismic data, match between Dc and b becomes convergent in 9 yrs from 1999 – 2008 and calculated values for these two parameters show decreasing trend. Decreasing trend of seismic potential parameter is a response to a decrease in seismic potential activity and beginning of strain concentration in the area. A decrease in fractal dimension of seismic distribution is related to seismic activity concentration in a certain area (clustering concentration of earthquake epicenters). A fact that mustn't be taken into granted is that concentration is apparently found in a farther distance from the center of main Roudbar- Manjil earthquake in 1990 and it south west.

Finally, one comes to the conclusion that match between seismic potential parameter and seismic distribution dimension changes depending on the nature of area seismic potential, local fault system and the relationship between faults as well as the amount of concentrated energy in the region.

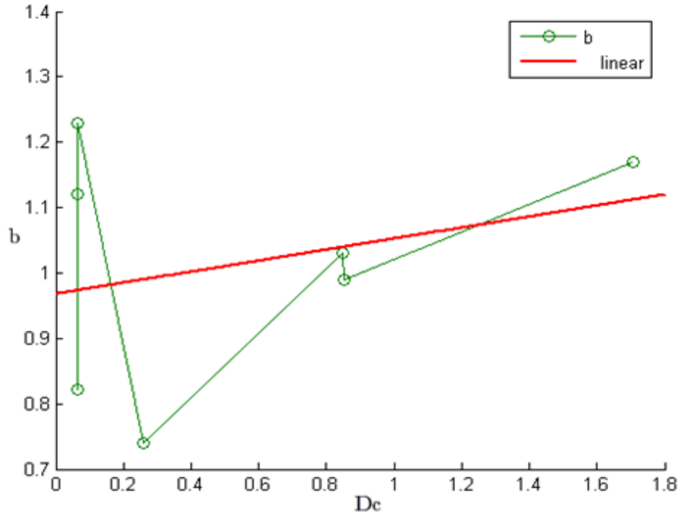

Fig. 3a: The relationship between seismic parameter and fractal dimension of seismic distribution in the period 1964- 2008.

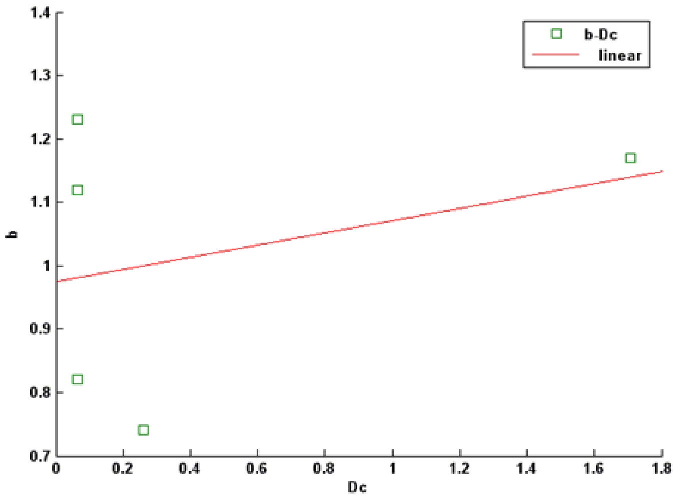

Fig. 3b: The relationship between seismic parameter and fractal dimension of seismic distribution in the period 1964- 1999.

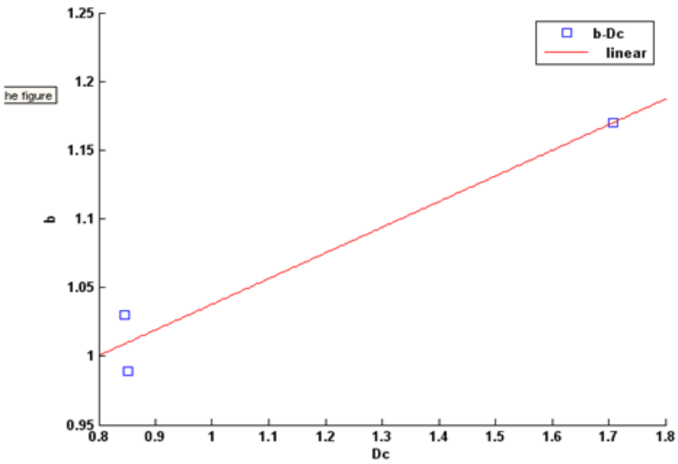

Fig. 3c: The relationship between seismic parameter and fractal dimension of seismic distribution in the period 2000- 2008.

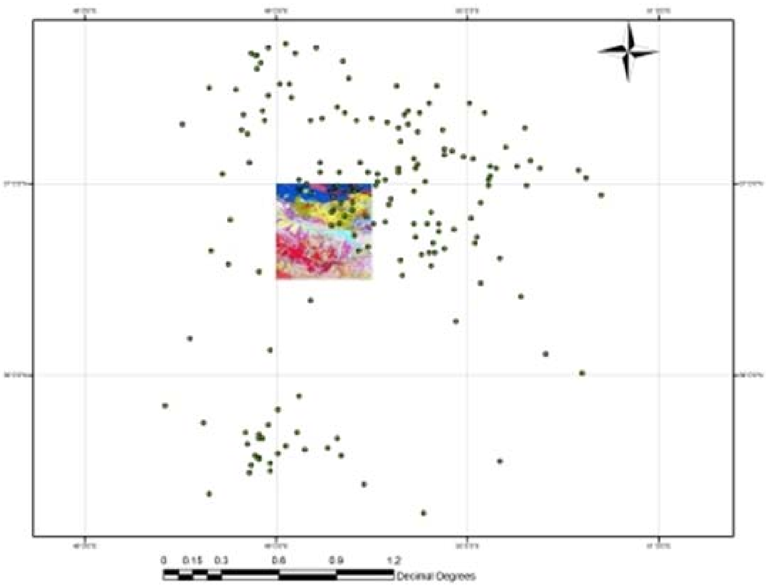

Fig. 4: The distribution of earthquakes in Roudbar region in the period 1964- 2008.

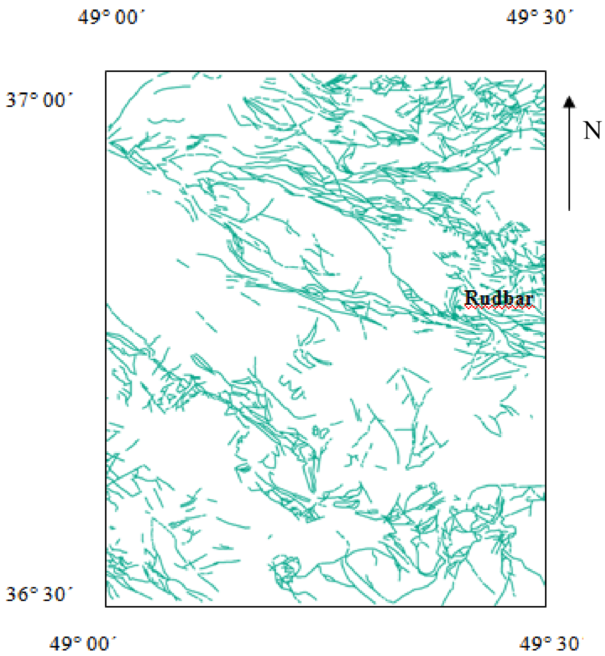

Fig. 5: Map of fractures and faults in Roudbar rectangle.

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