Earthquake Geology of Sagaing Fault, Between Latitude 19º and 20º, Pyinmana-Yaeni Area, Central Myanmar

Tun Tun Min[1], Than Soe[2], Saw Ngwe Khaing[3]

Abstract

The proposed area is located at the southern part of Pyinmana Township, along the Sagaing Fault, and lies between North latitude 19˚ to 20˚ and East longitude 96˚ to 96˚ 30′. The study area is mainly composed of sandstone, shale and clay of Obogon Formation (Late Miocene), thick bedded to massive, pale yellow to reddish brown color, gritty sandstones and highly cross-bedded, coarse-grained ferruginous, buff color sandstones of Irrawaddy Formation (Late Miocene to Pliocene), and silty, clayey soil and loose sand of recent alluvium deposits. Metamorphic rocks (Paleozoic and partly Jurassic) and igneous rocks (Mesozoic and Early Tertiary) are also exposed. Nearly N-S (between 340º to 360º) trending lineaments are dominant fractures. Most of the rocks are deformed by brittle and semibrittle deformation mechanism. The area was divided into four sections and according to their segment they were made active fault mapping. Highest vertical movement is about 3.2 m at section 4. It can be used as site selection for paleoseismic trenching and offset mapping. Magnitude 5.5 earthquake was recorded on the 8th of March, 2018. It is related with Sagaing Fault and epicenter is located at about 12 NW of Naypyitaw. The focal depth of this earthquake is 10 km shallow type. On the 28th March of 2018, 3.5 magnitude earthquake was recorded from 20 miles NW of Naypyitaw. Focal depth of this earthquake is 7 km. Therefore, earthquake activities occurred in this area during 2017 and 2018.

Kyewords: Sagaing fault, formation, active fault mapping, paleoseismic, active tectonic

Introduction

The study area is located at the northern part of Taungoo, along the Sagaing fault. The length of the area is about 96 km from north to south and 33 km from east to west and total area coverage is 4068 sqkm. It is bounded by the latitudes 19º N to 20º N and longitudes 96° E to 96º 30′ E. The research area is situated along the middle segment of the Sagaing Fault and lies on one inch topographic maps of 94A/1 to A/8. The area is flat low land region. However, eastern part of the study area is about 480 m to 1320 m high and topographic trend is nearly north-south direction.

Methods of Study

Firstly, investigated the tectonic geomorphology of study area on desk study. Images analysis of lineament mapping, surface offsets and tectonic geomorphology are prepared by ArcGIS, Global mapper, surfer software and Google earth. In field survey, compass, measure tape and GPS are used.

Purposes of Study

The main purpose is to point out the active fault criteria and recent earthquake activities. This research can also support paleoseismic study (e.g trenching) and recommend for future research in this area.

Regional Geologic Setting

Upper Paleozoic Units such as Taungnyo formation, Labyin Group and their equivalents and lower part of the Margui Group occupy the eastern part of the region and

[1]Demonstrators, Department of Geology, Hinthada University
[2]Assistant Lecturer, Department of Geology, Taungoo University
[3]Professor, Dr, Department of Geology, Hinthada University

these rocks are locally intruded by Mesozoic and Tertiary granitic and locally transformed into granite gneiss and meta-diorite. Metamorphic rocks, mainly Lower Paleozoic rocks of Mogok metamorphic belt and its extensions also occurred in eastern part. Upper Pegu Group of Miocene, Upper Miocene to Pliocene Irrawaddy Formation and its equivalents are covered along the central and eastern region.

The Sagaing fault, located at several kilometers to the west of the Shan Scarp, is a north-south trending fault system. It is the longest and the most active fault in the country. The Sagaing fault splays out several fault strands along its course, and terminates in horse tail pattern transpressively in the northern end and transtensively merging with the sea floor spreading in the Andaman basin. The estimated and calculated offset displacement across the Sagaing fault varies from 100-150 km to 460 km, depending on the criteria used but the total offset is more likely to 332 km (Win Swe, 2013). The most significant structures associated with the dextral motion of the fault are the inverted BagoYoma anticlinorium into the west and Lake Inle synclinorium into the east (G.I.A.C, final report, 1999). In Mandalay region, another significant structures are also observed, where Sagaing fault is associated with two pressure ridges, the Minwun ridge on the west and the Sagaing ridge on the east. This feature of pressure ridges clearly indicates the transpressional behavior during the dextral motion of Sagaing fault. The transtentional behavior (depression) of the Sagaing fault can be represented by Indaw Lake, Indawgyi Lake, Yega In and Shwedan In.

