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AN INSIGHT INTO THE SHILLONG PLATEAU SEISMICITY: A REVIEW

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ABSTRACT

The Shillong Plateau (SP), in northeast India, is a complex tectonic region with a record of past large earthquakes. A detailed study of the tectonics of the SP is required to understand and minimize the impact of future large earthquakes. The SP is situated amongst a maze of several crisscrossing faults. To the south of the SP lies the Dauki Fault which caused the 1923 Meghalaya earthquake (Ms 7.1). To the east of the SP lies the Kopili fault separating the SP from the Mikir hills. In the past the Kopili fault had caused two major earthquakes the 1869 Cachar earthquake (M 7.5) and the 1943 Assam earthquake (Ms 7.2). The 1897 Assam earthquake which is considered as one of the great earthquakes of India also occurred in the SP. The geology of the plateau and the surrounding areas provide evidence of large earthquakes prior to 1897. This confirms the future occurrence of large earthquakes in the plateau. Based on recent studies done at the national level in the country, various maximum potential earthquakes of magnitude greater than 8.0 were found and a total of 200 earthquakes of various magnitudes were observed along different segments of the SP. Several studies in the past have also proposed bedrock level of ground acceleration in the range of moderate to high values for the plateau and many of the past reported earthquakes have shown moderate damages to complete destruction of the infrastructure.

This paper presents a review of the past earthquakes in and around the plateau. In order to better understand the seismicity of the plateau a detailed review on the devastation caused by these large earthquakes in terms of damage to various structures, the number of casualties and the geological changes made in the region has been done. A comparison has been made of the previous works in terms of the location, orientation, movement and recent seismic activity of the faults in and around the plateau.

The plateau is spread across an area of approximately 50,000km^2 in the northeastern part of the country and is located at the boundary of India and Bangladesh. The great Assam earthquake of 1897 caused tremendous damages to the structures present and also changed the face of the earth at several places. However due to the presence of relatively minimal population during the time of the occurrence of the earthquake the casualties were very less. As per 2011 census the population of the plateau is 1.4 and 3.5 million at city and urban levels respectively. The occurrence of an earthquake of magnitude similar to the 1897 Assam earthquake would be catastrophic. Further considering the poor construction practices and the limitation of present IS code provisions in highlighting the regional seismicity; a detailed study on local level is very much mandatory including the identification of contributing sources for future earthquakes and slips along various causative faults. Also a collaborative attempt including the past seismic activities, reported

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damages, ground motion records as well as GPS measurements are necessary to understand the tectonics of the plateau.

Keywords: Shillong Plateau, seismicity, past earthquakes, surface deformations

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ABSTRACT: The Shillong Plateau (SP) is surrounded by several faults. Earthquakes were felt in the SP due to these surrounding faults. Several research studies have highlighted the damages felt in the SP during many of the past earthquakes. This paper presents a detailed discussion on the devastations caused by the past earthquakes in terms of geological changes, structural damages and loss of life during each of these earthquakes. This study also reviews the present day deformation of the SP, thus highlighting the need for detailed regional studies to be conducted in the plateau to understand the present state of seismic hazard.

INTRODUCTION

The collision and continued convergence of India with Eurasia have caused wide spread deformation in central and eastern Asia. This deformation as a result of the tectonic movements manifests itself as prominent topography, resulted in the formation of Himalayan mountain range. Several faults, folds and thrusts were thus formed as a result of this collision and continued convergence of the two tectonic plates. The tectonic movement along these faults is thought to be the primary cause of earthquake occurrences in the Indian subcontinent. During a span of approximately 50 years of history, three great earthquakes had hit the country. The first being the Assam earthquake of 1897 of magnitude (M_W) 8.1, followed by the Bihar-Nepal earthquake of 1934 of magnitude (M_L) 8.4 and finally the 1950 Assam earthquake of magnitude (Ms) 8.7. The epicenters of the both the 1934 Bihar-Nepal earthquake and the 1950 Assam earthquake have been traced back to the faults lying in the Himalayan region.

