SEISMOTECTONICS INVESTIGATION IN YANGON REGION, MYANMAR

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Abstract

The Yangon city is located on the convergence of the Yangon and the Bago rivers where the north-south trending ridge in the middle is made up of Miocene rocks and associated river terrace alluviums. Several major earthquakes visited this region frequently, some of which caused major damage to the built environment including ancient monuments and religious structures. There are a few noticeable events in the 20th century with their epicenters fell in and near the city such as the 1927 Rangoon Earthquake, the 1930 Bago earthquake, and the 1978 Dedaye Earthquake of which Yangon felt intensity from VI to VIII. Recently, slight to moderate earthquakes happened in the northern Yangon area (M5.1), causing damage to buildings and structures. Furthermore, several small-magnitude earthquakes were recorded in the city of Yangon itself. Therefore, an attempt has been made to understand the mechanism and sources of these events. Knowing the background geology of the area, field surveys were carried out to identify the regional structural trends and seismically active elements. Survey works include outcrop mapping of geological elements from which structural trends, sense of shear, and stress orientation can be interpreted. Generally, the observed faults have strikes of approximately N-S, NNW-SSE, NE-SW, and WNW-ESE directions. Field structural data also show right lateral and oblique reverse motion with the direction of maximum principle stress in NNE-SSW to NE-SW directions. In addition to field geological surveys, moment tensor solutions of significant earthquakes published by seismological centers are used to identify the nature of movement when the respective earthquakes happened. The recent events at the northern Yangon areas are found to be related to the WNW-ESE structural trend with an agreement of fault motion between seismic moment tensor and geological structural results. Several major geological lineaments are observed by distinct geomorphological expressions: some of them are often associated with earthquakes such as the Sagaing Fault in the east, the Dedaye Fault and faults near the Ma-u-bin area in the west, the Bago Yoma Fault, the Htan-ta-bin and Satthwartaw in the north and some cross faults in the Bago Yoma. Some concealed faults in the Ayeyawady Delta and off-coast of Pyapon and some faults of the Yangon are also highlighted in this paper as seismically active. In terms of fault size and seismicity of each area, the potential hazard that each tectonic element can give rise to is also discussed.

Keywords*:* Yangon, earthquake, fault, motion, seismically active, hazard

Introduction

Myanmar is situated within the Alpide-Himalayan earthquake Belt where devastating earthquakes have occurred from time to time. Yangon is the former capital and most populated city of Myanmar with > 5.2 million residents and is located at the southern part of Bago Yoma, as well as the southeastern part of the Ayeyarwady Delta and at the northern of the Andaman spreading center. The Sagaing Fault, which is located about 35 km east of the Shwedagon Pagoda, is a regional right lateral strike-slip fault trending in a north-south direction. There are several historical earthquakes in this region and the seismic sources for such events are from known and unknown structures. The location and regional seismicity of the area is shown in Figure (1). Study of seismicity and geomorphology and geological structures is carried out to identify active sources in the region. This research suggests earthquake potential concerning those identified seismic sources.

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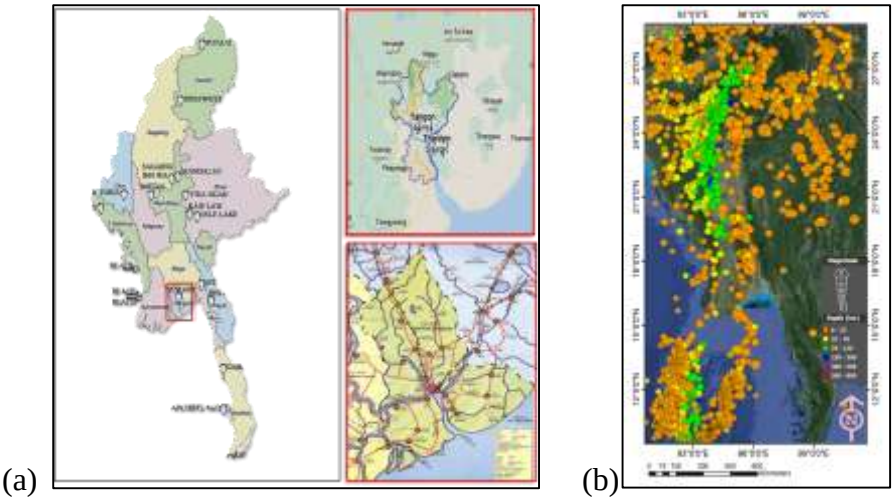


(a) (b)

Figure 1. (a) Location Map of the Study Area and (b)Seismicity of Myanmar Source from ANSS earthquake catalog (Evidence between 1900 -2024)

Tectonic Setting

Myanmar is one of the earthquake-prone countries in the world as well as in ASEAN region. Regionally, three major tectonics provinces are hosting significant earthquakes within Myanmar territory: namely, the Western Fold Belt, the ranges resulted from subduction and collision between the India Plate in the west and the Burma Plate in the east, the Central Basin and the Eastern Highland as part of Sibumasu. As a tectonically active region, significant earthquakes often visit in and surrounding of Myanmar Territory.