The pull apart basin system of the Central Cenozoic Basin was affected by the strong tectonic inversion during 15 to 10 Ma, when the dextral motion of the Sagaing Fault was probably initiated (G.I.A.C report, 1999). The Sagaing Fault moves at an average of 18-20 mm each year (Vigny *et al.*, 2003), Neither fault moves uniformly at their given slip rate.

Background Seismicity

Seismicity along the course of the Sagaing fault is quite well known in Myanmar since the days of the Myanmar Kings, because many of the ancient city states and royal capitals of Myanmar were located on or close to the Sagaing fault (Win Swe, 2013). Earthquakes of varying magnitude have hit the region in the past.

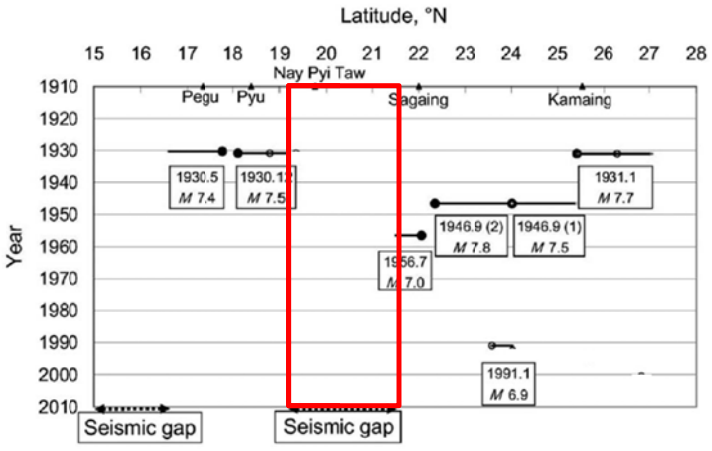

Figure (1) History of earthquakes along the Sagaing Fault and two seismic gaps (Hurukawa, N., P. Maung Maung (2011).

In Myanmar, there are two seismic gaps along the Sagaing fault (fig.1). The first one is between 19.2º N to 21.5º N and the next one is 16.6º N in Andaman Sea. The length of the first one is 260 km and a future earthquake of up to M 7.9 is expected to occur in central Myanmar. Because Nay Pyi Taw is located on the expected fault, its large population is exposed to a significant earthquake hazard (Hurukawa, N., P. Maung Maung (2011). Previous studies on the magnitudes of large shallow earthquakes from 1897 have reported that no other M ≥ 7.0 earthquake occurred in central Myanmar between 1897 and 1918 (Abe, 1981; Abe and Noguchi, 1983). Therefore, at least 113 years have passed since the last earthquake in this seismic gap. The recurrence interval of May 1930 – type earthquake (M 7.4) would be 160 years or longer, based on the horizontal slip rate of the Sagaing Fault and the 3 m of coseismic horizontal slip that occurred during the May 1930 earthquake (Tsutsumi and Sato, 2009). Consequently, it is likely that more than half of the recurrence interval has passed in this seismic gap, meaning that the fault has accumulated elastic strain of 2.0 m during the past 113 years (Hurukawa, N., P. Maung Maung (2011)). Therefore, the next large earthquake is expected to strike the area in the near future.

Geology

The area is mainly composed of sandstone, shale and clay, constitutes Obogon Formation (Late Miocene), Irrawaddy Formation (Late Miocene to Pliocene) and recent alluvial deposits (Fig.2). Metamorphic rocks (Paleozoic and partly Jurassic) and igneous rocks (Mesozoic and Early Tertiary) are also exposed. However, detail study of igneous and metamorphic rocks are not well done and are regionalized description in this research. The succession of the rock units are described as follows.

