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Earthquake Precursor and forecast in South Central Tibet Region of Himalaya

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Abstract

Seismicity fluctuations in time and space have been observed before several major earthquakes of the world. Precursors are indications before the occurrence of main event. Seismic precursors are a set of events occurring in an area over an interval of time which may continue to several months without any outstanding principal earthquake. In the present investigation precursory seismicity patterns were discussed and used for the identification of precursory swarm to forecast the future earthquake in the considered region. In this concern, Seismicity data from 1963-2006 with mb ≥4.1 have been examined in the light of three medium size earthquakes sequence 1996 (mb 5.9), 1998 (mb 5.8) and 2004–2005 (mb 6.2, 6.3) occurred in the South Central Tibet Region (SCT) of Himalaya. Analysis indicates that these earthquakes were preceded by well-defined patterns of precursory swarms and seismicity varies as low-high-low phases in episodic mode. However, two anomalous seismicity patterns having similar spatial and temporal distributions separated by about 15 month's duration exist during January 2002-February 2003 and June-August 2004 in the same area but without a mainshock till 2007. Study designates a potential location of future earthquake in the South Central Tibet (29.6-30.1^o N and 87.8-88.1^o E) with probable magnitude 6.0 and above in the depth ranges 25 ± 15 km. However, delay in this earthquake indicates a wider area be suspected at high risk as the swarm sequence follows another one.

Keywords: Seismic precursors; South Central Tibet Region (SCT); anomalous seismicity.

1. Introduction

Earthquakes are important components of complex dynamical Earth systems known as geocomplexity and one of the main contributors to geocomplexity is the seismic process. These processes result in seismic events of collective behaviors in the temporal, spatial and energy domains. Opinions vary on the possibility of predicting earthquakes from the mainly positive arguments [1]; [2]; [4] to the strongly negative arguments [3]. Earthquake prediction is a major challenge to Earth sciences and implies assessment of three main characteristics of impending earthquake: location; magnitude; and time of occurrence. It is the only way to save 100% the life of the people and their properties, if it is predicted reliably. The forecast of earthquakes is one of the most important societal goals in the seismological research. Earthquakes do not occur haphazardly either. They are severe near the plate boundaries and are quite significant in many plate interiors. A successful assessment of parameters of an impending earthquake depends on the ability to detect measure and evaluate premonitory phenomena that occur prior to the moderate to a large size earthquake. Earthquake predictability requires primarily three parameters the location, time of occurrence and magnitude (all with error windows) with probabilities that a particular event will occur [5]. While it is widely accepted that the chances of predicting these three parameters of an impending earthquake are remote, the main emphasis is now shifting to predict the seismic hazard in a particular locality. Therefore, it is important to adequately assess the seismic hazard in a given area which may be addressed statistically and should provide estimates for the maximum magnitude of the expected earthquake [6]. Forecast of earthquakes related hazards is usually undertaken on observing certain premonitory phenomena, known as precursors, developed at different stages in the pending focal region of an earthquake. The generation processes and the existence of the premonitory phenomena and their probable correlation with the mainshock can be explained by the dilatancy model which is defined as inelastic volumetric increase of rocks during deformation under applied differential stress [7]. Land deformations of various forms are considered to be the most direct evidence for earthquake processes taking place in the source region of an impending earthquake.

The changes in seismicity pattern are the utmost common precursory indicator [8]; [16]; [14]. In the pending focal region of a large earthquake, probably numerous ruptures or heterogeneities exist on the main fault that can produce earthquakes in response to the loading process [20]. It has been found that fluctuations of seismicity in time and space are observed before major earthquakes [8]; [18]; [17]. The model the every earthquake a precursor according to scale (EEPAS) was applied and tested for long-range forecasting for the several region of the world [19]. They were among the type of precursory phenomena. These are a set of events occurring in an area over an interval of time which may continue to several months without any outstanding principal earthquake [15]. In the present investigation precursory seismicity patterns were discussed for identification of precursory swarm prospective to forecast the location of preparatory area, magnitude and time of occurrence of impending earthquake in the considered region.