Yangon region is located on the southern spur of the NNW–SSE trending Bago anticlinal ridge; both geological and geomorphological prominence ridge with 600 kilometers long and 65 kilometers wide. The Sagaing Fault, a major right lateral strike-fault of Myanmar is located approximately 35km in the east of Yangon. The Bago Yoma anticlinorium, the Sagaing fault and the Andaman spreading center are the most significant tectonic elements in this area. Figure (2) shows regional tectonic setting in Yangon and neighbouring areas.

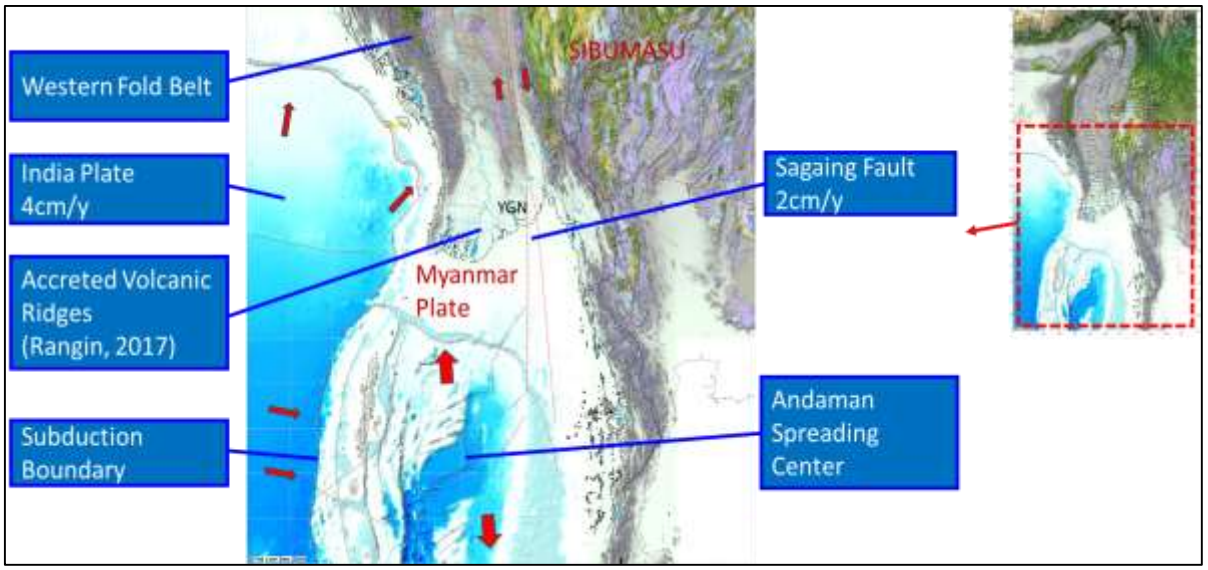


Figure 2. Regional Tectonic Setting of Yangon Region

General Geology

Regional geology of the Yangon Region comprises the rocks of Upper Pegu Group, Irrawaddy Formation and Alluvium (MGS, 2014). A previous study on the geology of the Greater Yangon (Win Naing, 1972) pointed out that the southern part of the Shwedagon-Hlawgar Ridge is composed of sand rocks of the Irrawaddy Group (Arzarnigon Sand rocks); it shows fairly consolidated nature by its exposed surfaces. Hlawga Shales (Win Naing, 1972) (equivalent to Pyawbwe Formation of upper Pegu Group) occupied the lowland areas in the west of Hlawgalake. Although the exposures are rare, some outcrops are found along the west bank of Hlawgalake. Shales and laminated clays of this formation are considered to be the core of the Hlawga anticline (Kyaw Tun, 1996). Thadugan Sandstone (Win Naing, 1972, Kyaw Tun, 1996) (equivalent to Kyaukkok Formation of upper Pegu Group) is mainly exposed around Thadugan Pagoda and also exposed in the southern western of Shwedagon Pagoda. Besapat Alternations (Win Naing, 1972) (equivalent to Obogon Formation of upper Pegu Group) which is exposed in the vicinity of Besapet Lake, Hlawga Park, and Kyauktan Township. Arzarnigon sand rocks (equivalent to Irrawaddy Formation) are the equivalent of the Irrawaddy Formation. The Danyingon clays (Win Naing, 1972) (equivalent to Irrawaddy Formation) mainly consist of blue clays, yellow clays, and siltstones interbedded with sand rocks. The younger alluvium is mostly exposed along the low-lying flat plains. The geology and locations of the outcrop are shown in Figure (3).

