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RESEARCH ARTICLE

Seismotectonics of Andaman-Sumatra Region: Seismic Quiescence and B Value as Possible Precursors

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Abstract

Objectives: a) To analyze the long-term seismicity and understand the potential of seismic quiescence study to use it as a reliable seismic precursor b) To estimate B value and understand the variation in B value as earthquake precursor in seismically active region. **Methods:** The present study analyses the seismicity pattern from the Andaman- Sumatra region for a period of 1964 to 2018. The area has been divided into epicentral blocks. Earthquakes preceding and succeeding a major earthquake with different seismic phases of quiescence and pattern of seismicity have been studied carefully. All quiescence periods are characterized by high b values and period of major shocks has a low b value. Main shock events for each epicentral block with different phases of quiescence (Q1, Q2 and Q3) and active seismicity have been identified and analyzed. **Findings:** The study suggests that there is generally approximately 6-12 years of gap between major earthquakes. There are 28 years of quiescence before the major earthquake of the stature of Dec 26, 2004 mega earthquake, suggesting that long term quiescence leads to great earthquakes. The study also proposes that the area between 2^0 and 6^0N latitudes shows a long-term quiescence which may lead to a major earthquake in the near future. A thorough analysis of long-term seismicity and seismic quiescence can be used as an earthquake precursor, though with limitations. The latest post seismic quiescence period Q2 after the greater events of 2004 and 2005, may yield an impending event of 6.5 M or even greater. **Novelty:** The present study deals with the precursor studies of one of the most important tectonic zone. Extensive analysis of 54 Years of data has been done and the scope of using seismicity and b value for the long-term prediction of earthquakes has been examined. The periodicity of seismicity has been used to quantify the precursors. Though various statistical studies have been attempted for this zone, methodology adopted here proved one of the reliable methods to check for the possible mega earthquakes of this seismically active zone, which can be applied to other seismically active areas as well.

Keywords: Seismicity; Andaman-Sumatra; Seismic quiescence; B-value; Precursors

1 Introduction

Sunda Arc is considered as a classic example of a volcanic island arc, where the Indo- Australian plate subducting under the Sunda and Burma plates (Figure 1). Subduction and active faults along with seismicity characterizes the arc and the tectonic deformation along this zone held responsible for the catastrophic Indian Ocean earthquakeof 26 December, 2004. The obliquity of the subducting plate make this zone a nodal area for the accumulation of strain energy [(1)]. Historic great earthquakes along this plate boundary occurred in 1797 (~ 8.4), 1833 (~ 9), 1861 (~ 8.5) and1907 (~ 7.8). It is observed that large thrust earthquakes in 1847 (~7.5), 1881 and 1941 occurred on intermediate regions of the down-dip boundary areas that have been surrounded and probably incorporated into the 2004 rupture [(2)]. The Andaman Sea, which extends approximately 1,250 km from Myanmar to Sumatra lying east of Andaman-Nicobar is a back-arc spreading ridge [(3–5)]. The fault systems divide Andaman Sea into Shallow fore arc and deeper back arc regions. The Andaman Sea has also experienced a number of earthquake swarms in 2014, 2015 and 2019 after the megathrust earthquakes a result of complexity in tectonic deformation [(6)]. West Andaman Fault (WAF) and the Sumatra fault system (SFS) form the boundary between Burma plate and Sunda plate south of the spreading ridge. The 1900-km-long Sumatran fault exhibits pure strike-slip faulting, which extends the entire length of the Sumatra Island. It is highly segmented and coincides geographically with the volcanic arc [(7,8)]. As per the historical and instrumental catalogs of Sunda arc, most of the major earthquakes are located in the Sumatran forearc and the deformation pattern suggest dominance of compressive stress in the area [(9)]. West Andaman Fault is another major strike-slip fault connected to the Sumatra fault in the south and Sagaing fault to the north. The Andaman spreading center in the northern part controlled the release of seismic energy to the trench, but absence of such a structure in the south which can accommodate the extensional deformation allowed the seismic energy to transfer towards the trench [(1)]. The earthquake activity appears to be starting from the trench location towards east, particularly in South Andaman [(10)].

