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Pattern of Propagation of Seismic Energy Associated with Large Earthquakes

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Abstract -- Earthquake data (1899-2009) of the Circum-Pacific seismic zone were extracted from the catalogue of Advanced National Seismic System (USA). The zone is the source of 90% of the world's earthquakes and the one with most recorded data. The zone was divided into five regions based on the pattern of occurrence of small earthquakes, each selected grid was analyzed with Compicat software to determine the location of the maximum seismic energy released and the most active zone. An expression was developed to study the pattern of propagation of the seismic energy and frequency with respect to a large earthquake in each sub-zone. While the Compicat result show that for almost all the distribution considered, the zone where the largest amount of seismic energy was released does not coincides with the most active zone in terms of frequency of occurrence of earthquake this shows that frequency of occurrence of earthquakes in an area may not be a comprehensive description of how active an area is seismically. The pattern of energy propagation for all the regions was not linear but flapping, undulating but not periodic with some symptoms of fractal geometry.

Index Terms-- Circum Pacific, Fractal, Large Earthquake, Non- Periodic, Pattern Recognition, Seismic energy, Seismicity

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1 INTRODUCTION

Seismicity or seismic activity is the distribution of earthquakes by frequency, type, size, intensity, depth, magnitude or energy and geography or latitude and longitude, over a period of time. The distribution of earthquakes globally is not uniform, observation shows that earthquakes are concentrated along narrow region with a large aseismic area within or in between these narrow regions, these highly seismic narrow regions are in between lithospheric plates and are known as plate boundary. Seismic energy *E* is the energy of elastic seismic waves radiated in time and space by an earthquake rupture or is defined as the energy E(r) that has been propagated by seismic waves to a distance r from the epicentre of the earthquake or as the wave energy that would be transmitted to infinity if an earthquake occurred in an infinite, lossless medium [1]. It is an important earthquake parameter for describing the dynamics during earthquake rupture and to characteristized an earthquake rupture zone [2], [3], [4], [5], it is a fundamental parameter for describing an earthquake and it contain information that can be useful for seismotectonic interpretation [6], [7], [8]. It is important for characterizing the intensity of shaking or seismic potential for damage and it useful in many equations use in studies of earthquake physics [3]. This research is based on the use of earthquakes' catalogue to describe the dynamics of seismic regions and derive precursory seismic pattern associated with earthquakes [9], [10]. This pattern may reflect the geodynamic characteristics of a region [11], several types of seismic patterns have been proposed [12], [13], [14], [15]. It has been suggested that though the result of seismic pattern may not be an outright solution but it may help in stimulating hypothesis and extraction of physical meaning from data [8].

2 STUDY AREA

The Circum-Pacific seismic zone or Pacific Ring of Fire encircles the basin of the Pacific Ocean and is a zone of frequent earthquakes and volcanic eruptions. It is the source of 90% of the world's major earthquakes. The earthquakes in the zone are the most recorded according to the United States Geological Survey Department [16], large numbers of earthquakes and volcanic eruptions occur in the basin of the Pacific Ocean. The area is associated with a nearly continuous series of topographic and tectonic features such as oceanic trenches, volcanic arcs, volcanic belts and plate movements, subduction zones in the circum-Pacific host approximately 70% of the world's earthquakes [17],[18].

3 DATA ACQUISITION

The data used in this study were obtained from Earthquake catalogue of Advanced National Seismic System (ANSS), Northern California Earthquake Data Centre, USA. The Period of catalogue is between 1899 and 2009. It contain the origin time, date, epicentre, depth in kilometre, latitude, longitude, magnitude, magnitude type (local magnitude, body wave magnitude, surface wave magnitude, energy magnitude and moment magnitude), and Event

Identification number. Total number of events were 805, 740.

4 METHODOLOGY

The study area was divided into five regions based on the pattern of occurrence of small earthquakes. Each selected grid volume was analyzed with CompiCat software to determine the location of the maximum seismic energy released and the most active zone or highest rate of activity in term of frequency of earthquakes. CompiCat is a software program designed for studies of seismic activity based on catalogue of earthquakes. It is an application for editing and compiling catalogue of earthquakes, which is an essential part of any study of seismic activity. The application combines the features of EdCat and Catal console applications [10], [19]. CompiCat program was designed for reproducible studies of seismic activity based on catalogue of earthquakes. Fig. 1 shows a snapshot of the typical visualization output window of the software. The expression in equation (1) was formulated and used to study the pattern of propagation of the seismic energy and frequency with respect to a major earthquake in each sub-zone.

$$R^2 = \left(X - X_i\right)^2 + \left(Y - Y_i\right)^2 \qquad (1)$$

X and Y are the latitude and longitude of the reference large earthquake in the region while X_i and Y_i are the latitude and longitude of the location of the maximum seismic energy released in each volume in the region respectively.