2. Organization of Subject Matter

Burst of seismic activity reflects the onset of the precursory sequence that follows a period of abnormal quiescence which continues till the occurrence of the major event [8]. The entire preparatory period starting from the date of considering the background seismicity to the occurrence of mainshock sequence may be classified in to four episodes as: Normal (or background) seismicity sequence (measured till the onset of swarm activity); anomalous seismicity (or precursory swarm) sequence (period from the onset to end of swarm activity); precursory gap (or seismic quiescence) sequence (from the date of termination of swarm activity to the onset of the mainshock sequence); and the mainshock sequence (duration of mainshock and its associated aftershocks) [8]; [9]; [10]. Within the preparatory area, the episodes of normal (N), anomalous (A), gap (G) and mainshock (M) sequences represent anomalously low, high, low and high seismic activities, respectively.

3. Earthquake Characteristics of Considered Region

South Central Tibet region of Himalaya is characterized by the extensional tectonic environment traversing with a prevalent north-south normal faulting in which earthquakes are generally of smaller magnitudes as compared to its adjoining Himalayan compression zone. Since 1963, only three large earthquakes with $mb \geq 6$ have occurred with the largest magnitude as 6.3 that occurred in 2005. The seismic activity is sporadic in nature and has been extremely low up to 1979, moderately active up to 1994 followed by a drastic increasing trend till 2006. The large earthquakes in this region are generally followed by a series of aftershocks. Three earthquake sequence occurred in 1996 (mb 5.9), 1998 (mb 5.8) and 2004-05 (mb 6.2, 6.3) were observed preceding the anomalous seismic activity. The nature of anomalous seismicity associated with these earthquakes has been investigated considering earthquakes with $mb \geq 4.1$ (cut off magnitude for this region). The analysis of the earthquakes which occurred between 31^o–31.5^o N shows that the events have no spatial and temporal relationship with the major event that occurred south of 31^o N. Therefore, the present study limits to 31^o N only.

4. Analysis of Seismicity Data

Two mainshocks of 11 July 2004 (mb 6.2) and 07 April 2005 (mb 6.3) occurred in sequence in an interval of about eight months separated by ~20 km distance in the north-south direction and are located about 100 km to the north of the ITS between 83.6^o-83.7^o E **(Fig 1)**. In order to investigate anomalous seismicity pattern associated with this mainshock sequence, the earthquake data from 1990-2005 was analyzed and selected an area bounded by 29^o-31^o N and 82.5^o-85^o E. In the five years periods prior to 1990, only three events were found to have occurred widely in the selected region. Seismic characteristics in the identified episodes within the preparatory area of 11 July 2004 (mb 6.2) and 07 April 2005 (mb 6.3) mainshocks in South Central Tibet are summarized in **table 1**.

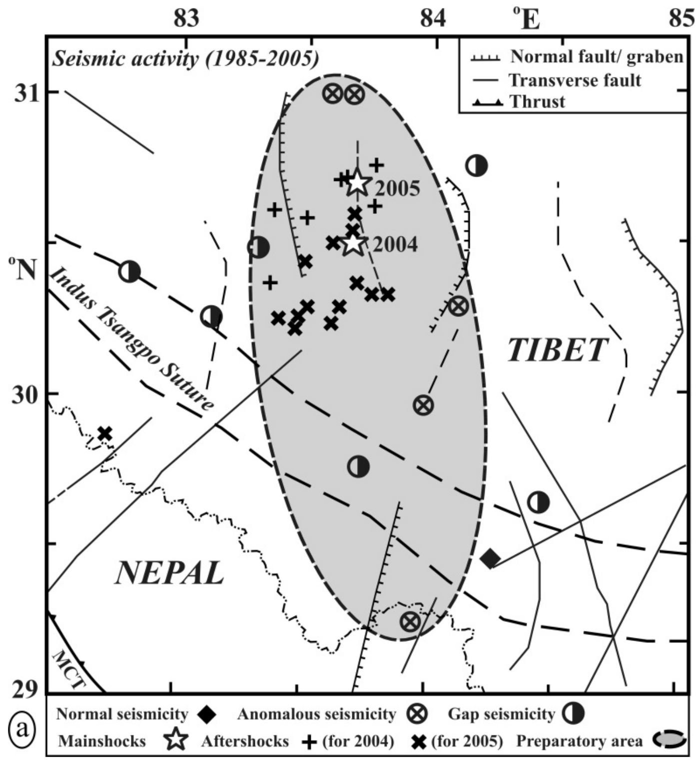

Fig. 1: Distribution of events ($m_b \geq 4.1$) for the period 1990-1995 associated with the mainshocks of 11 July 2004 (m_b 6.2) and 07 April 2005 (m_b 6.3) in South Central Tibet region. The dotted elliptical area is the preparatory area for the mainshock delineated based on spatial distribution of normal, swarm, gap and the mainshock sequences on the surface and with focal depth (**a** and **c**). Temporal pattern of these events with their magnitudes is shown in (**b**) [13].