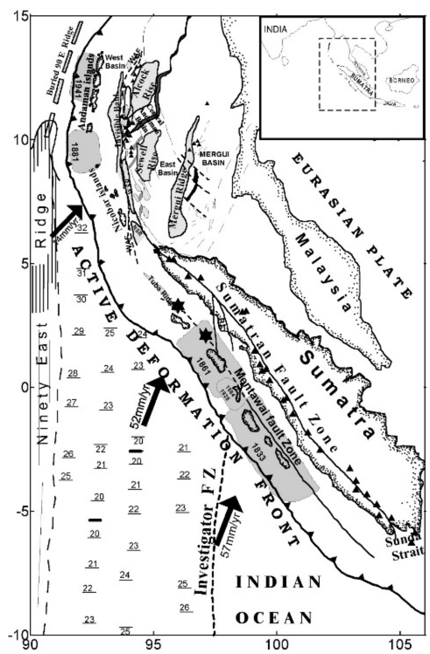

Fig 1. Detailed tectonic map of Andaman-Sumatra arc and adjoining region. The shaded region represents the rupture zones of great earthquakes prior to 2004 Mega earthquake. Stars indicate the locations of Dec 26, 2004 and 28 March, 2005 mega earthquakes. Magnitude and direction of plate motion also marked by the arrow (after Lasitha, 2015)

The study on seismicity and the rate of seismicity plays a key role in understanding the stress distribution in the crust. Several studies have been done on spatial and temporal correlations interpreted as possible precursors of earthquakes, such as gas emissions, fluctuations in ground water level, fluctuation in temperature and electromagnetic field, ionospheric perturbations and statistical analysis [(11)]. Geophysical precursors include seismic quiescence, Accelerating Moment release (AMR) and changes in b value. It may be never possible to predict an earthquake absolutely, we still have scope for identifying precursors which can be useful as part of an early warning system. Seismic quiescence analysis has shown promising results in identifying precursory abnormalities [(1,3,4,6,12,13)]. The objectives of the present study are proposed as understanding precursors like temporal quiescence, seismicity pattern, earthquake occurrence rate, and changes in temporal 'b' values to provide additional information regarding the seismic potentiality and future seismic hazard in Andaman- Sumatra region. Although researchers have attempted the quiescence study for Himalayas [14], Burmese arc [4,15] based on Scholz [16] methodology, Andaman- Sumatra region were studied based on statistical Z test using a data base for 35 years [12,13]. Long term data helps to recognize the seismic potential of active zones. The present study deals with the precursor studies of one of the most important tectonic zone. 54 Years (1964-2018) of data has been used for the analysis and the scope of using seismicity and b value for the long term prediction of earthquakes. The periodicity of seismicity has been used to quantify the precursors. Though various statistical studies have been attempted for this zone, the methodology of Scholz [16] proved one of the reliable method in order to check for the possible mega earthquakes of this seismically active zone.

2 Methodology

ISC (International seismological Center) bulletin data has been used for the present study. Considering the fact that monitoring capability for smaller earthquakes (magnitude <4.5) is inadequate, we consider data above this threshold magnitude for the analysis. For the study purpose we divided the area into 6 epicentral blocks with 2^{o} overlap of latitudes so as to understand the continuity in seismic activity (Figure 2). The study area is bounded by - 4^{o}S-10^{o}N latitude and 88^{o}E-100^{o}E longitude. Around 16363 events of body wave magnitude greater than 4.5 are reported from this region within a period from 1964 to 2018.