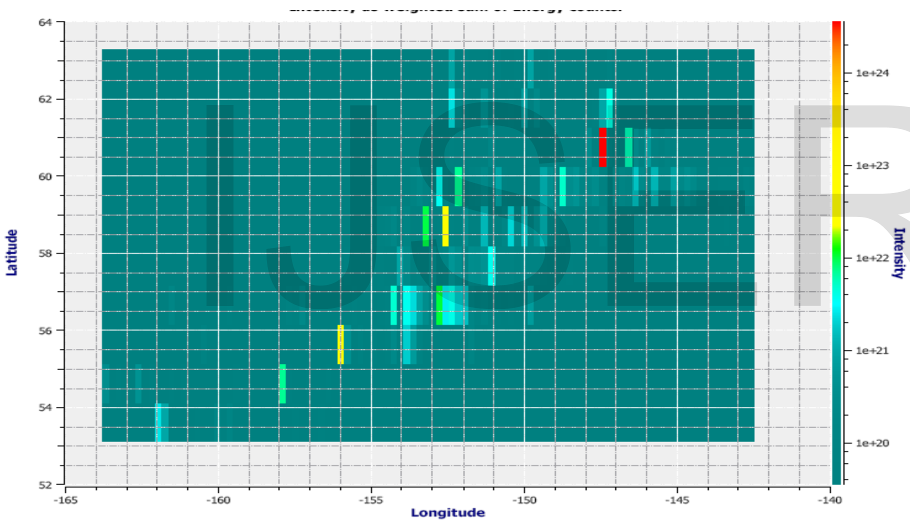

Figure 1: A snapshot of the typical visualization output window of the CompiCat program.

5 RESULTS AND DISCUSSION

Figures 1 shows a snapshot of the typical visualization output window of the program/software. The frequencies of earthquake distribution were recorded on the snapshot as 2-dimensional intensity with different colour code depicting the high, moderate and low level of activities. The red colour indicates the most active zone or highest frequency of occurrence of earthquakes location. The yellow colour indicates zones of moderate activities while the blue colour indicates zones of low activities. The red colour indicates locations at which high amount of energy released was concentrated, while the yellow and the blue colours indicates zones of moderate and low seismic energy respectively. The zones and locations where maximum seismic energies were released were identified. These locations are areas of probable future earthquakes if the pattern is periodic. Table 1 showed the result of the locations of maximum or highest seismic energy. The 2-dimensional weighted sum of energy counts showed that between 1960 and 1964, the largest amount of energies was released at Latitude 61.58^0 and Longitude -147.02^{0}.; For 1965 to 1969, 1970 to 1974, 1975 to 1979, 1980 to 1984, 1985 to 1989, 1990 to 1994, 1995 to 1999, 2000 to 2004 and 2005 to 2009 periods, the maximum energy was released at Latitude 65.38^0 and Longitude -149.97^0; Latitude 59.79^0 and Longitude

142.46^0; Latitude 60.75^0 and Longitude -141.46^0; Latitude 61.02^0 and Longitude -147.26^0; Latitude 56.86^0 and Longitude -142.91^0; Latitude 62.46^0 and Longitude-154.27^0; Latitude 57.34^0 and Longitude -154.21^0; Latitude 63.44^0 and Longitude 147.43^0 ; Latitude 55.89^0 and Longitude -153.43^0 respectively. Table 2 showed the propagation of seismic energy obtained or extracted from Table 1, using equation (1) where X and Y are the latitude and longitude of the reference large earthquake in the region while Xi and Yi are the latitude and longitude of the location of the maximum seismic energy released in each temporal volume in the region respectively. Figure 2 showed the pattern of propagation of maximum seismic energy obtained from Table1.

Table 3 showed the locations with the highest frequency of occurrence of earthquakes from 1960 to 2009 for region 1, while its propagation is shown in Table 4. The pattern of propagation is shown in Figure 3.

