American Scientific Research Journal for Engineering, Technology, and Sciences (ASRJETS)
ISSN (Print) 2313-4410, ISSN (Online) 2313-4402

http://asrjetsjournal.org/

The Surface Deformation and Earthquake History Associated with the 1975 M 6.8 Bagan Earthquake in Myanmar

Hla Hla Aung*

Myanmar Earthquake Committee, Federation of Myanmar Engineering Societies, MES Building
Hlaing University Campus, Yangon
Email: hhlaaung@gmail.com

Abstract

The 1975 M 6.8 Bagan earthquake occurred on 8th July 1975, at 12:04:38 (UTC). The epicenter was at 21.50N 94.70E with the depth of 112 km (ISC) and focal mechanism is thrusting (USGS). The intensity of earthquake was severe which involved destruction of many pagodas with a loss of at least one live and one injury. Most of the pagodas were damaged with their tops falling down to the ground. Bagan, the land of temples and stupas was shaken by a series of earthquakes since ancient time and the earliest records are about 25 November,1372; 14 July 1485 A.D. and another event in 1550 A.D.by which event Shwe-gu-gyi temple was damaged. Although the 1975 earthquake was one of the significant earthquakes that have occurred along inland zone in the western Myanmar, this event has not been analyzed within the context of present-day understanding of earthquake seismology. The mode of deformation and seismic history of these earthquakes remain unresolved. Due to another large earthquake, Chauk earthquake in 2016 with M 6.8, approximate numbers of pagodas of (400) were damaged as the previous 1975 Bagan earthquake. Pagodas left intact and withstand as before. Geologists and earthquake engineers went to Bagan city and neighboring towns for damage assessment a few days after the 2016 Chauk earthquake event. People explained that the main shock was very powerful and the houses and religious building were lifted about 3 times at initial shaking and then lateral shaking continued for a minute. It is due to the ground motion that was strong enough to fling up the buildings as the fault rupture beneath it.

----

* Corresponding author

On the base of field investigation that was carried out to map the surface rupture associated with this earthquake event, the 1975 Bagan earthquake and 2016 Chauk earthquake are intermediate-depth subduction earthquakes and such inland intermediate-depth earthquakes are hazardous earthquakes for the area along the Rakhine Western Ranges (Indo-Andaman belt) under which the India plate is subducting beneath the Burma plate. These earthquakes are the most significant events that occurred in intra-plate subduction zone setting.

Keywords: intensity; investigation; subduction; religious building; thrusting; rupture.

1. Introduction

The stupas and temples were erected mostly from the 11^{th} to 13^{th} centuries but the Bagan dynasty began from 108 A.D. ruled by 55 kings for 12 centuries according to local chronicles. But epigraphically evidence supported that the dynasty began with the reign of King Anawrahta (1044-1077 A.D.). Some believed that most of the temples and stupas in Bagan must have been built during a few centuries about more than 13,000 stupas and temples, but today only about 5000 (recorded 4474 structures) are remained but total 3122 in the list of the archaeological department [19]. The rest structures must have been disappeared due to weathering through times and recent successive earthquakes since 1975 event.

2. Tectonic setting

Hard collision between India and Burma plate during Oligocene to Miocene (45Ma-35Ma) and Rakhine Western Ranges became uplifted during Middle Miocene to Upper Miocene (Curray and his colleagues 2005). India oceanic plate is subducting obliquely beneath Burma continental plate along Sunda subduction. Northward and northeastward movement of India oceanic crust is the most important part for tectonic of Burma in Tertiary time. Tectonically Myanmar is made up of a mosaic of tectonostratigraphic terranes: four tectonic terranes and three accreted belts [1]. They are as follow:

(1) Rakhine Coastal Plain terrane (RC),

(2) Rakhine Western Range terrane (RWR), (Indo-Andaman Belt)

(3) Central Burma Basin terrane (CBB),

(4) Shan Massif terrane (S) and,

(5) Kachin terrane (K)