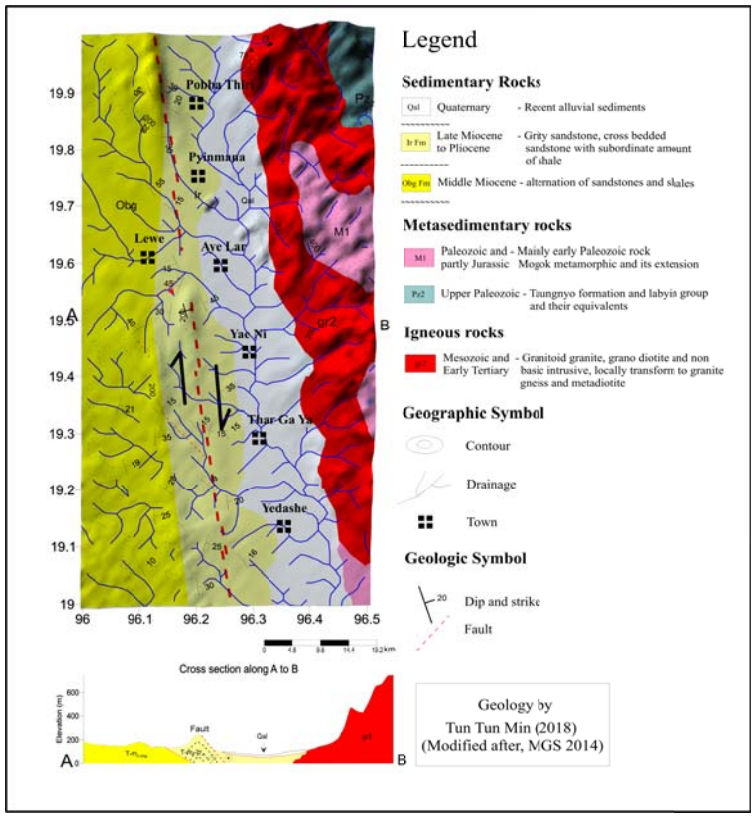

Figure (2) Generalized geological map of the study area (Modified after MGS, 2014)

Active Fault Mapping

The following sections describe tectonic geomorphology of the fault zone and surface deformation. To facilitate description, the area was divided into four sections (Fig. 3).

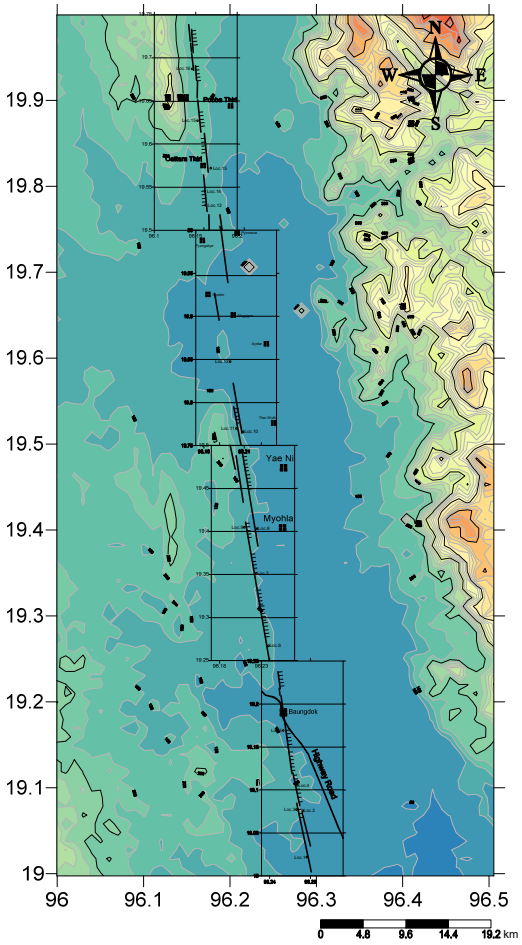

Figure (3) Active fault mapping of the Sagaing Fault from N 19º 00′ to N 20º 00′

First section (N 19º 00′ to N 19º 15′)

This section started at about 10 miles north west of Taungoo (Fig. 4). At the location – 1 (Fig. 5.a), vertical separation is approximately 1 m height and it is facing west. Strike of the fault is about 350º and bed rock type is soft sandstone unit of Ayeyarwady Formation. Approximately 2 m height fault line is also found in location – 2, where fault trend is about 350º (Fig. 5.b). Chaung Phyu Chaung is situated at location – 3 and it affected by fault and stream offset is about 5 m (Fig. 6.a). Location – 5 is at the southern part of Baungdok (Fig. 6.b). Where fault line is facing east and strike is 355º. This section is not well exposed and covered by small trees. Vertical separation of fault is about 2 m height and depression related pond is found.