Table 1: Locations of maximum seismic energy for Region 1

Period(yr)	Latitude(°)	Longitude(°)	Energy(J)
1960-1964	61.58	-147.02	3.981E+31
1965-1969	65.38	-149.97	2.398E+26
1970-1974	59.79	-142.46	1.800E+25
1975-1979	60.75	-141.46	3.199E+27
1980-1984	61.02	-147.26	5.880E+23
1985-1989	56.86	-142.91	1.798E+25
1990-1994	62.46	-154.27	1.396E+24
1995-1999	57.34	-154.21	1.799E+25
2000-2004	63.44	-147.43	2.317E+29
2005-2009	55.89	-153.43	1.863E+22

Table 2: Pattern of propagation of maximum Seismic energy for Region 1

Period (yr)	R
1960-1964	0.7017834
1965-1969	4.9948974
1970-1974	5.1776524
1975-1979	6.0272727
1980-1984	0.2220360
1985-1989	6.2000806
1990-1994	6.9348540
1995-1999	7.6839795
2000-2004	2.3905230
2005-2009	7.8757920

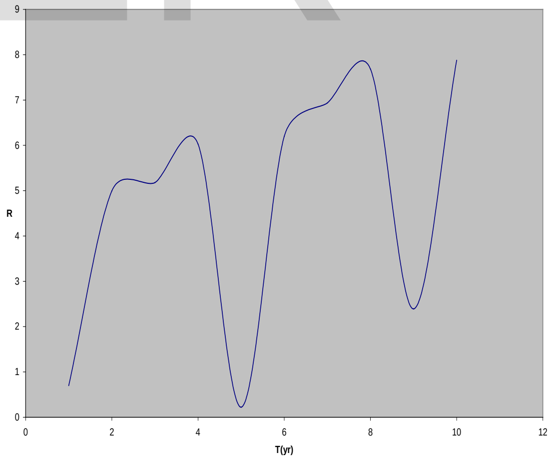

Fig. 2: Pattern of propagation of maximum Seismic energy for Region 1

Table 3: Location of highest frequency of earthquakes for Region 1

Period(yr)	Latitude(°)	Longitude (°)	Frequency
1960-1964	56.58	-152.02	10
1965-1969	65.38	-149.97	32
1970-1974	60.00	-152.83	12
1975-1979	64.82	-147.36	95
1980-1984	60.98	-147.15	50
1985-1989	66.21	-149.96	75
1990-1994	63.22	-151.03	200
1995-1999	57.96	-156.65	309
2000-2004	63.47	-147.50	417
2005-2009	60.04	-152.84	147

Table 4: Pattern of propagation of highest frequency of earthquakes for Region 1

Period (yr)	R
1960-1964	6.3712244
1965-1969	4.9958947
1970-1974	5.4510826
1975-1979	3.7719093
1980-1984	0.3414396
1985-1989	5.7250328
1990-1994	4.1572847
1995-1999	9.6706060
2000-2004	2.4200826
2005-2009	5.4543286

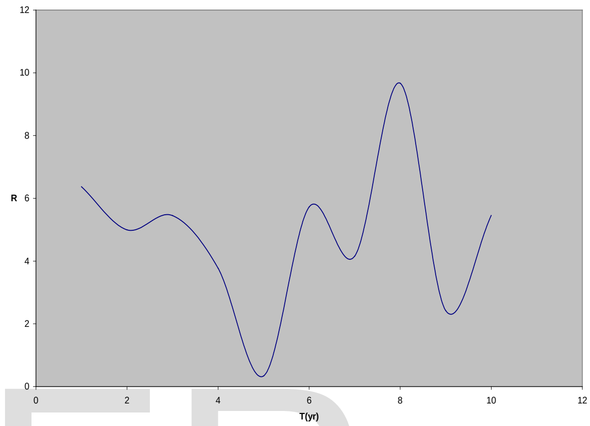

Fig. 3: Pattern of propagation of highest frequency of earthquakes for Region 1

Table 5: Location of maximum seismic energy for Region 2

Period (yr)	Latitude (°)	Longitude(°)	R
1960-1964	34.76	145.54	7.239577
1965-1969	40.34	142.19	3.116807
1970-1974	41.37	142.65	4.152438
1975-1979	43.38	147.67	8.140182
1980-1984	40.61	139.44	4.455644
1985-1989	33.25	146.90	6.046367
1990-1994	43.35	147.77	8.177429
1995-1999	43.25	146.90	7.553579
2000-2004	41.85	142.77	4.638312
2005-2009	34.07	136.01	7.073579

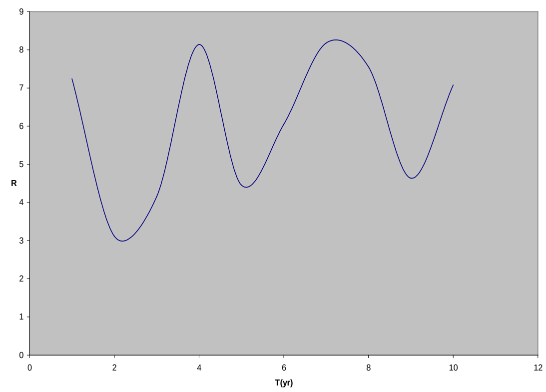

Figure 4: Pattern of propagation maximum seismic energy for Region 2

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Table 6; Location of maximum seismic energy for Region 3 1963-1978