In contrast to the prominent topography of the northern region little topographic expression is observed in the south of the Himalaya within the Indian shield [1]. The sole exception seems to be the Shillong Plateau (SP) where active deformation has been demonstrated by the occurrence of the great 1897 Assam earthquake [2]. The northeast region is one of most seismically active regions in the world. This region is jawed between the Himalayan arc to the north and the Indo-Burmese arc to the east. This intricate tectonic setting of the northeastern region has led to the formation of several faults and thrusts in the region. Such faults had become the sources of several past major to great earthquakes in the region. Some of the well-known earthquakes (EQs) that had occurred in the region include the 1869 Cachar EQ(Mw=7.5), 1897 Assam EQ(Mw=8.1), 1923 Meghalaya EQ(Ms=7.1), 1930 Dhubri EQ(Ms=7.1), 1943 Assam EQ(Ms=7.2), 1947 Arunachal Pradesh EQ(Ms=7.7), 1950 Assam EQ(Mw= 8.7), 1988 Manipur EQ(Ms=7.3), 2009 Assam EQ(Mw=5.1) and the very recent 2011 Sikkim EQ(Mw 6.9) [3].

A number of faults existing in the north-eastern region of the Indian plate are located around the SP. Tectonic movements along these faults have resulted in high seismic activity in the SP in the past. Past studies have suggested that the Assam earthquake of 1897 had occurred on one of the faults bordering the SP. The shaking from this great earthquake was felt as far as central India in the west and Myanmar in the east. The earthquake caused the formation of several sand vents, liquefied sites and ground fissures and caused wide spread structural damages. Also several other past major earthquakes have been found to originate in the faults surrounding the SP.

TECTONIC SETTING OF THE SHILLONG PLATEAU

The SP is spread over approximately 47,614km^2 [4].The coordinates of the SP are at latitude 25°34'60" N and longitude 92°0'0"E as shown in Fig.1 [5]. Various faults surrounding the SP as well as the different faults existing within the plateau itself are also shown in Fig.1 [5]. To the south of the plateau lies the Dauki fault and in the south-western side lies the Dapsi thrust within the plateau itself. In the west of the SP is the Dhubri fault and to the east of the plateau is the Kopili fault.

The Dauki fault lying to the south of the SP is approximately 320km long. It extends from latitude 25°14'30"N and longitude 91°13'00"E in the west to latitude 25°10'00"N and longitude 93°02'00"E in the east as shown in Fig. 1[5]. There are different opinions about the orientation of the Dauki fault. According to [6], the Dauki fault is not a single fault but a system of four faults. This system of faults dips towards north on the surface level and then continues further below the surface. However in later years [7] with the help of remote sensing studies found that the Dauki fault is a single fault and not a system of faults as proposed by [6]. Also, the fault was found to dip towards south as a normal fault. The investigation performed by [7] further highlighted that the sediments of the Surma valley south of the Dauki Fault had folded and pushed towards the west, thus implying a right strike slip movement of the Dauki fault. The north-western edge of the Dauki faults extends within the plateau as the Dapsi thrust. The Dapsi thrust is a 90~100km long reverse fault with a strike slip component.