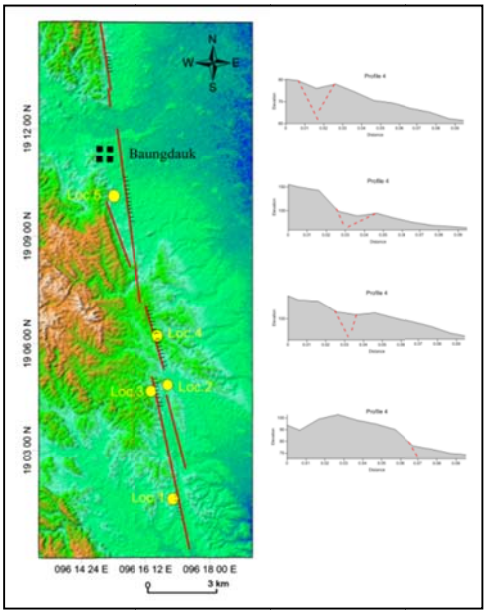

Figure (4) First section of active fault mapping (N 19º 00′ to N 19º 15′)

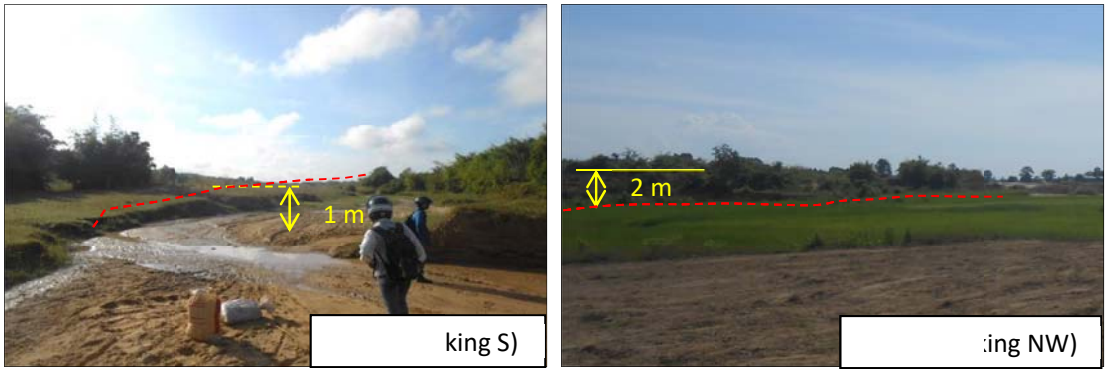

Figure (5) (a) West facing fault trace with vertical separation about 2 m (Loc. 19.035827º, E 96.286055º), (b) East facing fault line trace with 2 m vertical separation (Loc. N 19.087659º, E 96.276538º)

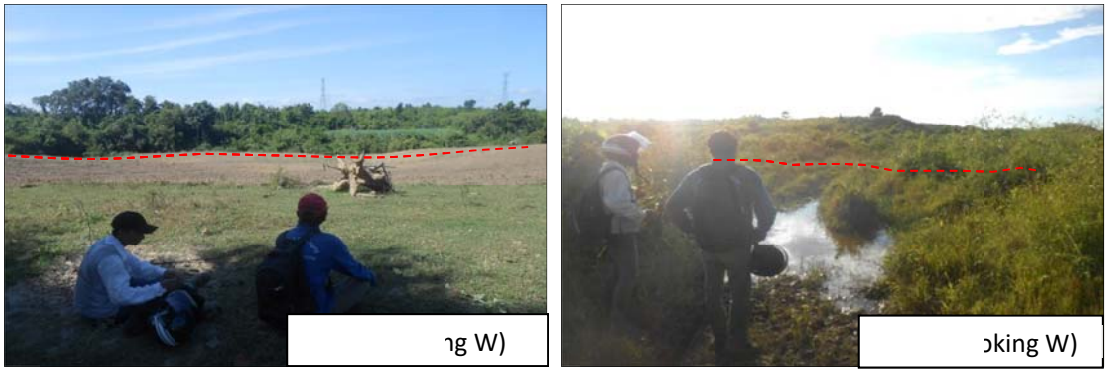

Figure (6) (a) Faulted Chaung Phyu Chaung (Loc. N 19.087659º, E 96.276538º), (b) Depression related small lake and 2 m height east facing fault trace (Loc. N 19.172786º, E 96.257863º)

Second Section (N 19º 15′ to N 19º 30′)

The section started from Swa to Yae Ni (Fig.7). At the loaction – 6 (Fig. 8.a), fault trace is facing west and found in alluvial sediments. Vertical separation is about 0.4 m height. Location – 7 is located at the south western part of Myohla (Fig. 8.b). Bedrock of the section is grity sandstone unit of Irrawaddy Formation with soil cover. Fault trace is facing east. Location 8 and 9 are located at the faulted valley. East facing fault trace is about 30 m height and it may be fault scarp. In these locations, fault strike is about 350º. However, Soe Min (2017) indicated that the vertical separation of this section is about 0.4 m.