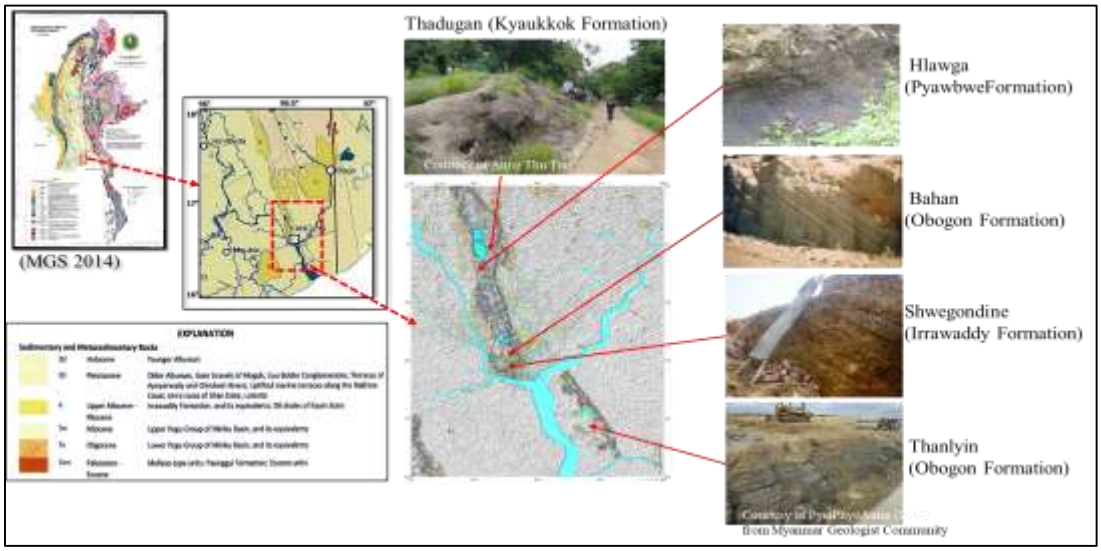


Figure 3. Geology and Some location of outcrop in the Yangon Region

Earthquakes of Yangon Region

The old settlements and ancient civilization of Myanmar had experienced the effect of strong earthquakes. Such historical records are available from some religious buildings, such as stupas and temples, in the form of stone inscriptions, remains, monuments, history documentation (Tint Lwin Swe, 2015). Some examples are the Shwedagon Pagoda of Yangon, the Shwemawdaw Pagoda of Bago and the Kyaikkauk Pagoda of Thanlyin, etc. These structures had long records of renovation works; some of them claim damage due to strong earthquakes. Summary of some significant historical earthquakes in this area are shown in (Fig-4). On 17 December 1927, a seven-grade earthquake hit Yangon and caused certain amount of damages. It was felt 15,000 sq.km from Kyangin to Dedaye along the western slope of Bago Yoma. In May

1930, Bago earthquake with magnitude 7.3M affected Yangon, vibration spread caused damage to the buildings and 500 persons and 50 persons were killed in Bago and Yangon, respectively. In 1978, magnitude 5.1M Dedaye earthquake with more than 20 aftershocks caused slight damage in that region and felt Yangon. Recent earthquakes in Yangon Region have happened on 17th March 2017, a shallow (33km depth) earthquake with magnitude of 5.1M in Taik Kyi area, about 40 km north of Yangon, the earthquake has injured 26 people. It damaged at least 40 buildings including religious structures, government and private offices and the bridges. On 23rd September 2023, a shallow (10 km depth) earthquake with magnitude 5.1M, near Hlegu shook Yangon, Hlegu , Bago and some buildings in the Mawbi Township, which are near the epicenter, were also affected (Fig-5). Some significant earthquakes in and around Yangon area since 1930 are summarized and shown in Figure 6.