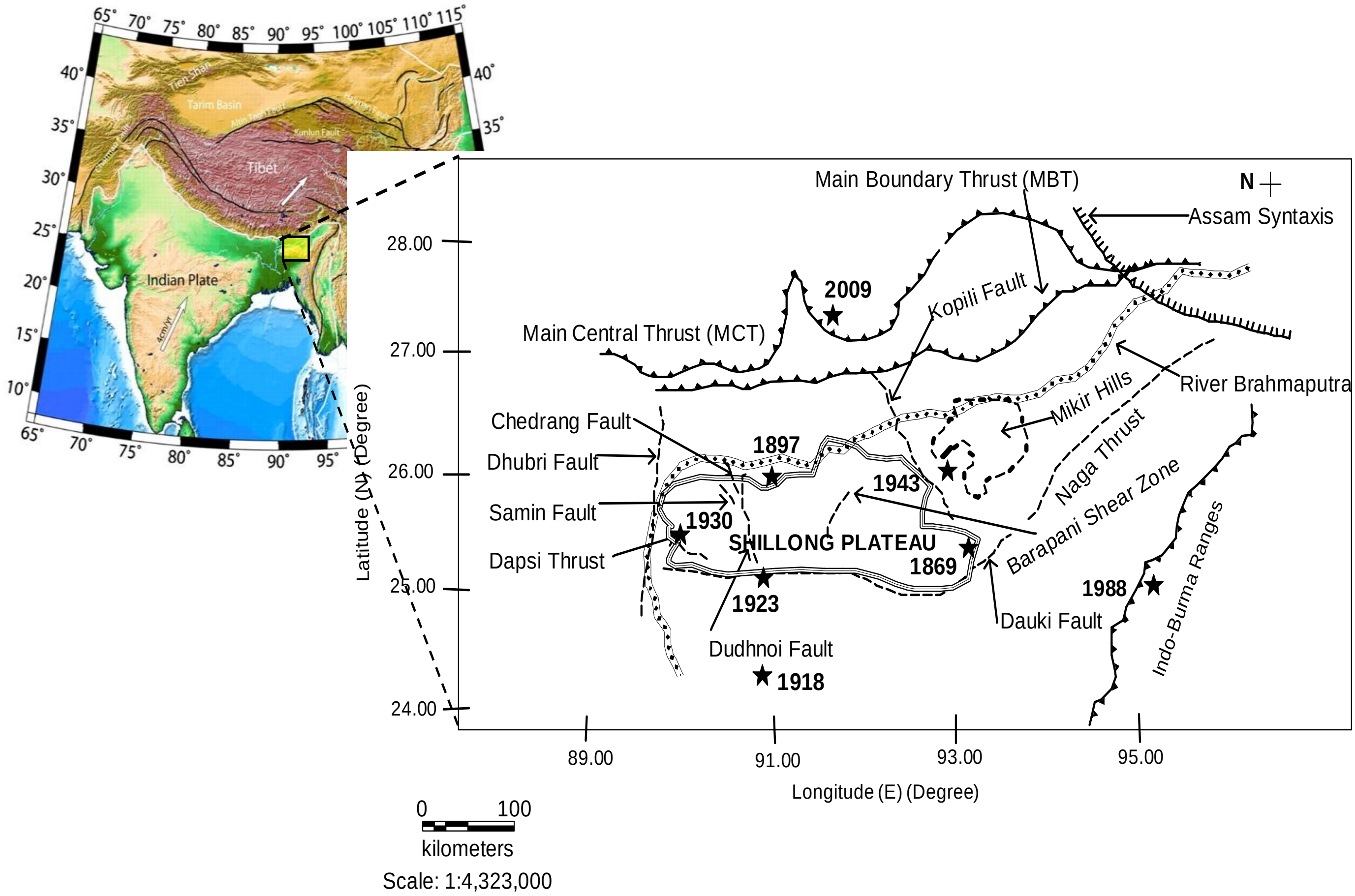

Fig. 1 Active sources and past earthquake details of the SP [5]

Towards the northeast of the SP lie the Mikir hills. The Kopili fault is approximately a 300km long and 50km wide fault which lies between the SP and the Mikir hills. This fault originates from the Main Central Thrust (MCT) in the Himalaya as shown in Fig. 1 [5]. As per [8] high level of seismic activity exists within the Kopili fault. It was found that the intensity of the seismic activities was concentrated at an approximate depth of 50km below the Kopili fault [8, 9]. The Kopili fault was also found to have a normal and strike slip faulting with a dip in the north-eastern direction. The recent seismicity discovered along the fault has led to speculations that the Kopili fault is one of the most seismically active faults of the region and a major earthquake could be expected in the future[8, 9].

As mentioned earlier apart from the faults surrounding the SP another set of faults also exist within the plateau itself. This set of faults existing within the SP include the Chedrang fault, the Samin fault, the Dudhnoi fault and the Barapani shear zone [10, 8] as shown in Fig.1[5]. Hence understanding the seismic potential of the SP is very important.