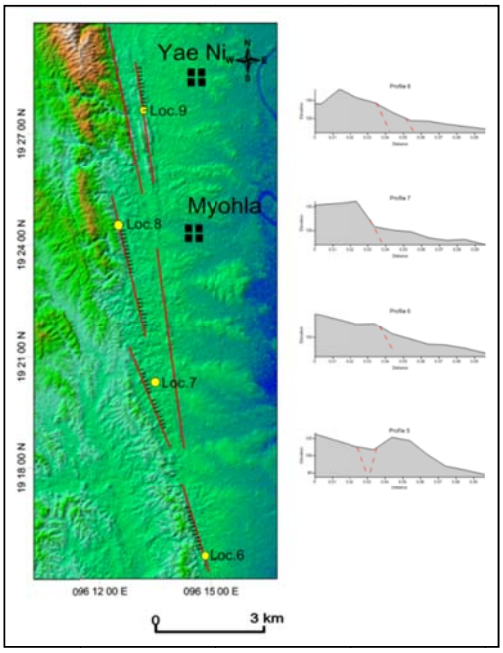

Figure (7) Second section of active fault mapping (N 19º 15′ to N 19º 30′)

Figure(8) (a) West facing fault trace exposed on recent alluvial sediment and vertical separation is about 0.4 m (Loc. N 19.265161 º, E 96.250278 º), (b) East facing fault trace (Loc. N 19.347900 º, E 96.231975 º)

Third Section (N 19º 30′ to N 19º 45′)

In the field, fault trace cannot be observed in this section because of the agricultures (Fig. 9). West facing fault trace is well observed in recent alluvial sediment at location 10 (Fig. 10.a). Vertical separation of this trace is about 0.7 m (Soe Min, 2017). Another one is about 310º trending fault trace where depression related artificial small lake occurred in location – 11 (Fig. 10.b). Location 12 is not well recognized in the field. According to Soe Min (2017), fault trace is facing west and vertical separation is about 1.5 m (Fig. 11).

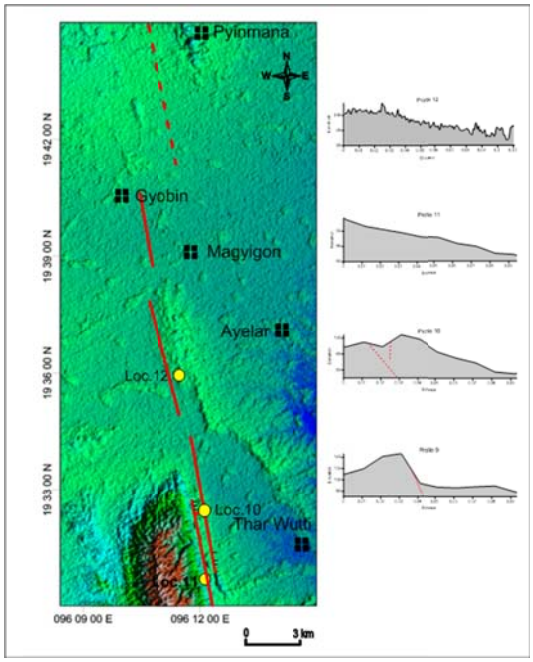

Figure (9) Third section of active fault mapping (N 19º 30′ to N 19º 45′)

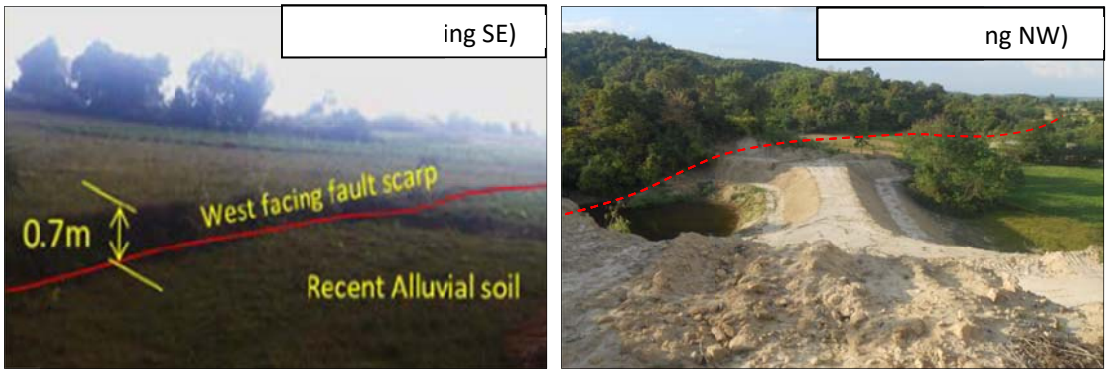

Figure (10) (a) West facing fault trace with vertical offset of 0.7 m (Loc. N 19.536568º, E 96.221400º), (b) About 310º trending fault trace and depression in which artificial small lake occurred (Loc. N 19.516568º, E 96.201400º)