(6) Shan Boundary Belt

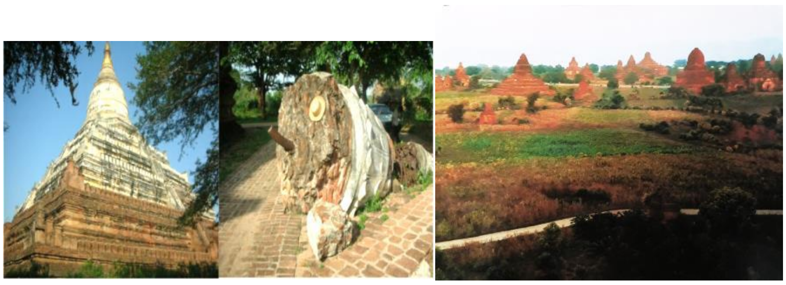
(7) Than Lwin Belt

The ancient city, Bagan or Pagan is located at latitude 21°10’N, Longitude 94°51’E, in Mandalay Region, on the east bank of the Ayeyarwady River in Central Myanmar Basin. The geology of Bagan area consists of Holocene surficial deposits of gravel, sand, silt and clay. The underlying rock formations that crop out around the Bagan area are mostly sandstone, siltstone and shale of the Pegu Group of Oligocene-Miocene and the Irrawaddy Group of Pliocene-Pleistocene.

3. Co-seismic Deformation of Intermediate-depth Earthquakes and History

The earliest earthquake on record took place at 5 p.m. on 2nd April, 1762. It was very violent and destructive, and was felt all over Bengal, Rakhine ranges and western part of central lowland area, mostly along the Rakhine coastal area. A historical record of a large earthquake in 1762 ruptured 250 km of the Arakan segment. A large but poorly documented earthquake in 1548 ruptured the Naga segment [17]. The Thayet earthquake of 24th August, 1858 was most severe near Thayetmyo and Prome and destructive and the general direction appears to have been from east-north-east to west-south-west. It occurred at 3:38 at Thayetmyo. Tops of pagodas were knocked down. The shock was sharp and severe, lasted almost a minute. The shock was preceded by a loud sound and the houses rocked considerably and most of the pagodas were badly damaged with their tops falling to the south-west, while several were entirely destroyed. False Island, situated south-east of the island of Cheduba, latitude 18°38'N, longitude 93°55½'E, was entirely disappeared, no trace of it being seen after the 24th August event. Two aftershocks were felt on 26th Auguset at 8:30am., and 27th August at 9 am., at Prome and Thayetmyo respectively [4]. Another earthquake on record occurred at Kyaukphu at 11p.m on 6th February, 1843 after 1762 Great earthquake. It caused magnificent eruptions from the mud volcanoes and slight tremors at Ramri, lasting till 1 o'clock in the morning.

(a)Dammayangyi temple (b) Sularmani temple



(c) Shwesandaw stupa (d) Panorama view of Bagan

Figure 1: A mosaic of photos showing damages of Bagan pagodas due to earthquakes in history. Their tops are falling down by heavy shaking of the ground. Photos [19].

Another earthquake in the same year, on 30th October at 7.45a.m, was more violent, but lasted only two minutes. It was felt only slightly at Ramri, but more severely at Cheduba. On 3rd January, 1848, another earthquake at Kyaukpyu damaged buildings [4].