PAST REPORTED EARTHQUAKE DAMAGES IN THE SHILLONG PLATEAU

Clearly, the SP has undergone various major to great earthquakes. Previous studies have attempted to provide information about the damages caused by past earthquakes. [11, 12] conducted paleo-liquefaction studies for the 1897 Assam earthquake. The paleo-liquefaction studies were conducted at various sites in the alluvium river valley of the Krishnai and the Dudhnai rivers close to the Chedrang fault. The first site was at Jira, south of the Krishnai River in Assam. At a depth of 8m, a 30cm thick sand dykes breaking into the overlying clay layer of 1m height was found [11,12]. From the samples collected at this clay layer, a major earthquake was found to have occurred ≤50 years ago. Similar results were obtained from the Rongkhaminchi site in Meghalaya. This corresponding earthquake for these alterations was deduced to be the 1897 Assam earthquake [11, 12]. At another site at Bedabari, near the Krishnai River, clear signs of shaking and faulting of the alternating clay and sand subsurface layers were found. Also at the Kharidhara site, sand dykes that had rose to a height of 2m intruding the silt layer above the sand reservoir were found. Again at Nayapara similar sand dykes were found and at the Dainadubi site, along the Dudhnai River, organic samples were found at sedimentary beds which had deformed due to seismic shaking. Testing all the samples from these sites concluded a major earthquake during 1450-1650 AD [11, 12]. Based on the samples collected during the paleo-liquefaction study, site at Beltaghat near the Krishnai River evidenced a major earthquake dating back to 700-1050 AD [11, 12]. Another site located 200m downstream of Beltaghat, paleo-liquefaction studies on peat sample suggested another major earthquake that had occurred before 600AD [11, 12].Based on the paleo-liquefaction studies performed by [11,12], the return period of 400 to 600 years was concluded for major earthquakes in SP. Also, for the great earthquakes to occur in the SP, a return period of 500 years was suggested [11, 12]. Further, the above studies concluded that liquefaction is not a common phenomenon in the SP as past earthquakes of magnitude 6.0-6.5 had not triggered any liquefaction [11, 12]. The above discussion clearly stated that paleo-liquefaction studies as per [11, 12] suggested that major to great earthquakes reported in the past are responsible for the origin of the SP. Further, the sand dykes formed during earthquakes prior to 1897 and those formed by the 1897 Assam earthquake itself were found similar.

Similar to the studies discussed above, in another attempt, paleo-liquefaction studies were conducted along the Chedrang fault [13]. Four trenches 5-10m long, 4-5m wide and 5m deep were dug. The first trench was located 0.5km south of Jira where a sand dyke was found from a dried riverbed [13]. This sand dyke was found to intrude the upper alternate layers of sand and clay which was also confirmed by the second trench dug near the first trench [13]. The third trench was dug further south of the first two trenches. This trench consisted of inclined sand dykes which cut through alternate layers of sand and clay. Among these, layers of clay were found slumping as reported by [13]. The fourth trench was dug near Mendipathar, Meghalaya where a trunk of a dead tree was found at a depth of 4m below the ground surface. Based on carbon dating of the tree trunk, it was found died about 1200 to 1300 years ago. Further at the base of the trench a dried river bed consisting of alternating clay and sand layers was found. The study of the sand dykes and the slumping of the clay layers indicated the occurrence of liquefaction phenomenon in the area due to major to great earthquakes in the past [13]. From the field investigations, [13] concluded that the presence of the sand dykes in all the four trenches and the finding of a 1200 year old dead tree was a clear indication of occurrence of a major to great earthquake approximately 1200±100 years ago in the SP region.

In addition to the prehistoric times (1000 AD or before) several major to great earthquakes have occurred in the last few centuries which had changed the topography of the SP considerably.