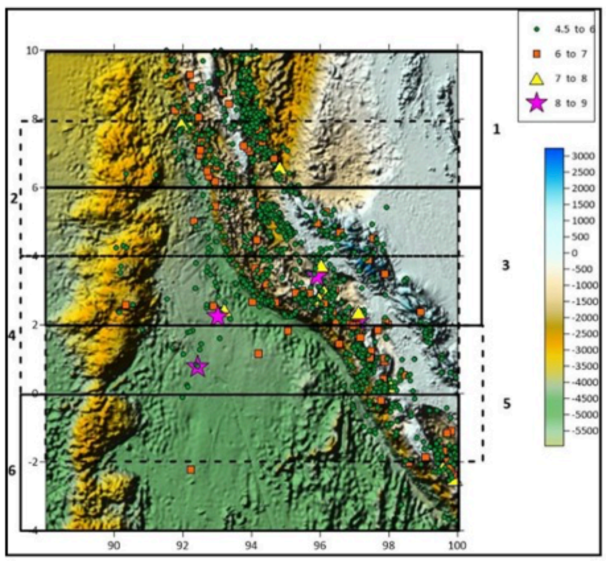

Fig 2. Bathymetry map of the study area prepared using GEBCO bathymetry data. Epicentral blocks considered for the study are shown as rectangles with 4^0 widths with 2^0 overlapping. Seismicity of the area is shown and the great earthquakes are marked as stars.

2.1 Seismic Quiescence

Scholz [16] has divided the seismic cycle of an active seismic domain into alternate domains of quiescence (Q1, Q2 and Q3) and active seismicity. "Q1 is defined as quiescence period between a major shock–aftershock sequence and a further increase in background seismicity. Q2 is defined as a lull period between the previously defined increase in background seismicity and further renewed seismicity. Q3 is defined as a short-term quiescence of seismicity prior to a major shock–aftershock sequence". Based on number of events, seismic occurrence rate and magnitudes seismic quiescence periods of each epicentral block are found out. Since the epicentral blocks 3, 4, and 5 are greatly influenced by two major 'intraplate' earthquakes in 2012 and the aftershocks and foreshocks associated with it, those earthquake events are carefully removed from the data set.

2.2 B-Value

'b-value' in the Gutenberg–Richter frequency–magnitude relation [17] is one of the basic seismological parameters used to describe an ensemble of earthquakes. Size distribution of earthquakes in a seismogenic volume can often be adequately described over a large range of magnitudes for different tectonic regions by a power law relationship. Gutenberg and Richter [17] is one of the well-fitted empirical relation in seismology, it represents the frequency of occurrence of earthquakes as a function of magnitude:

where 'N' is the cumulative number of earthquakes with magnitude larger than 'M', a and b are constants.

While the parameter a describes the heterogeneity of the medium, b denotes the slope of the linear frequency– magnitude plot. b-value represents properties of the seismic medium like stress and/or material conditions of the focal region [18]. The method of estimation of b value by regression is known as least squares method (LSQ). Alternatively, the maximum likelihood method (MLM) [19] is widely used for estimation of b value which is also used for study of epicentral blocks in this project. Generally, for b value estimation the MLM method is preferred over the least squares method (LSQ) [20], since there are more uncertainties associated with LSQ. The b value represents the relative occurrences of small and large earthquake events [21] and a measure of ratio between them. It suggests the effective stress regime and tectonic character of the region [22,23]. Prior to major earthquake events, 'b' value decreases within the seismogenic volume that correlates with increasing effective stress levels [24] or an increase in applied shear stress /effective stress demonstrated that b- value varies for different styles of faulting. Highest b- values (~1.2) are associated with normal faulting, intermediate values (~1.0) are associated with the strike-slip events and lowest values (~0.90) show thrust events. Thus, 'b' acts as a stress meter in earth crust and depend inversely on the applied differential stress [3].

In the present study, maximum likelihood method [19] has been adopted for the estimation of the b-value and it is estimated as b = (log 10 e) / (Mav – Mmin), where Mav is the mean magnitude above the threshold Mmin. The maximum-likelihood method provides the least biased estimate of b-value. Confidence limits of the b-value are inversely proportional to the square root of the number of events; thus, error is estimated by the formula, b /$\sqrt{}$N. As b-value is dependent on data, earthquake data is treated separately as per techniques described by KulhÃ¡nek, Ota [18] to make the calculated b-value statistically strong and tectonically significant. The b-value here is calculated for different time period from 1964 to 2018 for each epicentral block. Here also 2012 events are excluded from the data of epicentral blocks 3, 4, and 5.