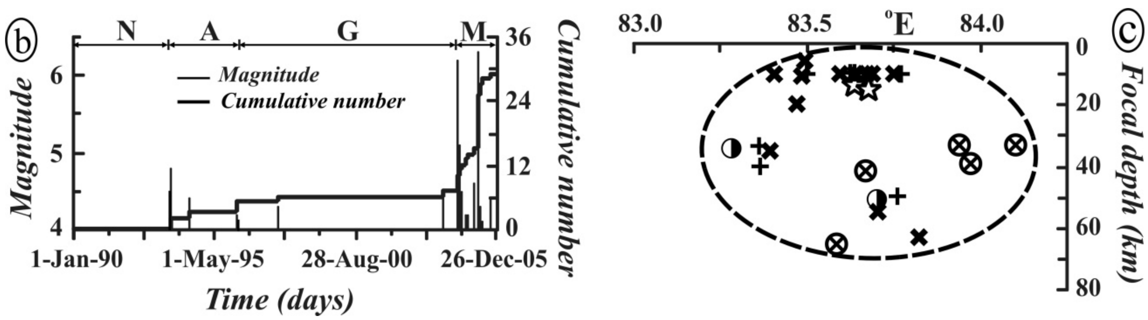

Table 1: Identified four seismic episode

Seismic episodes	*Duration*	*Days*	*Total events*	*Level of activity*
Normal/ background (N)	01 Jan.1990-11 Sept.1993	1350	0	Extremely low
Anomalous/ swarm (A)	12 Sept.1993-26 Feb.1996	898	5	Extremely high
Precursory gap (G)	27 Feb.1996-10 Jul. 2004	3057	2	Moderately low
Mainshock sequence (M)	11 Jul. 2004-31 Dec. 2005	539	25	-

4.1. Earthquake Precursor Search Analysis

4.1.1 Mainshock of 03 July1996 (m_b 5.9)

An area bounded by 29.5°-31° N and 87o-89° E has been considered here primarily, to investigate the anomalous seismic activity preceding the mainshocks of 03 July 1996 and 20 July 1998. The major geological features are the north-south trending normal faults. The available seismicity data show that this region was almost quiet till 1979. After that region faced very short lived abrupt increase in the seismic activity for during 1980's with the occurrence of a moderate size mainshock (m_b 6.2), but not preceded by any seismic sequence and region remained quiet till 1994. However, sudden spurt of activities observed forming well defined precursory swarm sequences are summarized in **table 2**

Table 2: Seismic characteristics in the identified episodes within the preparatory area of 03 July 1996 (mb 5.9)

Seismic episodes	*Duration*	*Days*	*Total events*	*Level of activity*
Normal/ background (N)	01 Jan 1995-11 Mar 1996	436	5	Moderately low
Anomalous/ swarm (A)	12 Mar 1996-17 May 1996	67	10	Extremely high
Precursory gap (G)	18 May 1996-02 Jul 1996	46	-	Extremely low
Mainshock sequence (M)	03 Jul1996-31 Mar 1997	324	18	-

After examining the seismicity data from 1995 to 1998 and anomalous episodes, it was found that mainshock occurred on 03 July 1996 after a very short gap period of 46 days in the northeastern corner of the preparatory area (~0.8 x 103 km^2) delineated based on the spatial distributions of the events in all the episodes.