Period(yr)	Latitude(°)	Longitude(°)	Energy(J)	R
1963-1964	44.73	149.52	4.68E+30	6.388606
1965-1966	44.18	145.26	1.05E+23	2.257762
1967-1968	40.78	143.31	2.32E+29	2.124625
1969-1970	43.53	147.35	9.77E+28	3.997290
1971-1972	46.53	141.24	2.40E+26	4.218895
1973-1974	43.25	141.82	4.12E+28	1.620125
1975-1976	43.05	147.69	1.01E+26	4.295523
1977-1978	44.26	148.86	1.74E+28	5.626100

Table 7: Location of maximum seismic energy for Region 3 1978-2003

Period(yr)	Latitude(°)	Longitude(°)	Energy(J)	R
1978-1981	43.47	146.81	1.01E+26	1.144142
1981-1983	44.72	151.13	4.27E+25	4.554799
1984-1985	44.13	148.24	6.33E+23	1.716991
1986-1988	42.59	142.85	3.20E+24	4.237401
1989-1991	48.22	154.39	2.49E+23	8.612606
1991-1993	45.50	151.09	3.20E+27	4.594832
1994-1996	43.76	147.42	1.30E+30	1.187454
1996-1998	43.82	149.25	3.20E+24	2.780273
1999-2001	43.03	146.92	1.80E+25	1.593692
2001-2003	47.85	146.15	1.35E+27	3.283018

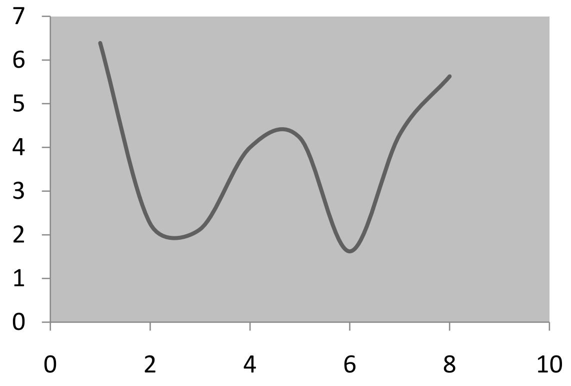

Fig. 5: Pattern of propagation of maximum seismic energy for Region 3(1963- 1978

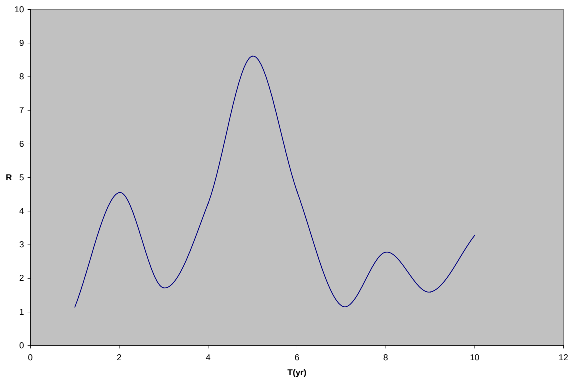

Fig.6: Pattern of propagation of maximum seismic energy for Region 3 (1978 -2003)

Table 8: Location of maximum seismic energy for Region 4

Period (yr)	Lat (°)	Long (°)	Energy (J)	R
1965-1969	-32.31	-71.20	3.055E+26	4.1739192
1970-1974	-38.50	-73.46	2.399E+26	2.4418857
1975-1979	-38.25	-73.21	4.121E+28	2.1471333
1980-1984	-30.71	-71.18	2.483E+23	5.6781395
1985-1989	-33.18	-71.87	9.773E+28	3.1188149
1990-1994	-31.30	-71.98	1.396E+24	4.9046855
1995-1999	-30.95	-71.12	2.399E+26	5.4711458
2000-2004	-30.64	-71.58	1.799E+25	5.6364545
2005-2009	-31.24	-71.34	5.888E+23	5.1276287