The earthquake size distribution (Guttenberg –Richter relation) [17] follows the well-known power law designated as b value that is commonly used to designate the relative occurrences of large a n d small earthquake events [23]. The b values are calculated using the equation

$$b = \frac{(n * \sum x_i y_i - \sum x_i \sum y_i)}{(n * \sum x_i^2 - (\sum x_i^2))}$$

where x_i is magnitude, $y_i = \log N$

where 'N' is the number of earthquakes and 'n' is the number of magnitudes. A decrease in b value within the seismogenic volume indicate increasing stress levels prior to major shocks [24]. Several studies have been carried out to check the potential temporal changes in b value as a short term, medium term and long term precursor. Results show that large earthquakes are often preceded by a medium-term increase in b, followed by a decrease in the weeks-months before the earthquake.

3 Results and Discussion

3.1 Seismic Pattern of the Area

For the time period 1964 to 2018, 18 major shocks have occurred along the arc of which 16 events are of magnitude greater than 7 and 2 are of magnitude greater than 8, thereby attesting to its seismic potentiality. During 2012 the area also encountered two intraplate earthquakes of magnitude 8.5 and 8 (Figure 2). The graphs of sequential magnitude occurrences over the years (Figure 3a) and number of earthquakes against years (Figure 3b) clearly reveal the high and low periods of earthquake occurrences in the study area. Magnitude occurrence plot (Figure 3a) shows more than four main shocks above 8.0 magnitude including the intraplate events. It is visible that great earthquakes of 2004 and 2005 are masking the events for the rest of the years. To resolve this, the events associated with 26-dec-2004 and 2005 are deliberately excluded from the data for Figure 3c.

It can be observed from the graph that earthquake occurrence is comparatively less in number prior to 2004 and suddenly increased after 2004 (Figure 3a and Figure 3b). Part of it must be ascribed to aftershocks of the major events of 2004 and 2005 and partly to an increase in station coverage. Though the major earthquake events of 2004 and 2005 are removed, it appears that associated seismicity is continuing in this area (Figure 3c). Another highlight is the 2012 intraplate earthquakes.

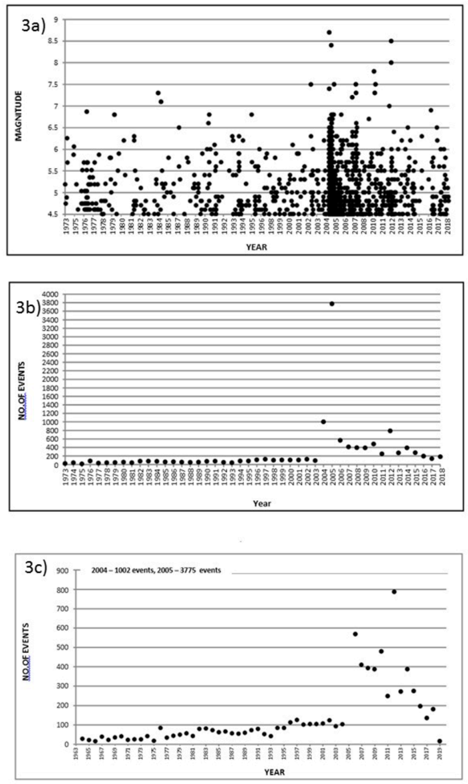

Fig 3. 3a: Yearly variation of earthquake magnitudes for the study area, 3b: Yearly variation in the number of earthquakes for the study area, 3c: Yearly variation in the number of earthquakes for the study area (The major 2004 and 2005 events and aftershocks are excluded)

Overall seismicity pattern of the area shows increased seismicity in recent times especially after 2004 megathrust earthquakes, suggesting disturbances in the tectonic setup caused by these megathrust earthquakes lead to the increased tectonic activity in this zone.

3.2 Seismic Quiescence Periods and b-Value Estimates

The number of major shocks pertaining to epicentral blocks and b value calculated for each block has been carefully analyzed in the following session.