1869 Cachar Earthquake

The Cachar Earthquake of 1869 (M_W 7.5) occurred on 10th January. The epicenter of this earthquake was located within the Kopili fault [14]. The damages due to this earthquake were spread across entirely over northeast India and some parts of eastern India. The damages were reported by Captain Godwin-Austen, surveyor of Topographical Survey of India (TSI) and by Thomas Oldham, the Superintendent of the Geological Survey of India (GSI) under the British rule [15, 16]. In the city of Guwahati, the primary shock was followed by a number of minor shocks. As per [16], the walls of the jail in Guwahati had suffered horizontal cracks and slight cracks in the arches as well. Also, the brick buildings in Guwahati had undergone damage. However, no loss of life had occurred due to this earthquake in Guwahati. Oldham [16] had reported severe shocks in Goalpara that continued till the night of 10th January 1869 and were again felt on the 14thJanuary 1869. In the Khasi Hills to the west of Shillong city, public buildings had undergone moderate to severe damages. The arches and the walls of the Overseer's bungalow and Deputy Commissioner's courthouse were cracked. As per [16], severe shocks in Nongpoh which is located 48km south of Guwahati city in the SP were also reported. Damage reports collected by [16] from Manipur highlighted the complete damage of the Manipuri King's two-storied brick house. Ground fissures and formation of sand vents were also reported in Manipur, along the banks of the Jiri River in Assam and the Surma River in Bangladesh [16]. In north Cachar, the native houses of bamboo and wood had however survived this earthquake [15]. The river Barak had flowed backwards for almost an hour and the depth of the river bed became shallower due to the earthquake. Also, a number of ground fissures and sand vents had occurred in the area during the main event [15]. The aftershocks for this earthquake had lasted till 1stFebruary 1869 as per [15].

1897 Assam earthquake

The Assam earthquake of 1897 is known to be one of the great earthquakes of India. The massive shaking during the 1897 Assam earthquake transformed the landscape of the SP. As per [17] the magnitude of this earthquake was 8.1(Mw).The shaking from this earthquake not only transformed the topography of the SP but had also caused wide spread damages in the SP. Damages were also reported from several places across the Indian subcontinent [3]. Large fissures of 18 to 30m width appeared parallel to the banks of the Brahmaputra River and its various tributaries. The Dhubri bazaar in Dhubri, Assam was severely affected by fissuring. Further east of Dhubri at Rowmari, Assam, sand vents were formed which ejected sand and mud even upto a height of 1m above the ground level [2]. Since this earthquake had occurred at the peak of the monsoon season, it had increased the number of sand vents and liquefied sites. Also flooding and landslides at several places throughout the Assam valley were triggered during this earthquake. The abutments of the bridge on Grand trunk road located west of Guwahati were moved forward while one of the many piers had tilted due to liquefaction at its base. The Brahmaputra River was flooded due to the monsoons. Shaking from the earthquake gave rise to standing waves resulted in 3m rise in the water level above the existing water level in the Brahmaputra River. As a result, the bazaars and the houses located along the banks of the Brahmaputra River were flooded [2]. Numerous landslides were reported at Nongpoh and the hilly town of Tura in the West Garo hills [18]. At Tura most of the masonry houses were severely damaged due to the collapse of the masonry plinth. The ground had cracked and slid at places blocking water courses and forming lakes at various locations. As per [18], fissures and landslides occurred along the Guwahati-Shillong (G-S) road. Also, the houses and bridges in above areas had turned to rubble. According to [18], the bazaar and the masonry houses of the people as well as the Government house, local church and the Telegraph Office were destroyed in the Shillong city. The houses built of wood or masonry bound with lime mortar had however survived. The tombs and the gate pillars of the cemetery also twisted turned and were thrown over. As per [18], several aftershocks of 1897 Assam earthquake were reported to last till 25th July 1897. The hills behind the hill to the west of the Mawphlang valley became visible after this earthquake. This was either due to the uplift of the distant hills or due to the subsidence of the intermediate hills [18]. In Cherrapunji, similar damages to the houses, roads and tombstones had occurred resulted approximately 500 to 600 casualties mainly due to landslides [18]. Kumar [19] observed that one of the ancient traditions of the Khasi tribes of Meghalaya is to erect a set of upright and flat stone monoliths in the memory of their ancestors. Several of these Khasi monoliths at Maokhar, Maophlang and Maosmai had fallen after this earthquake. The vertical acceleration at the SP was reported to be greater than earth's gravitational force based on reported observations mentioning stones hurled into the air at several locations. Due to the severe damages reported in the SP by the 1897 Assam earthquake, [20] attributed an intensity of X on the Rossi-Forel scale to the plateau.