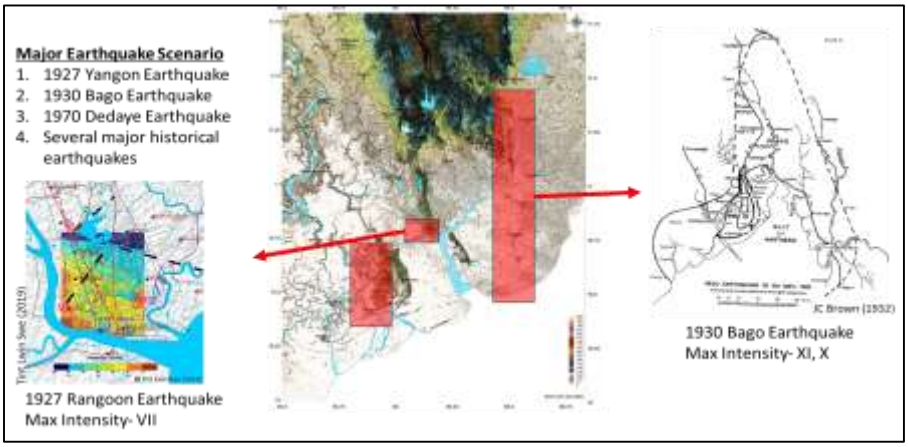


Figure 4. Earthquakes of Yangon Region- Historical Events

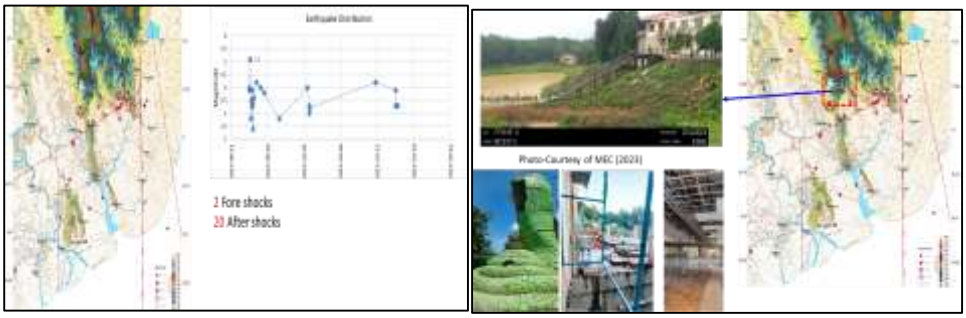


Figure 5. Earthquake events of 5.1 M (Hlegu) and Some damage at Mawbi

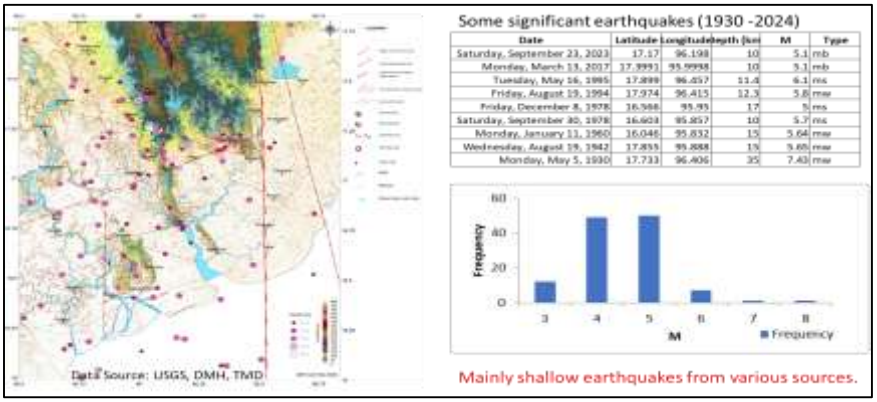
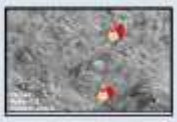
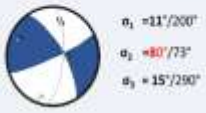


Figure 6. Significant earthquakes of Yangon Region (1930-2024)