3.2.1 Epicentral block 1

Five major shocks have been identified for the epicentral block 1 during the time period 1964 to 2018. The first major shock happened in 15-7-1964 whose magnitude was 6.8. This main shock was followed by a post seismic quiescence Q1 which lasted two years (seismic occurrence rate = 4 events/year).1967 to 1968 marks a period of increase in background seismicity (seismic occurrence rate = 8.5 events/year). 1969 was a period of intermediate quiescence Q2where only 3 noticeable events happened in the year. This Q2 period was followed by main shock (mb=5.6, seismic occurrence rate = 20events/year) in 1970. The Q3 quiescence before this event lasted 2 hrs. The three other main shocks happened in 1982, 2004 and 2014, which follow the same pattern and is listed in the Table 1. Currently the area is in a period of post seismic quiescence.

Table 1. Earthquake statistics in epicentral block 1

Epicentral block 1					
Year	**No.of events**	**Mmax**	**Seismic occurrence rate (events /year)**	**b value**	**Observations**
1964	8	6.3	8	-	Mainshock

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Table 1 continued

1965	4	5.1	4	0.448904	Q1
1966	4	5.1			
1967	7	5.7	8.5	0.440735	increase in background seismicity
1968	10	5.5			
1969	3	4.9	4.9	-3.0103	Q2
1970	20	5.6	20	-0.89177	mainshock - 25-10-1970, mb=5.6, Q3= 2 hours
1971	5	5.6			
1972	4	5.2			
1973	6	5.8	4.4	-0.54511	post seismic quiscence Q1
1974	1	4.8			
1975	6	5.3			
1976	16	5.7	16	-0.39222	increase in background seismicity
1977	9	5.1			
1978	7	5.5			
1979	4	5.2	6.4	-0.56824	Q2
1980	6	5.2			
1981	6	4.9			
1982	17	5.6			
1983	12	5.2			
1984	2	5.3	11.4	-0.74129	mainshock 20-1-982, mb=5.6,Q3= 4 hrs
1985	15	5.3			
1986	11	5.8			
1987	2	4.8	3	-0.86009	post seismic quiscence Q1
1988	4	4.7			
1989	11	5.3			
1990	10	5.6	10	-0.99552	increase in background seismicity
1991	12	5.6			
1992	4	5.9			
1993	3	5.7			
1994	15	5.6			
1995	8	5.4			
1996	15	5.2			
1997	10	4.8			
1998	12	5.5			
1999	3	4.9			
2000	9	5.2			
2001	7	5.5	5.06	-0.95236	intermediate term quiescence Q2
2002	8	5.1			
2003	1	4.6			
2004	262	6	394.5	-1.3489	Mainshock i) 26-12-2004- mb=6 (ms=6.2)-Q3 of 38 days ii) 24-1-2005, mb=6.4(Ms=7), Q3 of 1 day
2005	527	6.4			
2006	15	5.6			
2007	15	5.5	13	-0.60227	post seismic quiscence Q1
2008	12	5.3			
2009	10	5.9			
2010	26	7			
2011	9	5.9	18.33333333	0.890128	increase in background seismicity
2012	20	5.6			
2013	6	5.2	6	-0.81359	Q2
2014	49	6	49.5	-0.9129	main shock i) 21-2-2014, mb=6(ms=6.2), Q3= 3 years ii) 8- 11-15, mb=6.1 (ms=6.4), Q3= 1year and 9 months
2015	50	6.1			
2016	13	4.9			
2017	9	5.9	11	-0.35424	post seismic quiscence Q1
2018	11	5.4			

3.2.2 Epicentral block 2

The epicentral block 2 has witnessed three major earthquakes for the period of 1964-2014. The first main shock occurred in 1967 with magnitude 6.1(seismic occurrence rate= 19 events/year), which was preceded by a Q2 quiescence period of two years (seismic occurrence rate = 5 events/year) and a Q3 period of three hours. Then followed a Q1 period of 2 years (seismic occurrence rate is 5 events/year). The second major event happened in 1982 followed by 2004. The seismic cycle of this area is shown in Table 2.