1923 Meghalaya earthquake

On 9th September 1923 the Meghalaya earthquake of magnitude 7.1 (Ms) occurred on the Dauki fault [3]. There is a dearth of knowledge regarding the damages caused during this particular earthquake. However, many of the past studies report damages from the southern part of Meghalaya, Sivasagar and Borjuli in Assam and Nagrakata in West Bengal. In the south the ground shaking was felt across Srimangal, Barisal, Chittagong, Midnapore and Narayanganj. Also heavy damages were reported in Mymensingh in Bangladesh, Cherrapunji and Guwahati in India by [3].

1930 Dhubri earthquake

The 1930 Dhubri earthquake of magnitude 7.1 (Ms) occurred within the Dhubri fault located to the west of the SP. The intense shaking due to this earthquake lasted for several minutes causing wide spread damages. The area affected by this earthquake was spread over approximately 80,0000km^2 from Dibrugarh and Manipur in the east, Kolkata in the south, Patna in the west and Nepal, Bhutan and Sikkim in the north [21]. As per [22] the Dhubri town lying in close proximity to the Dhubri fault was the worst affected region with an intensity of IX on the Rossi Forel scale. Tura in Meghalaya, south of Dhubri in the SP, was shaken with an intensity of VIII. In Tura several of the government buildings were affected; some suffered minor damages while others underwent severe damages. To the west of the Garo hills near the N-S trend of the Brahmaputra River, fissures and sand vents were reported by during this earthquake [22]. Further, as per [22], an intensity of VII on Rossi Forel scale for Goalpara and Guwahati in Assam and an intensity of VI for Cherrapunji and Shillong parts of SP on Rossi Forel scale were reported during the 1930 Dhubri earthquake. As per [22], in spite of the high intensity of ground shaking reported in the city of Shillong the building damages were comparatively less. This may be attributed with the fact that after 1897 Assam earthquake, most of the houses were built of bamboo and other locally available light materials. In Cherrapunji however the houses faced considerable damages due to poor construction practices. Number of aftershocks for this earthquake was also reported even till 5th July 1930 [22].

1943 Assam earthquake

After the 1897 Assam earthquake, the state of Assam was once again hit by an earthquake (Ms=7.2) on 23rd of October. The epicenter of this earthquake was located 13.6km east of Hojai in Assam. The source fault of this earthquake was the Kopili fault which had previously caused the 1869 Cachar earthquake [3]. Very little information is available about the 1943 Assam earthquake. The only information is of the intense shaking brought by the earthquake that woke up people in the night and the report of a rumbling noise. Fissures and unevenness of the ground, falling of trees and damaged buildings due to the earthquake were also reported [3].

2009 Assam earthquake

On 19th August 2009, an earthquake of magnitude Mw 5.1 was recorded on the Kopili fault at a depth of approximately 10km. The fault had undergone a right lateral strike slip movement as per [9]. On 21st September 2009 another earthquake of magnitude Mw 6.3 located approximately 100km north of the 19th August 2009 earthquake was felt in Bhutan and along the same Kopili fault. This earthquake had similar focal depth and focal mechanism as that of 19th August 2009 earthquake. As per [9] the 19th August earthquake in the Assam valley is the foreshock of the Bhutan earthquake.

The damage reports of the past earthquakes originating in the faults surrounding the plateau shed light upon the seismic potential of the SP. The limitation of the present IS codes in understanding the true seismicity of a region has been highlighted by many researchers. Keeping this in mind, several remote sensing studies have been conducted in recent times with the help of GPS to identify the possible locations of strain accumulation and the in-situ slip mapping in the SP. Such studies provide a more clear and updated knowledge about the present seismic status of the SP.