Structural Analysis

Regional structural trends are generally in NNW-SSE to N-S, NW-SE and NE-SW directions. They may include older and younger fracture systems and regional stratigraphic trends including the West Bago Yoma and Thanlyin ridges. Lineament analysis suggests the maximum regional principle stress field varying from NNW-SSE to NNE-SSW direction. Boudin features are found in sandstone and shale interbedded near Thadugan Pagoda north of Yangon. Fault-related structural are parallel to the NNW-SSE regional stratigraphic trend; some show a dextral sense of shear and dextral oblique shear under NNE-SSW to NE-SW compression. The younger structural feature cut across the regional stratigraphic trend and older structural elements. Generally, the dipping of the beds and the structural dips are in the same eastward direction. At the northern part of the study area (N 16˚ 58’ 12.51’’, E 96˚ 6’ 12.11’’) east of Insein Township, it shows a dextral sense of shear in beds of the Besapet alternations. Sense of shear is vertical sigma σ_2 and orthogonal horizontal position of sigma σ_1 and sigma σ_3 under NE-SW compression. Near Thadugan Pagoda (N16˚ 59’13.03’’ E 96˚ 6’1.04’’), a dextral sense of shear is vertical sigma σ_2 and orthogonal horizontal position of sigma σ_1 and sigma σ_3 under NNE-SSW compression. At the south, beside the Thanlyin-Kyauktan car road (N16°39'45.40", E 96°19'15.72"), dextral sense of shear is observed on Thadugan sandstone showing vertical sigma σ_2 and orthogonal horizontal position of sigma σ_1 and sigma σ_3 under NNE-SSW compression. At southern part of Kyauktan Township (N16˚37’48"; E 96˚19’24"), a lateral oblique sense of shear on the NW trending nodal plane is obtained from of fault plane solution. The amount of maximum principle stress (σ_1 =45˚) is close to normal principle stress (σ_2 =60˚), which leads to the lateral sense of shear is followed by the oblique sense of shear and it is vertical sigma σ_2 and orthogonal horizontal position of sigma σ_1 and sigma σ_3 under NE-SW compression (Table -1).

Table 1. Interpretation of field survey and fault plane solution

No	Location	Rock type	Lower-hemisphere stereographic projection Shear sense interpretation	Principal Stresses orientation	Description
1.	N 16 ˚58’12.51’’ E 96 ˚ 6’ 12.11’’ near No.6 police station, Shwepyithar Tsp	 Besapet Alternation	 Dextral sense of shear	 NE-SW compressional field	Dextral (right lateral) shear sense under NE-SW direction σ_1 stress
2	N16˚59’13.03’’ E 96˚ 6’1.04’’ Thardugan , near Nat Nan	 Thardugan Sandstone	 Dextral sense of shear	 NNE-SSW compressional field	Dextral (right lateral) shear sense under NNE-SSW direction σ_1 stress
3.	N16°37'48" E 96°19'24" At Kyauktan Yay-lal Pagoda	 Obogone Formation equivalent	 Conjugate joint data show oblique slip shear sense	 NE-SW compressional field	Oblique shear sense under NE-SW direction σ_1 stress
4.	N16°39'45.40" E 96°19'15.72" Beside the Thanlyin-Kyauktan car road	 Obogone equivalent unit	 Dextral Sense of Shear	 NNE-SSW Compressional field	Dextral (right lateral) shear sense under NNE-SSW direction σ_1 stress

Generally, the strikes of faults mentioned in this area are approximately trending in N-S, NNW-SSE, NE-SW, and WNW-ESE directions. Field structural data also show right lateral and oblique reverse motion with the direction of maximum principle stress in NNE-SSW to NE-SW directions. In addition to field geological surveys, moment tensor solutions of significant earthquakes published by seismological centers are used to identify the nature of movement when the respective earthquakes happened. The recent events at the northern Yangon areas are found to be related to the WNW-ESE structural trend with an agreement of fault motion between seismic moment tensor and geological structural results (Fig-7). Several major geological lineaments are observed by distinct geomorphological expressions: some of them are often associated with earthquakes such as the Sagaing Fault in the east, the Dedaye Fault and faults near the Ma-u-bin area in the west, the Bago Yoma Fault, the Htan-ta-bin and Satthwartaw in the north and some cross faults in the Bago Yoma.