4.1.2 Mainshock of 20 July1998 (m_b 5.8)

Similar rigorous analysis for the anomalous seismic pattern associated with the mainshock of 20 July 1998 is studied for the same region using the seismicity data from April 1997, because the aftershock activity of the mainshock of 03 July 1996 ended in March 1997. It is observed that the preparatory areas of these two mainshocks partially overlap having similar orientations show more or less the same region of intense seismic activity. The episodic variations of seismic activity are furnished in **table 3**

Table 3: Seismic characteristics in the identified episodes within the preparatory area of 20 July 1998 (mb 5.8) mainshocks

Seismic episodes	*Duration*	*Days*	*Total events*	*Level of activity*
Normal/ background (N)	01 Apr. 1997-12 Sept.1997	165	0	Extremely low
Anomalous/ swarm (A)	13 Sept.1997-05 Oct.1997	23	4	Extremely high
Precursory gap (G)	06 Oct.1997-19 Jul.1998	287	2	Moderately low
Mainshock sequence (M)	20 Jul.1998-25 Dec.1998	159	48	-

The preparatory area (~1.3 x 103 km^2) oriented along the northeast-southwest. It is marked that the concentrated

seismic activities for both the mainshocks are spatially correlated but they occurred at different times. The only marked difference is that the precursory swarm and the aftershock activity for 1998 mainshock were distributed in a wider area extending towards the north as compared to the 1996 mainshock. The 1998 mainshock was followed by an intense aftershock activity concentrated in a narrow linear belt of about 27 km long trending northeast-southwest approximately parallel to the major axis of the preparatory area. The aftershock activity was ceased by 25 Dec. 1998 and region became calm for the next nine months. It may be specified here that the mainshock of 20 July 1998 was preceded by a short period earthquake swarms activity that initiated about ten months prior to the mainshock. The seismic pattern associated with this mainshock varies with low-high-low and is analogous in nature as that of 1996 mainshock in many respects.

4.1.3 Earthquake forecast in the region

Two medium size earthquakes of 1996 (m_b 5.9) and 1998 (m_b 5.8) occurred in the vicinity of region (30° N, 88° E) in the South Central Tibet were preceded precursory swarm. But the explained preparatory areas and the preparatory time periods for both were very small in comparison to other studies earthquakes in the Himalaya. After the closure of the aftershock activity of 20 July 1998 mainshock in December 1998, the region was totally quiet for about five months till 02 June 1999. After analyzing seismicity data it has been observed that some events occurred in the preparatory area of 1996 mainshock and distributed towards it northeast, till 30 January 2002. Taking it as background seismicity, there has been spurt of seismic events with an annual rate of 18 events (mb $\geq$ 4.1) from 31 January 2002, and the sequence continued till 26 February 2003. Subsequent to this high active phase, a gap with extremely low seismic activity both in space and time domains existed for about next 15 months till 01 June 2004 which is evident from the temporal distribution pattern. The continuing gap period following an anomalous seismic sequence is, in general, disrupted by a mainshock and the precursory time period is reported to be dependent on the magnitude of the anomalous events [14]. On the contrary, another swarm sequence with more intense activity occurred from 02 June to 21 August 2004 in the same locality but comparatively of lower magnitudes than the previous sequence. The region is again showing a gap, similar to that existed prior to the onset of this swarm sequence, which still continues. Hence, two anomalous seismicity patterns having similar spatial and temporal distributions separated by about 15 months duration exist during January 2002-February 2003 and June-August 2004 in the same area but without a mainshock till 2007. Which shows the repeated swarm activity, a wider area may be suspected under high risk if a swarm sequence follows another one [11], and similar situation exists in the present case.). Such an anomalous pattern shows some kind of the causal relationship of the time of occurrence and the magnitude of the mainshocks. For this purpose, an attempt has been made here to search for the pattern of the seismicity changes in space and time domains prior to the mainshocks with $m_b \geq 5.4$ that occurred during 1963-2006 in South Central Tibet region. Generally, magnitude of mainshocks is reported to be 1 to 2 units higher than the magnitude of the largest swarm event in most of the anomalous sequences as observed in different regions [8]; [12]; [10]; [14]. But for South Central Tibet region, such difference is 0.8-1.6 units. It is observed that difference between the magnitudes of two largest swarm events is 0 to 0.3 in the South Central Tibet region. In view of this, the magnitude of the impending earthquake may exceed 6.0.