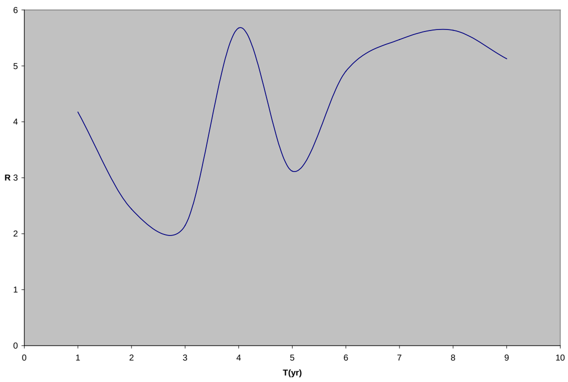

Fig. 7; Pattern of propagation of maximum seismic energy for Region 4

Table 9: Pattern of propagation of maximum seismic energy for Region 5

Period (yr)	R
1960-1964	2.5382502
1965-1969	3.9786186
1970-1974	5.5204635
1975-1979	3.3524847
1980-1984	7.7506008
1985-1989	0.4022002
1990-1994	4.1830553
1995-1999	1.2566499
2000-2004	4.5995367
2005-2009	8.0158129

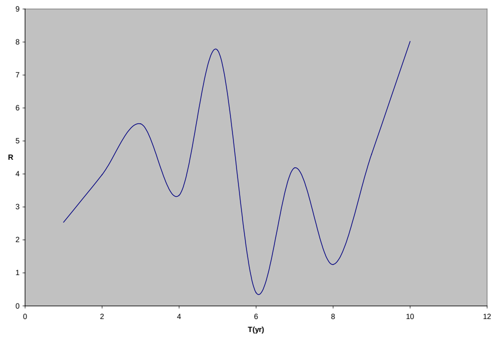

Fig. 8; Pattern of propagation of maximum seismic energy for Region 5.

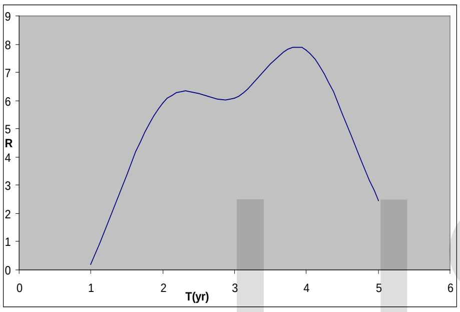

Fig 9a

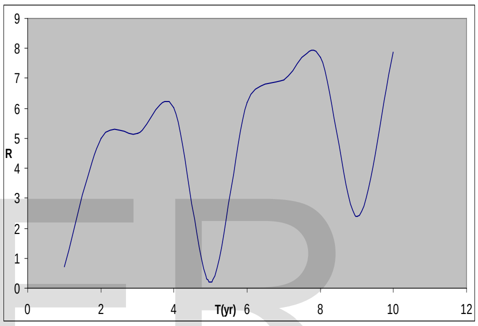

Fig 9b

Fig. 9: A symptom of fractal geometry;
9aSeismicenergy propagation pattern for 10 years
9bSeismic energy propagation pattern for 5 years

The results showed that for almost all the temporal distribution considered, the temporal volume at which the largest amount of seismic energy was released does not coincide with the most active zone or the highest frequency of occurrence of earthquake because of the ten folds magnitude increase and the thirty two folds energy increase since large earthquake (M greater than or equal to M8 are less frequent than smaller earthquake) but the energy released is enormous (Table1.)The location at which the largest amount of seismic energy was released between 1960 and 1964 which is within the first annular grid (0-100km) is the epicentre of the 1964 great Alaska earthquake of magnitude Mw 9.2. Observation shows that this point of maximum energy coincide with the most active zone, this is because of the many aftershocks associated with this earthquake. Tables 5 to 9 are the results for the locations where maximum seismic energy were released in the regions 2, 3, 4 and 5 respectively, while Figures 4 to 8 shows the pattern of propagation of the maximum seismic energy for the regions respectively. The pattern of energy propagation was not linear but flapping. It was undulating but not periodic. A periodic pattern will imply that the location of the next seismic energy is predictable. This predictable location will be assumed to be the location of the next earthquake. Figures 9a and 9b are the pattern of propagation of seismic energy for temporal volume of ten years and five years respectively, it appears to be geometrically fractal i.e. self similarity. Fractal is as an object which appears self-similar under varying degrees of magnification. It possesses symmetry across scale, with each small part of the object replicating the structure of the whole.

6 CONCLUSIONS

The pattern of energy propagation was not linear but flapping. It was undulating but not periodic. A periodic pattern will imply that the location of the next seismic energy is predictable. This predictable location will be assumed to be the location of the next earthquake. The pattern of propagation of the maximum seismic energy was non-linear and geometrically fractal. The most active zone in term of the highest frequency of occurrence of earthquake differs from the zone at which the largest amount of seismic energy was released, which implies that the most active zone does not necessarily produces large earthquakes.

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