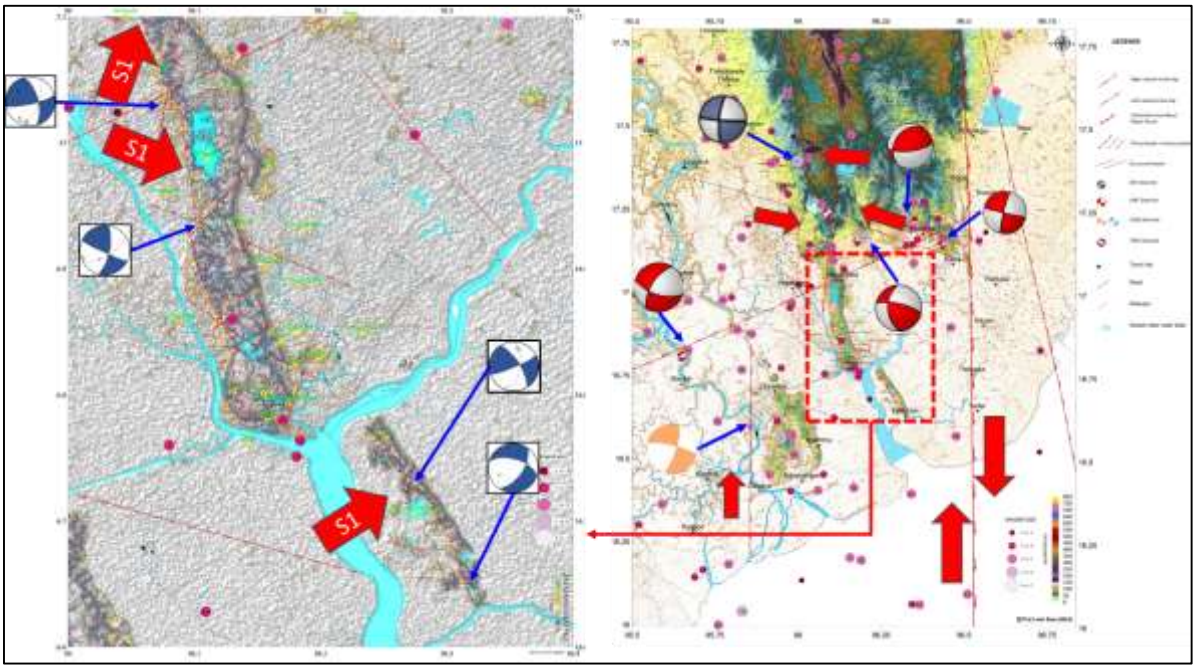


Figure 7. Fault Plane Solution and their related Fault Source in Research Area

Seismicity of Yangon Region

As a tectonically active region, significant earthquakes often occur in and surrounding Myanmar Territory. The distribution of magnitude, focal mechanism of earthquakes from 1923 to 2023, based on data available in the USGS earthquake catalog, DMH, TMD, GFZ earthquake data and related seismic sources are summarized in Figure (8).

Generally, an earthquake with equals or greater than 6 magnitude scale trembles in this region every year including the Andaman-Nicobar Islands. High seismic activities are related to mechanism of subduction and collision between the India plate and the Burma Plate, especially in the north, west and north-western parts of Myanmar as well as along the Sagaing Fault in the central Myanmar (Win Swe, 1981). Further south, the Sagaing Fault and its associated structures play crucial role for seismic hazard for the Yangon Region.

Focal mechanism interpretation indicates that majority are related to strike-slip motion especially related to NW-SE, NE-SW and N-S trending faults, and some oblique-slip (lateral shear together with reverse or normal) motion along NNW-SSE trending faults (Table-2).

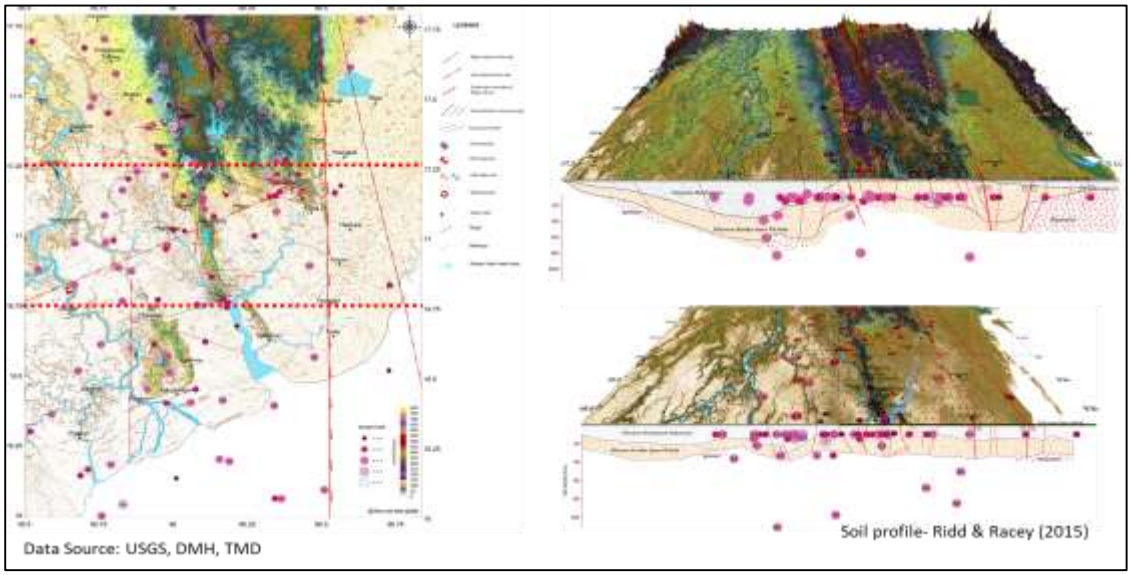


Figure 8. Generalized cross-section together with seismicity and their source structures