Figure (11) West facing fault trace on alluvial sediment with 1.5 m vertical separation (Loc. N 19.596568 º, E 96.191400 º)

Fourth Section (N19º 45′ to N 20º 00′)

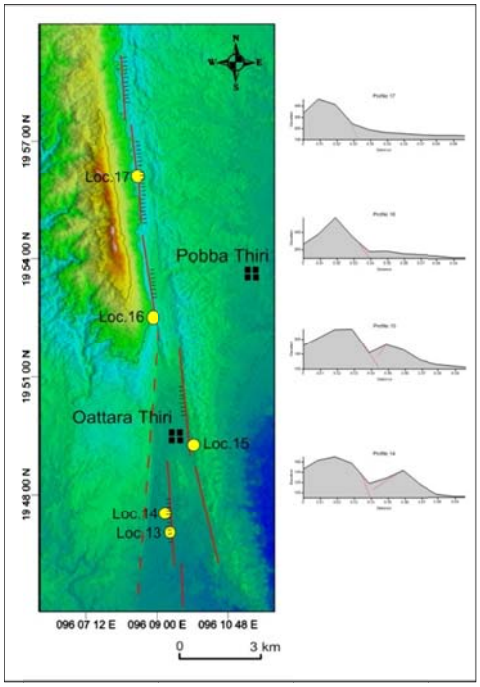

Figure (12) Fourth section of active fault mapping (N19º 45′ to N 20º 00′)

This section is started from Pyinmana (Fig. 12). West facing fault trace is observed at the location – 13 (Fig. 13). Vertical separation of the trace is about 0.45 m and fault trend is about 350º. Location 14 is located near Yay Pya Village (Fig. 14.a). In this location, fault trace is also facing west and vertical separation is about 3.2 m. Offset stream channel is right laterally offset about 3 m. This location is the suitable site for paleoseismic trenching. Bedrock type of gravel, sandstone and alluvial fans are also dominant. Location – 15 is located near the Ottara Thiri, where bed rocks are strongly affected by brittle deformation and found as brecciated zone (Fig. 14.b).

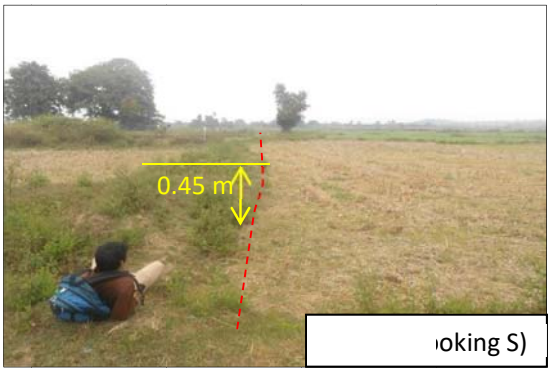

Figure (13) 1.5 m displacement west facing fault trace (Loc. N 19.786432º, E 96.161629º)

Figure (14) (a) West facing fault trace on recent alluvial fan with vertical separation of 3.2 m (Loc. N 19.788494º, E 96.160712º), (b) Brecciated deformation in fault zone (Loc. N 19.934994º, E 96.146668º)

Recent Earthquake Activities

In Myanmar, there are more than 505 times of earthquake occurred during 17 July, 2017 to 2018 (MEC, facebook). Most of the earthquakes occurred in Madalay Division, Bago Division and Sagaing Division (Fig.15). In 2018, about 14 earthquakes occurred around the study area (Tab.1) (Fig.16) (www.mozala.gov.mm).