The significant intermediate-depth intraplate events have shown considerable destructiveness and these earthquakes occur in the interior of downgoing slab of the India plate. The 6.8 magnitude strong earthquake occurred on 24th August 2016 at intermediate depth of 84.1km with epicenter 20° 919' N 94° 579'E, 25 km west of Chauk. Local people explained that the main shock was very powerful and the houses and religious building were lifted about 3 times at initial shaking and then lateral shaking continued for a minute. It is due to the ground motion that was strong enough to fling up the buildings as the fault rupture beneath it. Their tops are falling down by heavy shaking of the ground (Fig.1). Focal mechanism solution of this event is given as compressional faulting (USGS) in subducting slab of India plate. On April 13th 2016, at 8:25 (Local Time) an earthquake of magnitude 6.9 (CMT determination) occurred at depth of 134 km, at 23.133°N- 94.900°E , compressional stress (USGS Report), 74 Km southeast of Mawlaik. Tama-thi earthquake occurred in northwest Myanmar with magnitude 4.8 on 11th October,2016 at 14:00:15,GMT/UTC Time at depth (Hypocenter) 97.5 km. The 2018 4.9 magnitude Kyauk-tu earthquake occurred on 19 November 2018 at intermediate depth of 76.1 km with epicenter 21° 30' 39"N 94° 22'54"E, 77km west-north-west of Pakokku. An earthquake occurred with magnitude 5.3 at 18.487°N-94.511°E occurred on 18.8.2019 03:24:23(UTC) in the northeast of Thandwe at 40.3 km depth. Another earthquake occurred with magnitude 4.7 at 18.486°N-94.608°E occurred on 18.8.2019 03:24:23(UTC) in the northeast of Thandwe at 54.7 km depth. It shook Thandwe moderately for 30 seconds. Focal mechanism is normal faulting (USGS). The Thayet earthquake occurred 26th November, 2019 at 11:05:57 (UTC).The epicentral location is 19.227°N-94.938°Eat the depth of 70 km with M 5.3. There are many subaerial earthquakes occurred in western part of Myanmar under Rakhine ranges. From focal mechanism solution and hypocenter location, it is found that there occur both normal fault type events due to down-dip extension type earthquakes at depth 40-70 km and normal fault type events and reverse fault type events within down- going slab of India oceanic plate at depth of 70-200 km. Unlike most of the plate's oceanic continental boundaries in the world, this one between Indian oceanic plate and the Burma continental plate is unusual in that it is located on shore and several hundred km in land because of large volume of sediments shed following the uplift of Himalaya [18:99-114].

4. Structures of the India-Burma Subduction Zone from Earthquakes

The earthquake activities associated with the down going slab occurred as a result of four distinct processes: (a) earthquakes generated in response to the bending of the plate when it begins its descent. It makes downward flexure of the lithosphere puts the upper surface of the plate into tension and normal faulting; (b) earthquakes generated from thrust faulting along the contact between overriding and underthrusting plates (interface); (c) at the depth greater than thickness of the plate at the surface are not generated by thrusting at the top of a descending plate; (d) at the depth between 70- 200 km, earthquakes are common features of subduction zones seismicity. In some cases focal mechanism solutions for the upper zone, earthquakes imply down dip compression and those for the lower zone earthquakes down dip tension [8]. On the west of Myanmar in coastal area, the Indian oceanic plate has been subducting beneath the Burma plate at the rate of 46mm/year [15:367-

378]. Strain release associated with deformation within the subducting india slab is evident with continental epicenter at the intermediate depth of 50 to 150 km. GPS measurements of plate motion in Bangladesh, combined with Myanmar and North East India strongly suggested subduction in the sub-aerial section of the plate boundary is active, despite the highly oblique plate motion with 46mm per year. The collision between India oceanic plate and Burma plate has shifted to the west at 20mm per year and propagated southward at 50mm per year [15:367-378]. Active subduction of the Indian oceanic plate below the continental Burma plate is primarily documented by Manoj Mukhopadhyay and Sujit Dasgupta[10:299-322], using seismic data, gravity data, focal mechanism data and geological data. These studies outline the configuration of Benioff zone where the Indian oceanic plate underthrusting the Burma plate below the Naga Hills, Chin Hills and Arakan Hills for a length of 1100 km from north to south, which extend to a depth of about 150 km. The hypocenter distribution along the subduction zone was also previously studied by Khan [9:341-361]. In 2012, detailed geometry of the subducting India Plate and subcrustal seismicity in the Burma Plate derived from joint hypocenter relocation was done by Hurukawa and his colleagues [6:333-343]. Their studies show that earthquakes in Myanmar are concentrated in two tectonic domains: (1) the continued subducting of the north-and north-eastward-moving Indian plate underneath the Burma plate at depth between 50-150km , and (2) the fore-arc and back-arc seismicity at depth of 0-50km on overriding Burma plate. The first area corresponds to inclined zone of India subducting plate and the second area corresponds to the overriding Burma plate. Previous studies on seismic data, gravity data, focal mechanism solution, relocated hypocenters data and recent earthquake data (USGS) (Table 1) had been taken for interpretation by the author to delineate the plate boundary of the Indian- Burma for configuration of subduction zone. It was drawn using earthquakes foci range in shallow to intermediate depths with a maximum depth of about 150 km [3].