Table 2. Focal- mechanism solution of significant earthquakes in Yangon Region

Date	latitude	longitude	depth	M	Source	Picture	str1	dip1	rake1	str2	dip2	rake2	f1	f2
9/30/1978	16.603	95.857	10	5.7	USGS		17	76	-168	284	78	-14	strike-slip	left lateral strike-slip
3/13/2017	17.45	95.91	15	5.1	GFZ		95	87	-12	185	77	-176	left lateral strike-slip	strike-slip
6/7/2023	16.648	95.462	13	4.9	TMD		108	64	-29	211	64	-151	normal left-lateral oblique	normal right-lateral oblique
8/21/2023	20.462	94.454	20	4.8	TMD		128	44	-90	308	46	-90	pure dip-slip normal	pure dip-slip normal
9/25/2023	17.199	96.343	10	4	TMD		83	72	110	214	27	45	right lateral strike-slip	reverse left-lateral oblique
9/23/2023	17.17	96.198	10	5.1	TMD		283	74	44	178	48	158	reverse left-lateral oblique	rerverse right-lateral oblique
10/29/2023	20.021	94.251	20	4.5	TMD		104	90	-155	14	65	0	normal right-lateral oblique	pure strike-slip
11/23/2023	17.168	96.435	10	4.1	TMD		103	88	-6	193	84	-178	left lateral strike-slip	strike-slip

Data Source: USGS, TMD, GFZ

Majority are in strike-slip motion

Seismic Source of Yangon Region

There are many possible seismic sources around the Yangon Region (Tint Lwin Swe, 2018) which are summarized below;

- The Bago segment of the Sagaing Fault- the important seismic source in the region which has sufficient size to generate a large magnitude earthquake and it has well-established

long earthquake history. Earthquakes in 1917 and 1930 Bago earthquakes were reported severe damage of Bago and Yangon cities.

- The Thanlyin Fault- the northwest trending structure seems a subsidiary of the Sagaing Fault. Some small magnitude earthquakes were recorded occasionally in this area, but the mode of faulting is not clear.
- The Dedaye Fault- located in the west of Yangon. The earthquakes with magnitude 5.7, 6.0 and 5.7 in 1970, 1991 and 2004 respectively were related to this strike-slip source.
- The West Bago Yoma Fault- Long, persistent and prominent structure at the north of Yangon. Recently, an earthquake with magnitude 5.1M jiggled near Taikkyi, giving minor damages.
- Satthwartaw Fault -located in the north of Yangon. The earthquakes with magnitude 5.1 and 20 aftershocks respectively were related to this strike-slip source.

Further to the above summary, some concealed faults in the Ayeyawady Delta and off-coast of Pyapon and some faults of the Yangon shall be included in account of geomorphological studies and recently recorded seismicity.

Based on the size of each active lineaments and areas and seismicity pattern, the potential of earthquake from each seismic source can be indicated in Figure 10, from which the Sagaing Fault may cause the major earthquake potential to this region.