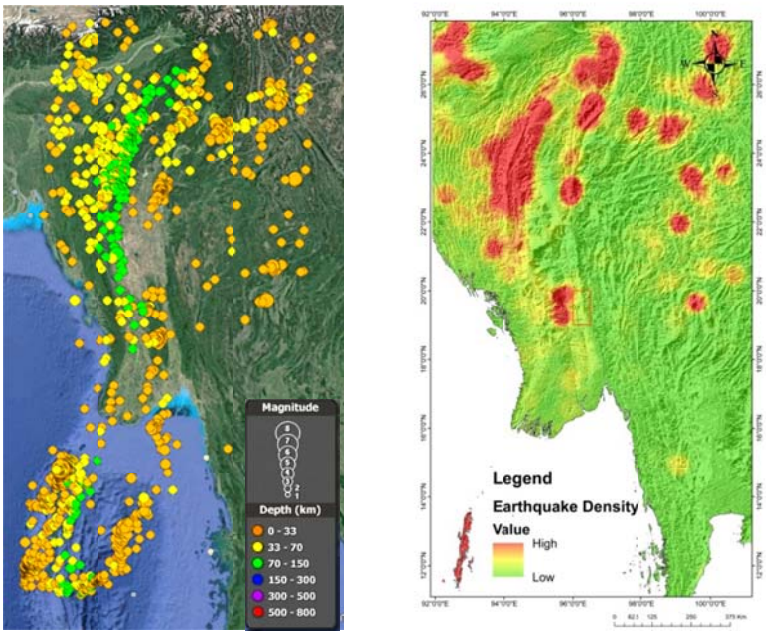

Figure (15) (a), Seismicity of Myanmar (2008 -2018)
(b), Earthquake density map (1950-2018)

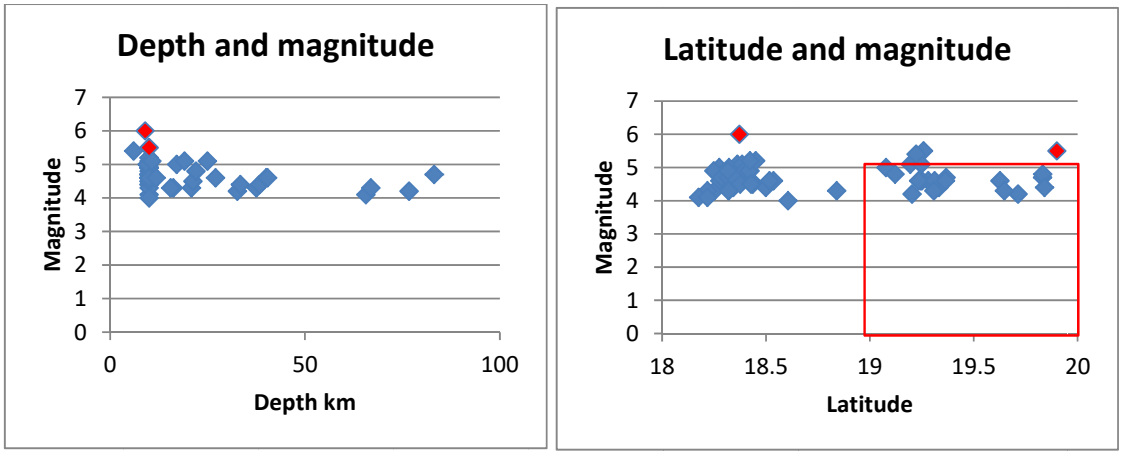

Figure (16) Earthquake activities of study area (magnitude greater than 4 and 100 km depth (2008 to 2018 earthquakes).

Table (1) Earthquake catalogue during 12 Jan to March 2018 around the study area

Time	Latitude	Longitude	Depth	Mag (Richter)	Place
28, Mar, 2018	**20.5^0 N**	**96.04^0 E**	**7**	**3.5**	**20 miles NW of Naypyitaw**
18, Mar, 2018	18.27^0 N	96.10^0 E	57	5.3	About 26 miles SW of Phyu
8, Mar, 2018	**19.90^0 N**	**96.01^0 E**	**10**	**5.5**	**12 miles NW of Naypyitaw**
7, Feb, 2018	18.33^{0}N	96.26^0 E	10	4.5	16 miles SW of Phyu
7, Feb, 2018	18.36^0 N	96.25^0 E	5	4.4	15 miles SW of Phyu
5, Feb,2018	18.29^0 N	96.21^0 E	10	5.2	20 miles SW of Phyu
22, Jan, 2018	18.26^0 N	96.13^0 E	29	4.9	25 miles SW of Phyu
20, Jan, 2018	18.13^0 N	96.38^0 E	18	4.0	24 miles SSW of Phyu
17, Jan, 2018	18.35^0 N	96.18^0 E	7	4.5	19 miles SW of Phyu
15, Jan, 2018				5.0	16 miles WNW of Phyu
14, Jan, 2018				4.5	25 miles WSW of Phyu
13, Jan,2018				4.3	16 miles WSW of Phyu
12, Jan,2018				4.8	21 miles SW of Phyu
12, Jan, 2018				4.6	21 miles SW of Phyu
12, Jan,2018				**6.0**	**17 miles WSW of Phyu**

Magnitude 5.5 (slight) earthquake was recorded on the 8th of March 2018. It is related with Sagaing Fault and epicenter is about 12 NW of Naypyitaw. The focal depth of this earthquake is 10 km shallow type. On 28th March 2018, 3.5 magnitude earthquake was also recorded from 20 miles NW of Naypyitaw. It has 7 km depth.