Table 1: Parameters of recent earthquake events: date, time, epicenter location, Magnitude, depth and their focal mechanism solution

Serial	Name	Date	Time (UTC)	Epicenter	Tensor	M	Depth
1#	Myanaung	9.2.2018	4:41:43 UTC	18.213°N 94.288°E		4.2	28.7km
2#	Thandwe	18.8.2019	3:24:23 UTC	18.486°N 94.609°E		4.7	54.7km
3#	Mawlaik					4.7	22km
4#	Falam					4.8	42km
5#	Mawlaik-2	26.5.2018	11:42:23 UTC	23.004°N 94.608°E		4.5	95.3km
6#	Mawlaik-3	24.4.2018	4:08:35 UTC	22.923°N 94.804°°E	thrusting	5.2	105.9km
7#	Mawlaik-4	20.1.2018	10:00:06 UTC	23.89°N 94.702°E		4.2	85.5km
8#	Thandwe2	20.1.2018	4:00:05 UTC	18.24°N 94.06°E		4.0	
9#	Monywa	3.12.2018	9:47:14 UTC	22.361°N 94.504°E		4.7	96.8km
10#	Pyay	14.2.2018	7:14:01 UTC	18.724°N 95.251°E		4.7	81.4km
11#	Chauk	29.4.2018	5:58:57 UTC	21.124°N 94.435°E		4.5	89.6km
12#	Monywa-2	26.6.2016	12:00	22.209°N 95.034°E		4.6	21.8km
13#	Taunggup	27.3.2019	11:00:18 (MST)	18.88°N 94.14°E		4.5	10km
14#	Haka	25.1.2019	4:06:03 (MST)	23.12°N 94.08°E		4.2	
15#	Paung Pyin	17.3.2019	1:53:40 (MST)	24.02°N 94.59°E		4.8	84km
16#	Chauk-2	24.8.2016		20.919°N 94.579°E	thrusting	6.8	84.1km
17#	Mawlaik-5	13.4.2016	8:25 (MST)	23.133°N 94.900°E	thrusting	6.9	134km
18#	Kyauk-tu	19.11.2018			normal fault	4.9	76.1km
19#	Thandwe-2	18.8.2019		18.486°N 94.609°E	normal fault	4.7	54.7km
20#	Thandwe-3	18.8.2019		18.487°N 94.511°E		5.3	40.3km
21#	Shibweyan	26.8.2019	2:49:15 UTC	26.523°N 96.090°E		4.7	93.5km
22#	Chauk-3	6.9.2019	10:09:49 UTC	21.189°N 94.650°E		4.8	98.9km
23#	Bagan(Pagan)	8.7.1975	12:04:38 UTC	21.48°N 94.04°E	thrusting	6.8	112 km
24#	Min Kin	10.10.2019	07:10:47MST	22.75°N94.47°E		4.1	84km
25#	W.Thayet	26.11.2019	11:05:57	19.227N94.938E	normal fault	5.3	70km
26#	W.Thayet	26.11.2019	9:36:12UTC	19.263N95.024E		4.7	76.48km
27#	Homelin	29.1.2020	20:13:04	24.55N95.01E		4.2	114km
28#	Minbya	23.1.2020	9:48:05	20.437N93.378E		4.9	31.8km
29#	NW.MKNa	28.6.2004	08:18:32UTC	26.45N96.56E		4.7	82.6km
30#	Nagaland	3.6.2004	13:1:21UTC	25.248N95.149E		5	100km

Detailed investigation of new seismic data and recent earthquake activities associated with the down-going India slab was carried out by drawing two cross-sections across the Myanmar region as follow: (1) the profile and surface geology have been shown and hypocenters of recent earthquake events that occurred in 2018 and 2019 are plotted by projecting the epicentral location below the section line according to their focal depth (Fig.2). (2) location of hypocenters of six significant earthquake events and their focal mechanism solution are plotted (Fig. 3).