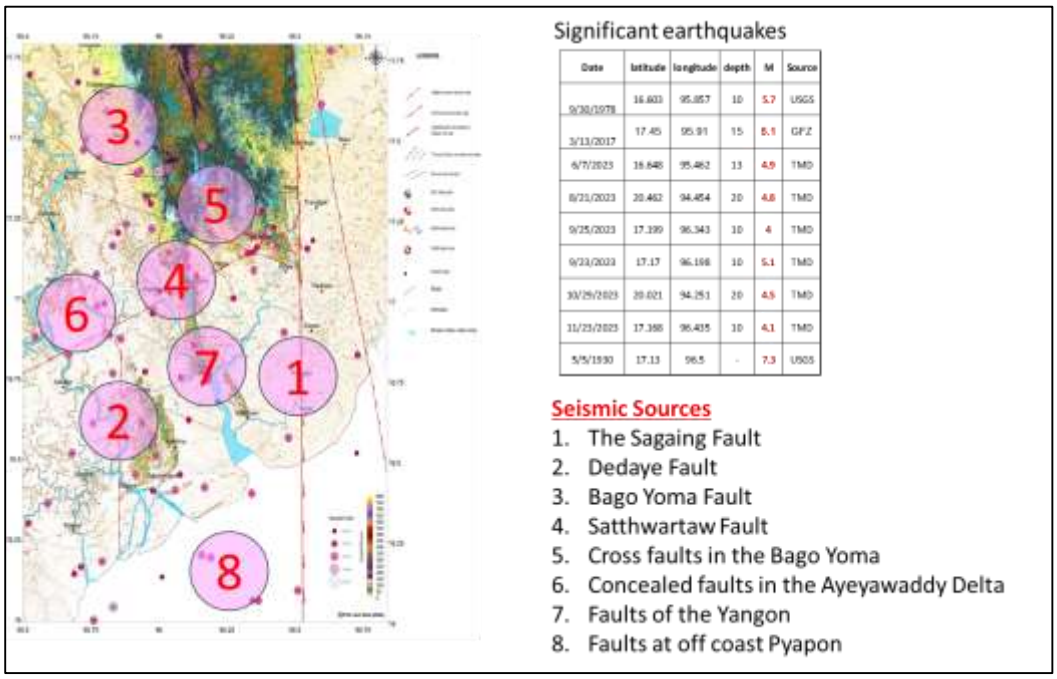


Figure 9. Significant earthquakes and Seismic Sources of Research Area

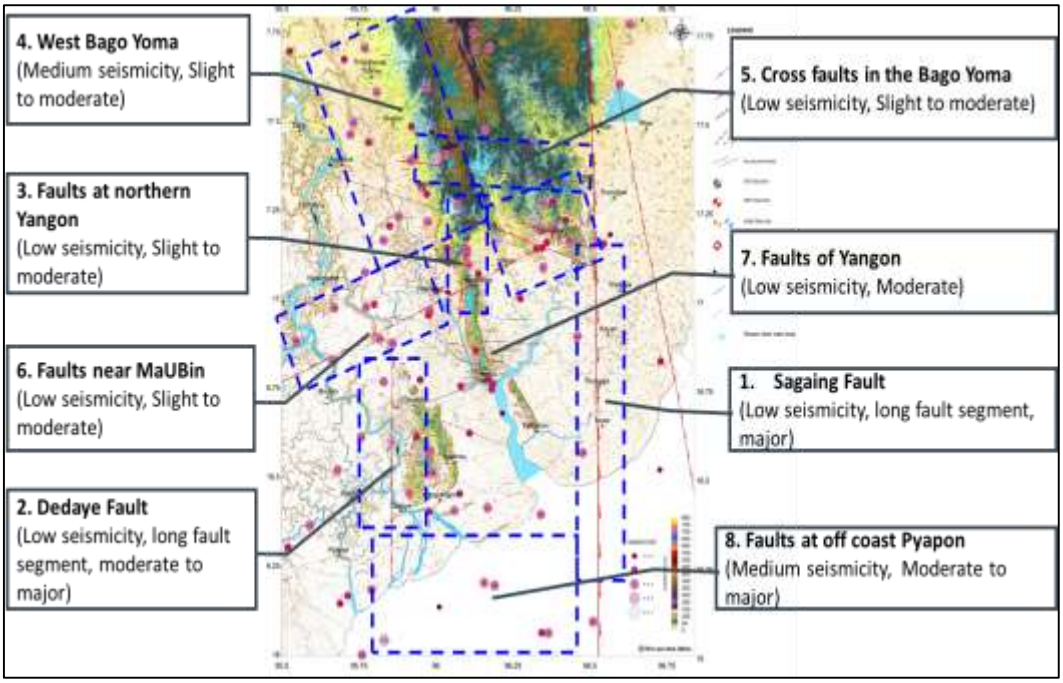


Figure 10. Earthquake Source and Potential of Research Area

Summary and Conclusion

Geology and field survey indicate geological structures including the well-known Sagaing Fault in the east, east dipping Bago Yoma Fault; apparently, extends to the Yangon Ridge. Generally, the observed faults have strikes of approximately N-S, NNW-SSE, NE-SW, and WNW-ESE directions. Field structural data show right lateral and oblique reverse motion with the direction of maximum principle stress in NNE-SSW to NE-SW directions. The cross faults are also observed from geomorphological and field survey; some of them are associated with minor earthquakes. Majority of recorded earthquakes are shallow and often associated with strike-slip and minor oblique reverse fault movements. It is due to east-west convergence and northward movement of the shallow igneous basement below the Bago Yoma and Ayeyawaddy Delta along the Sagaing Fault. There are total 8 earthquake sources identified in this area and each of them can give slight to major earthquake potential in this region.

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