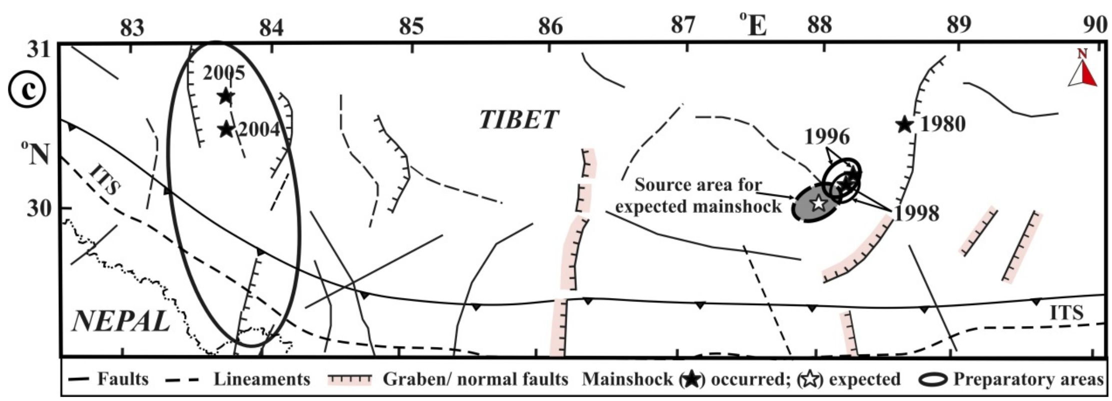

Fig. 2: Orientation of preparatory areas of mainshocks from 1963-2006 that were preceded by anomalous seismic activity. The probable preparatory areas for expected future mainshock is also depicted.

In general, the preparatory areas oriented in the direction of the local tectonic features are found to be of different size for similar magnitudes of the mainshocks in the same areas. The preparatory areas of the mainshocks, there are two prominent orientations of the preparatory areas mainly in NE-SW and N-S directions. There is a significant variation in the sizes of the preparatory areas in this region being smallest (~800-1300 km^2) for the mainshocks of 1996 and 1998. The preparatory area of the expected mainshock is observed to be of a comparable size with similar orientation as that of the mainshocks of 1996 and 1998 (Fig 2).

5. Discussion and conclusion

Based on the data from 1963 to 2006, the earthquake swarms prior to the medium size earthquakes in South Central Tibet region has been studied. It is established here that the swarm patterns follow episodes of relatively very low seismic activity and it is an important finding to visualize that an area might be preparing for the occurrence of a forthcoming mainshock. Such anomalous seismic patterns were observed prior to the four mainshocks that occurred from 1963 to 2006 in South Central Tibet region. It is interesting to note that the identified episodes of precursory seismic activity were characterized by an extremely high annual earthquake frequency as compared to the preceding normal and the following gap episodes, and is the characteristics of the events in such an episode is causally related with the magnitude and the time of occurrence of the forthcoming earthquake. It is observed here that for the shorter duration of the preparatory time period, there will be the smaller mainshock, and vice-versa. The study envisage that the patterns of earthquake swarms may be measured as an important precursor for the forecasting of long-range earthquake hazards in the considered region. The spatial and temporal clustering of swarm events which are prominent and confined in a vertical column of 10-45 km (Fig. 1 b & c), facilitate a potential location of future earthquake in the South Central Tibet (29.6-30.1^o N and 87.8-88.1^o E) with probable magnitude 6.0 and above in the depth ranges 25 ± 15 km. It is advocated here that this area might be preparing for the occurrence of forth-coming mainshock. However, delay in this earthquake specifies possibly wider area be placed at high risk if the swarm sequence follows another swarm sequence [11]. In this situation, revised estimates for magnitude and time of occurrence of the impending earthquake may be necessary.

Although, the uncertainty in the determination of expected earthquake parameters cannot be ignore. The occurrence of the repeated swarm sequence may indicate that a wider area is under threat which requires re-estimates of the magnitude and the time of occurrence of the impending earthquake. Such situation may also change the rate of stress accumulation in the pending focal region which is evidently increases the duration of the preparatory period and the magnitude associated with impending earthquake. In appreciative, multi-parameter short-term precursory signal monitoring is suggested for the predicted preparatory area to minimize the possible uncertainty. Now, it is thought here that the delay in the occurrence of an expected earthquake is probably due to the interruption in the continuing gap episode of the first sequence by the second one that has enhanced both the preparatory period and the magnitude.

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7. Copyrights

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