Table 2. Earthquake statistics in epicentral block 2

Epicentral block 2					
Year	**No. of events**	**Mmax**	**Seismic occurrence rate (events /year)**	**b value**	**Observations**
1964	14	5.7	14	-	Mmax= 5.7
1965	6	5.5	5	-0.12404	Q2
1966	4	5.1			
1967	19	6.1	19	-0.02151	main shock i)12-4-1967 mb=6.1 (Q3) of 3 hrs
1968	4	5.4	5	-0.15221	Q1
1969	6	5.2			
1970	8	5.1			
1971	4	5.6			
1972	3	5.2			
1973	10	5.8	7.8	-0.492	increase in background seismicity
1974	4	5.1			
1975	6	5.6			
1976	20	5.7			
1977	6	5.7			
1978	8	5.3			
1979	4	5.6	6.6	-0.51684	Q2
1980	8	5.5			
1981	7	5.1			
1982	20	5.6			
1983	22	6.5			
1984	9	5.3	15.6	-0.68527	Main shock i) 4-4-1983 (mb=6.5) Q3 of 1 year and 70 days
1985	12	5.2			
1986	15	5.8			
1987	11	5.5	11	-0.26183	Q1
1988	11	5.8			
1989	19	5.8			
1990	18	5.5			
1991	16	5.6			
1992	6	4.9			
1993	11	5.7	13.23076923	-0.9897	increase in background seismicity
1994	19	5.6			
1995	8	4.7			
1996	18	5.2			
1997	13	5.7			
1998	14	5.5			
1999	10	5.8			
2000	9	5.2			
2001	11	5.6			
2002	7	4.7	8.5	-1.55253	intermediate term quiescence Q2
2003	10	5.1			
2004	267	6.1	413.5	-1.17612	Main shocks i) 27-12-2004(mb=6.1) i) 6-01-2005(mb=6.1) Q3of 1 day ii) 24-7-2005(mb=6.4)-Q3 of 1 day
2005	560	6.4			
2006	61	6			
2007	29	6.2			
2008	27	5.6			
2009	20	5.4			

Continued on next page

34.23076923 -0.93641 Q1

Table 2 continued

2010	31	7
2011	24	5.7
2012	27	5.6
2013	27	6
2014	65	6
2015	69	6.1
2016	22	6.3
2017	21	6
2018	22	5.4

3.2.3 Epicentral block 3

Epicentral block 3 produced three major events in 1967, 1976, and 2004 respectively. its seismically active periods and quiescence periods are listed in table 3. The earthquake events associated with 2012 intraplate earthquakes have been removed from the data set. In epicentral block 3, the mainshock of 20-6-1976 (mb=6.3, Q3 of 86 days) is followed by a post seismic quiescence (Q1) from 1977 to 1986 with a low seismic occurrence rate of 5.58 events / year. This low seismic occurrence rate indicates a stress relaxation after a large earthquake. A distinct increase in background seismicity (18events / year) is clearly noticed between 1987 – 2002, that was followed by intermediate term quiescence (Q2, 13 events / year) during 2003. Analyses of the data for the year 2004 indicate a Q3 quiescence of 52 days prior to the great event of 26-12-2004 (mb=8.7).

Table 3. Earthquake statistics in epicentral block 3

Epicentral block 3					
Year	**No.of events**	**Mmax**	**Seismic occurrence rate (events /year)**	**b value**	**Observations**
1964	13	5.7	13	-	-
1965	7	5.2	6	-0.21932	Q2
1966	5	5.2			
1967	23	6.2	23	-0.0641	mainshock-21-8-1967,mb=6.2- Q3 of 131 days
1968	4	5.4	4	-0.43004	Q1
1969	16	5.4	13.5	-0.4055	increase in background seismicity
1970	11	5.7			
1971	7	5.3			
1972	6	5.4			
1973	5	5.1	7.2	-0.59795	Q2
1974	14	5.2			
1975	4	5.6			
1976	54	6.3	54	-0.49951	Mainshock i) 20-6- 1976(mb=6.3) Q3 of 86 days
1977	11	5.8	5.58	-0.79761	Q1
1978	7	5.3			
1979	9	5.6			
1980	9	5.5			
1981	11	5.6			
1982	14	5.5			
1983	24	6.5			
1984	19	5.7			
1985	7	5			
1986	11	5.3			
1987	24	5.8	18	-1.08572	increase in background seismicity
1988	19	5.8			
1989	19	5.8			
1990	32	6			
1991	25	5.9			
1992	14	4.9			
1993	16	6.1			
1994	20	5.6			