Conclusion

The study area is located at the northern part of Taungoo, along the Sagaing fault (latitude 19º to 20º and longitude 96º to 96º 30′). Regionally, Tertiary sedimentary rocks and metamorphic with granitic and basic intrusive of Mesozoic and Cenozoic age occupy large part of Central Myanmar Basin. Geology of the study area is Obogon Formation (Late Miocene), Irrawaddy Formation (Late Miocene to Pliocene) and recent alluvial deposits. Metamorphic rocks (Paleozoic and partly Jurassic) and igneous rocks (Mesozoic and Early Tertiary) are also exposed. Structurally, the area is strongly affected by right lateral strike slip fault, and Sagaing Fault. However, most of the structural features are related with not only dextral motion of Sagaing Fault but also deformation of weak planes. Most of the leneament are major Sagaing Fault or related features. Nearly N-S (between 340º to 360º) trending lineaments are major fractures. Field data analysis indicated that there are two types of deformation; brittle deformation and semibrittle deformation. According to the active fault mapping, fault trace, vertical separation and active fault criteria are well known in section – 1 to section – 4. Therefore, the present research indicates not only active geomorphological features but also selecting paleoseismic trench sites. More than 505 times of earthquake occurred during 17 July, 2017 to 2018. Most of the earthquakes occurred in Madalay Division, Bago Division and Sagaing Division. Magnitude 5.5 earthquake was recorded on March 8, 2018. It is related with Sagaing Fault and epicenter is located at about 12 NW of Naypyitaw. The focal depth of this earthquake is 10 km shallow type. On 28th, March 2018,

3.5 magnitude earthquake was also recorded from 20 miles NW of Naypyitaw. Focal depth of this earthquake is 7 km. Therefore, this area has earthquake activities during this year and needs detail studies such as quaternary geology, recent active geomorphic features, active tectonic study (trenching), etc.

Acknowledgements

We would like to express our thanks to Dr Tin Htwe, Rector and Dr Mar Lar, Pro-Rector, Hinthada University, for giving the permission to report this research work. We are also thankful to Dr Theingi Kyaw, Professor and Head, for her permission to do this research.

References

Abe, 1981. *Magnitudes of large shallow earthquakes from 1904 to 1980*, Phys. Earth Planet. Inter., 27, 72–92, doi:10.1016/0031-9201 (81)90088-1.

Abe and Noguchi, 1983. *Determination of magnitude for large shallow earthquakes 1898–1917*, Phys. Earth Planet. Inter., 32, 45–59, doi:10.1016/0031-9201(83)90077-8.

G.I.A.C Final Report, 1999. G.I.A.C Project, TOTAL UNOCAL-MOGE, Ecole Normale Superieure, Yangon, Dagon, Mandalay, Chiang Mai and Chulalongkorn Universities.

Hurukawa, N., P. Maung Maung, 2011. Two Seismic Gaps on the Sagaing Fault, Myanmar, Derived from Relocation of Historical Earthquake since 1918. Geophysical Research letter, January 2011.

Soe Min, 2017. Some evidences of Active Tectonic Deformation along the Sagaing Fault between Nay Pyi Taw and Myo Chaung, Myanmar. SMERM, 2017.

Thura Aung, 2005. Dextral Shearing and Related Structural Deformation Along the Sagaing Fault, Between Latitude 18 15 N and 21 15 N, Central Myanmar, M.Sc thesis, unpublished (2005).

Tsutsumi and Sato, 2009. Tectonic geomorphology of the southernmost Sagaing Fault and surface rupture associated with the May 1930 Pegu (Bago) earthquake, Myanmar, Bull. Seismol. Soc. Am., 99, 2155–2168, doi:10.1785/0120080113.

Vigny *et.al,* 2003. Present-Day Crustal Deformation around Sagaing Fault, Myanmar: Journal of Geophysical Research 108, ETG 6-1-10.

Win Swe, 2013. The Sagaing Fault of Myanmar; A Brief Overview, In Commemoration of 9thAniversary of MGS (2013, March).