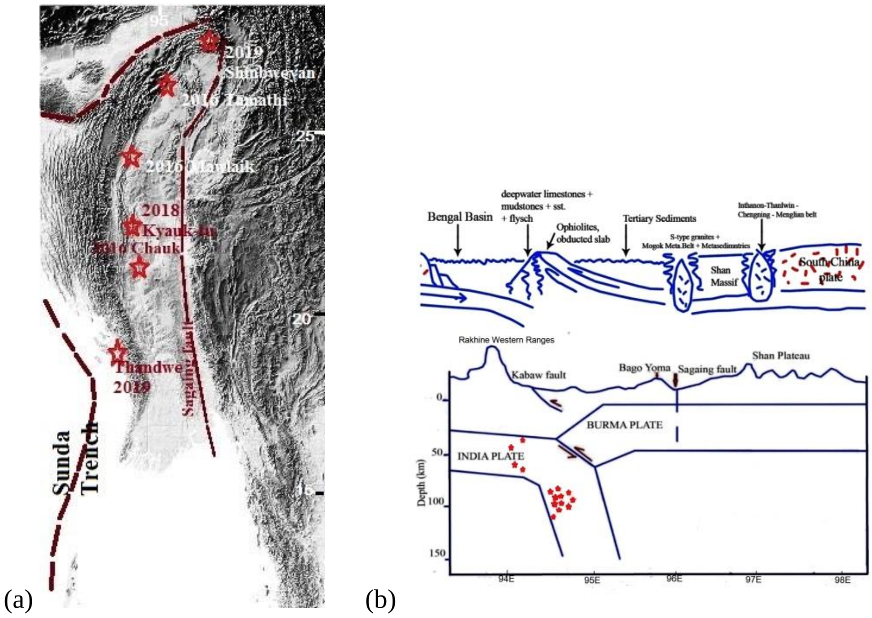


Figure 2: (a) Satellite topographic map showing tectonic-geomorphic features in Myanmar and recent earthquake location. (b) Cross-section (A-B) along latitude 21°N in E-W direction through Myanmar showing surface profile, surface geology and configuration of India-Burma subduction zone.

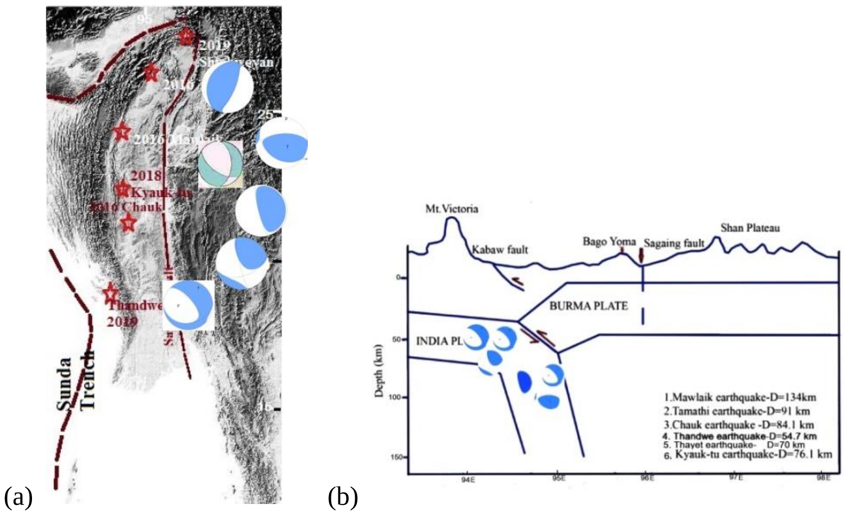


Figure 3: (a) Satellite topographic map showing tectonic-geomorphic features in Myanmar and Focal mechanism solution of significant earthquakes. (b) Cross-section (C-D) along latitude 21°N in E-W direction through Myanmar Showing configuration of India-Burma subduction zone.