Continued on next page

Table 3 continued

1995	15	5.5			
1996	10	5.5			
1997	12	5.7			
1998	5	4.8			
1999	15	5.8			
2000	12	5.2			
2001	13	5.6			
2002	37	5.6			
2003	13	5.1	13	-1.07049	intermediate term quiscence Q2
2004	213	6.8	374	-1.9592	mainshock i) 26-12-2004(mb=6.8,ms=8.7) Q3 of 52 days ii) 28-3-2005 (mb=7, ms=8.4) Q3 of 1 day
2005	535	7			
2006	123	6			
2007	67	6.2	52.33333	-1.04234	post seismic quiscence Q1
2008	76	6.3			
2009	40	5.7			
2010	36	6.7			
2011	43	6.5			
2013	53	6			
2014	43	5.9			
2015	41	5.6			
2016	47	6.3			
2017	34	5.7			
2018	25	5.2			

3.2.4 Epicentral block 4 and 5

Epicentral block 4 suffers 2 major earth quakes in 1976 and 2004 during the period of 1964-2018. Block 5 witnessed major earthquakes in 1983, 1994 and 2005. And block 5 in 1994 and 2005. Epicentral block 6 is not covered properly, hence excluded from the discussion.

Table 4. Earthquake statistics in epicentral block 4

Epicentral block 4					
Year	**No.of events**	**Mmax**	**Seismic occurrence rate (events /year)**	**b value**	**Obervations**
1964	11	5.8	9.5	-0.4358	increase in background seismicity
1965	7	5.5			
1966	6	5.2			
1967	8	6.2			
1968	3	5.3			
1969	22	6.4			
1970	9	5.7	9	-0.51966	Q2
1971	13	6.2			
1972	5	5.4			
1973	5	4.9			
1974	20	6			
1975	2	4.8			
1976	50	6.3	50	-0.56044	mainshock-20-6-1976-mb=6.3- Q3 of 117 days
1977	14	5.8	13.7	-0.96321	Q1
1978	6	5.3			
1979	16	6.2			
1980	13	5			
1981	16	5.6			
1982	12	5.5			
1983	15	5.3			
1984	22	6.2			
1985	13	5.4			

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Table 4 continued

1986	10	5.3			
1987	16	5.8			
1988	15	5.5			
1989	17	5.6			
1990	25	6			
1991	22	5.9	15.4375	-1.02219	increase in background seismicity
1992	15	5.1			
1993	13	6.1			
1994	12	5.6			
1995	14	6			
1996	10	5.5			
1997	12	5.4			
1998	6	5.2			
1999	12	5.1			
2000	11	5.5			
2001	13	5.4			
2002	34	5.6			
2003	6	4.7	6	-0.94322	intermediate term quiscence Q2
2004	79	6.8			
2005	751	7	273.75	-1.13037	mainshock i) 26-12- 2004(mb=6.8, ms=8.7) Q3 of 1 day ii) 28-3-2005 (mb=7, ms=8.4) Q3 of 2 days
2006	160	6.5			
2007	105	5.8			
2008	94	6.3			
2009	56	5.7			
2010	50	6.7			
2011	61	6.5			
2013	56	5.8	54.2	-1.08954	post seismic quiscence Q1
2014	53	5.8			
2015	52	6.1			
2016	46	5.7			
2017	40	5.7			
2018	34	5.5			

Table 5. Earthquake statistics in epicentral block 5

Epicentral block 5					
Year	**No.of events**	**Mmax**	**Seismic occurrence rate (events /year)**	**b value**	**Observations**
1964	5	5.6			
1965	7	5.5			
1966	4	4.8	4.4	0.132463	Q1
1967	4	5.6			
1968	2	5.3			
*1969-7	13	6.4			
1970	5	5.8			
1971	8	6.2			
1972	12	5.6	10.5	-0.51898	Increase in background seismicity
1973	10	5.8			
1974	15	6			
1975	2	5.4			
1976	6	4.9			
1977	7	5.6			
1978	8	5.2			
1979	13	6.2	7.125	-0.60675	Q2
1980	9	5.1			
1981	7	5			