PRESENT SEISMICITY OF THE SHILLONG PLATEAU

Deformation in the collision zone of the Indian and Eurasian plates along the Himalayas was attempted by [23]. As per the study by [23], it was concluded that the SP is moving towards south with a velocity of 6.3±3.8 mm/year approximately. Another study conducted by [17] showed that the SP is presently being uplifted and is also shortening. It was found that the SP is rising vertically along the Dauki and the Oldham faults at a rate of 3.3±1.3 mm/year and shortening horizontally at 4±2 mm/year. However according to [24] no significant deformation is occurring in the SP. Further, [24] suggested that only 1.5±1 mm/year deformation is taking place within the SP. Another study performed by [25] proposed that 1.5 to 3.5 mm/year of the convergence in the northeastern Himalaya as well as 8-9 mm/year of convergence in the Indo-Burma fold-thrust belt is occurring in the SP. Recently,[26]proposed that the western part of the SP is rotating clockwise towards south at 3 mm/year, similar clockwise rotation was also observed on the eastern edge of the plateau at 6 mm/year. As per [27] the Kopili fault located to the east of the SP is also undergoing active deformation with a slip of 2.9 ± 1.5 mm/year. The present ongoing deformation in the SP presents a clear picture of the hazard potential of the plateau from future earthquakes. With the view of understanding the present day seismic hazard of the SP as well as the rest of the country the National Disaster Management Authority (NDMA) [28] performed probabilistic seismic hazard analysis for India. To perform the probabilistic seismic hazard analysis the entire country was divided into thirty two seismic source zones. The SP and its neighboring Assam Valley region was grouped under the source zone 8. The seismicity of each of the source zone was characterized by the Gutenberg-Richter recurrence relation

$$\log_{10} N(m) = a - bm \qquad (1)$$

where, *N(m)* is the number of earthquakes of magnitude ≥ m, a and b parameters describes the seismicity of the zone. In Eq. (1) values of the b parameter can range from 0.6 to1.5. From Eq. (1) the value of the b parameter for the source zone 8 was found to be 0.73±0.04. This implies that the chances of occurrence of future higher magnitude earthquakes in the SP are more. Further [28] also reported that the potential maximum magnitude earthquake that could occur in the future in source zone 8 is of magnitude 8.4.

CONCLUSIONS

The SP in the northeastern region of India is one of the most seismically active regions in the world. Several of the past reported major and great earthquakes of India have originated in the SP and caused wide spread damages. The 1897 Assam earthquake is particularly noteworthy as it drastically deformed the SP. This high seismic activity of the plateau is attributed to the presence of a number of faults around the plateau. The Dauki fault, the Dapsi thrust and the Kopili fault have been the source of past major to great earthquakes. The Kopili fault in particular has shown an active seismicity based on the evidences from the last century till present. Detailed *in-situ* monitoring of the Kopili fault with the help of remote sensing studies have shown a slip of 2.9 ± 1.5 mm/year along the fault. Similarly, present day deformation for the entire SP region has been observed. Presently the SP is undergoing deformation by rotating clockwise and moving in the southern direction. This deformation of the SP is occurring due to the ongoing convergence in the northeastern Himalaya as well as the convergence in the Indo-Burma ranges. It can be understood that with ongoing continuous deformation of the SP as well as the *in-situ* slip in the Kopili fault bordering the SP, the seismic hazard potential of the plateau remains very high. It was evident that the past reported earthquakes have caused wide spread damages in the SP. During the occurrence of the last great earthquake, even though the population of the SP was relatively less, the loss of lives were less but the earthquake had caused extensive damages in the SP. At present the population of the SP is comparatively very high. With a high level of ongoing seismic hazard and potential for the occurrence of a great earthquake similar to 1897 Assam earthquake, huge catastrophe is possible in the SP in the future. Hence a detailed study of the tectonic setting of the SP in support of the present day strain accumulation on each of the faults surrounding the SP should be done. Such a study will provide a realistic scenario for the future earthquakes in the region. This will help in minimizing the casualties as well as building damages due to probable future earthquakes in the SP.

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