The 2018 Myanaung earthquake, the 2019 Taungup earthquake, 2019 Minbya earthquake and 2019 Thandwe earthquakes (event no.1, 13,19,20, 28 in Table 1) are taken to delineate the upper plate boundary located at the vicinity of Rakhine coastal area. These events occurred in the plate that dips to the east and this area represents the initial stage of descending Indian oceanic plate. Earthquakes generated in response to the bending of the plate when it begins its descent. It makes downward flexure of the lithosphere puts the upper surface of the plate into tension and normal faulting [8].Focal mechanism solution of Thandwe earthquake is normal faulting (USGS) of down-dip extensional type. Both types of normal faulting and thrust faulting (USGS) are found at The 2016 Chauk earthquake, 2016 Mawlaik earthquake, Thayet earthquake and 2018 Kyauk-tu earthquake (event no.16,17,18, 25 in Table 1) as intermediate-depth earthquake events within the slab of the down-going India oceanic plate. At the depth between 70km to 200 km, earthquakes are common features of subduction zones seismicity. In some cases focal mechanism solutions for the upper zone, earthquakes imply down dip compression and those for the lower zone earthquakes down dip tension [8]. The upper and lower plate boundary of the overriding Burma plate are delineated according to the upper and lower limit of concentration of seismicity obtained from hypocenter relocation. When the Burma plate approaches to the India oceanic plate to the west, the overriding plate deflected downward as interface geometry onshore area [3]. Unlike most of the plate's oceanic continental boundaries in the world, this one between Indian oceanic plate and the Burma continental plate is unusual in that it is located on shore and several hundred km in land because of large volume of sediments shed following the uplift of Himalaya [18:99-114].

5. Conclusion

Myanmar region is resting on three plates: India, Burma and Indochina so that many areas in Myanmar area at risk from future earthquakes. The inland intermediate-depth earthquakes are hazardous earthquakes for the area along the Rakhine Western Ranges (Indo-Andaman belt) under which the India plate is obliquely subducting beneath the Burma plate. Based on interpretation of post- earthquake damages in Bagan area and field survey in surrounding areas, the geometry, geomorphology and kinematics of co-seismic rupture as well as geologic hazards along the subduction zone indicate neotectonic deformation due to the reorganization of plate motion between India, Burma, Indochina and Eurasia. These intermediate-depth earthquakes that happened along the Naga-Tripura-Arakan subduction zone in 2016, 2017, 2018, 2019 can be grouped into two categories (1) normal faulting events and (2) reverse faulting events. These intermediate-depth seismicity events are due to extensional or compressional intraplate stress in subducting slab of the India plate. The earthquakes: the Bagan, the Chauk the Thandwe, the Thayet and the Tamathi earthquakes in 2016 and 2019 ruptured the Arakan segments and the Homelin, the Paungpyin and the Mawlaik earthquake ruptured Tripura segment whereas the Nagaland and the Shinbweyan earthquakes ruptured Naga segment respectively.

6. Discussion and Recommendation

The ancient city, Bagan or Pagan is at latitude 21°10'N, longitude 94°51'E, in Mandalay Region, on the east bank of the Ayeyarwady River. These ancient religious buildings in Bagan are now in the age of more than 1000 years and we expect these monuments must last for long term in Myanmar. The stupas and temples were erected mostly from the 11^{th} to 13^{th} centuries but the Bagan dynasty began from 108 A.D. ruled by 55 kings for 12 centuries according to local chronicles. Some believed that most of the temples and stupas in Bagan must have been built during a few centuries about more than 13,000 stupas and temples, but today only about 5000 (recorded 4474 structures) are remained but total 3122 in the list of the archaeological department. The rest structures must have been disappeared due to weathering through times and some believed to have dismantled a considerable number of monuments to collect materials for building forts by invaders. Since then the great mass of the religious edifices were left to decay and ruin some by human vandalism. To mitigate the seismic risk to these stupas and temples in Bagan, effective earthquake preparedness and recovery, rehabilitation, reconstruction should be introduced for Build-Back-Better. In preparedness, acquired satellite imagery and geospatial information will be carried out to produce rapid maps that can support government, disaster management agencies and first responders for damage assessment especially in remote areas and overall picture during and post disaster situation. In that case, we need to develop a way of detecting earthquake source from satellite image and to apply the same technique to detect the damages. Remote sensing + GIS technologies and geodesy survey are greatly needed for effective preparedness to keep the religious buildings to be able to withstand future earthquakes.