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Table 5 continued

1982	5	4.8			
1983	13	5.4			
1984	17	6.2	13.66667	-0.45031	mainshock 17-11-1984- mb=6.2 Q3 of 1 day
1985	11	5.4			
1986	8	5.4			
1987	4	4.8	6	-0.00551	Q1
1988	9	5.5			
1989	9	5.1			
1990	11	5.1	10.25	-0.61875	Increase in background seismicity
1991	12	5.7			
1992	1	5.7			
1993	8	5.8	4.5	-0.38529	Q2
1994	30	6.1	30	0.158849	Mainshock, 2-5-1994,mb=6.1, Q3=35days
1995	10	6			
1996	6	5.3	8	-0.45271	post seismic quiscence Q1
1997	12	5.4	5.36	0.231403	Increase in background
1998	14	5.3			
1999	7	5.5			seismicity
2000	11	5.4			
2001	15	5.2			
2002	3	5.3			
2003	2	5.7	6.666667	-0.9815	Q2
2004	15	6.3			
2005	562	5.7			
2006	95	6.5			
2007	98	5.9	180	-1.08999	mainshock-16-8-2009-mb=7.1- Q3 of 1 day
2008	47	5.7			
2009-	98	7.1			
2010	33	5.5			
2011	38	5.8			
2013	35	5.5			
2014	35	5.8			
2015	41	6.1	32.875	-0.93064	bpost seismic quiscence Q1
2016	19	5.7			
2017	27	6.6			
2018	35	5.6			

3.2.5 b Value estimates

The b value calculated for each time periods (quiescence periods active periods and period of increase in background seismicity) listed in the tables. Effective stress regime and tectonic character of the region decides on the parameter 'b' [(22,23)]. Lowering of 'b' within the seismogenic zones correlates with increasing effective stress levels prior to major shocks [(24)]. All quiescence periods are characterized by high b values and period of major shocks has a low b value. This pattern is followed in all epicentral blocks.

4 Conclusion

The seismicity pattern from the Andaman- Sumatra region has been studied for 1964 to 2018. The area has been divided into six epicentral blocks with 50% overlapping, in which major earthquakes have been identified. The study suggests that there are generally approximately 6-12 years of gap between major earthquakes. But combined analysis of blocks 3 and blocks 4 reveals that the area was comparatively quiet for a long period of around 28 years before the megathrust earthquakes of 2004, suggesting that long term quiescence leads to great earthquakes. Studies on long term quiescence before 2004 earthquake was also carried out by other researchers [(25)]. Magmatic pulsations can result in earthquake swarms in volcanically active areas such as Off Nicobar region [(6)]. Our analysis shows that the northern segments are comparatively quiet since the megathrust earthquake which can lead to a major earthquake in the near future. Bhatt et al [(26)] based on the mapping of coseismic ruptures of the Eastern boundary thrust of Andaman over the last 2000 years also suggest an increase in slip deficit which can lead to a large magnitude earthquake in the Andaman- Nicobar region.

The study suggest that a proper study of the long term seismicity and seismic quiescence can be used an effective earthquake precursor. All quiescence periods are characterized by high b values and period of major shocks has a low b value. Such studies can help in preparing a mitigation plan of seismic hazard. The major conclusions of the study are

- Combined analysis of epicentral blocks suggest that blocks 3 and 4 reveals that the area was comparatively quiet for a long period of around 28 years before the megathrust earthquakes of 2004, which was unusual.
- Long term quiescence leads to great earthquakes and special attention may be given to such regions.
- Changes in the temporal b-value, including decrease in b value can be used as a parameter for the prediction of an impending event.
- Our analysis shows that the northern segments of Andaman region are comparatively quiet since the megathrust earthquake that may be leading to a major earthquake in the near future.
- The study can be helpful in long term forecasting. However, the exact location and time of the event cannot be predicated from the earthquake data alone. Detailed information based on local seismic network and GPS studies can lead to more precise calculations on seismicity.

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