References

[1]. Aung,H.H., 2013. Tectonic Styles and Deformation Patterns of Terranes in Myanmar. Wathan Press, Yangon, Printed in Myanmar

[2]. Aung,H.H., 2015. Myanmar Earthquakes History, Wathan Press, Yangon, Printed in Myanmar

[3]. Aung, H.H., 2019.The 18th AOGS Conference, Singapore; The Naga-Tripura-Arakan Subduction Zone and Intraslab earthquakes in western Myanmar http://www.asiaoceania.org/aogs2019/public.asp?page=browse_abstract.htm

[4]. Chhibber, H.L,1934. The Geology of Burma: Macmillian London, 538p.

[5]. Curray, J.R., et al.2005, Tectonics and history of the Andaman Sea region, J.Asia Earth Science XX1-42

[6]. Hurukawa,N.,Pa Pa Tun, and Bunichiro Shibazaki,2012: Detailed geometry of the subducting Indian Plate and subcrustal seismicity in the Burma Plate from joint hypocenter relocation.Earth Planets Space,64, pg.333-343,2012

[7]. Isacks, b.L. & Barazangi, M.(1977) Geometry of Benioff zone: Lateral segmentation and downward bending of the subducted lithosphere in Talwani, M.& Pitman, W.C. III(eds),Island Arcs, Deep Sea Trenches and Backarc basins, pp.99-114. American Geophysical Union, Washington.DC.

[8]. Jordan, T.E. et al.(1983) Andean Tectonics related to geometry of subducted Nazca plate. Bull.Geol.Soc.Am.94, 341-361.

[9]. Khan,P.K.,2005, Variation in dip-angle of the Indian plate subducting beneath the Burma plate and its tectonic implication. Geo.Scie.Journal,vol.9,no.3.p.227-234.

[10]. Kearey, P.2009. Global Tectonics, John Wiley & Sons, TheAtrium, Southern Gate, Chichester,West Sussex, PO 198SQ, UK

[11]. Leyton,F., Javier Ruiz, Jaime Campos, Edger Kausal, 2001: Intraplate and interplate earthquakes in Chilean subduction zone: A theoretical and observational comparison, Physics of the Earth and Planetary Interiors,175(1): 37-46, June, 2009.

[12]. Mukhopadhyay, M. and Dasgupta, S.1988, Deep structure and tectonics of the Burmese Arcs constraints from earthquake and gravity data, Tectonophysics,149 (1988) 299-322 Elsevier Science Publisher B.V, Amsterdam, Printed in the Netherlands.

[13]. Mondal, M.; Cecillia M.G. Mchugh; Goodbred, S.; Akhter, S.H 2014.; Paleoseismic Records of 1762 and similar Prior earthquakes along the SE coast of Bengladash: Conference paper AGU Fall Meeting 2014

[14]. Rangin C.,1996-1999.Deformation of Myanmar, Results of GIAC Projects, GIAC Conf. (Yangon,Myanmar)

[15]. Ruff, L.J., 1996, Large Earthquake in Subduction zones: segment interaction and Recurrence Time Department of Geological Sciences,University of Michgan, Ann Arbor, Michigan

[16]. Satyabala, S.P.,2003 The Historical Earthquakes of India, National Geophysical Research Institute, Hydrabad-500 007, India

[17]. Steckler, M. et al., 2008, Collision of the Ganges Brahmapudra Delta with the Burma Arc: Implication for earthquake hazard; Earth and Planetary science Letters 273 (3-4): 367-378 Sept.2008

[18]. Stein,S.and Wysession,M., 2003,An Introduction to Seismology, Earthquakes and Earth Structure Blackwell Publishing,350 Main Street, Malden, MA 02148-5020, USA

[19]. Syed Humayun Akhter: The northern rupture of the Arakan megathrust earthquake and other potential earthquake sources in Bangladesh, the 5th International Workshop on Seismotectonics and Earthquake Risk Management 2015, Abstract Volume page 6, Yangon, Myanmar

[20]. Talwani, M.& Pitman, W.C. III(eds),Island Arcs, Deep Sea Trenches and Backarc basins, pp.99-114. American Geophysical Union, Washington.DC.

[21]. Pictorial Guide to Bagan ,Ministry of Culture, Archaeology and National Museum Department ,The Union of Myanmar, Yangon.