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The 2020 M 5.9 Falam Earthquake the Subduction-Induced Strike-Slip Earthquake, West Myanmar

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Author's contribution

The sole author designed, analysed, interpreted and prepared the manuscript.

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ABSTRACT

An earthquake with magnitude 5.9 occurred in the east of Falam on 16th April, 2020 at 11:45:23 (UTC). The epicenter is situated at latitude 22.789°N, longitude 94.025°E, 38 km ESE of Falam, at the depth of 10 km. Focal mechanism solution for this event is normal faulting (USGS). The epicentral location is in the Kabaw Valley along which Kabaw fault runs through in N-S direction. The Kabaw fault is situated in forearc region at the eastern base of N-S trending Rakhine Western Ranges under which the India oceanic plate is obliquely subducting beneath the Burma continental plate. The 2020 M 5.9 Falam earthquake occurred along two closely linked tectonic settings: north-eastward oblique subduction zone and north-south trending Kabaw fault zone system in the forearc region.The Falam earthquake ruptured the Tripura segment, one of the segments of India subduction zone, located approximately between latitude 22°-24°N according to the geographical location. This event is a rare intraplate earthquake and a subduction-induced strike-slip earthquake that ever occurred for the recent time in Myanmar. The shock was felt by cities of Gangaw, Kalemyo, Kalewa, Mandalay, Kyauk-se, Monywa. This earthquake was preceded by a loud sound and shaking lasts 1 minute. A few aftershocks of magnitude >3.5 followed the main shock in the vicinity of the epicenter. The vibration spread a wide area along Rakhine Yoma and Myanmar lowland area. The investigation of field survey from social media was found that the event reaches Modified Mercalli Intensity scale VIII based on people's perception, indoor effects and damaged buildings. Damage is severe in some poorly built structures and upper parts of stupa and pagodas.

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1. INTRODUCTION

The town Falam is situated on the Chin Hills in the west of Myanmar. The valley is covered by Holocene alluvium in the north up to Kalaymyo area, and southward up to the Gangaw-Tilin area (Myittha Valley). The Kabaw valley is fairly wide fault zone occupied by valleys-filled Pliocene-Pleistocene non-marine deposits. The Kabaw Fault forms a major tectonic boundary between the accretionary sedimentary wedge of the Rakhine Western Ranges and strata of forearc assemblage of the Central Myanmar Basin. The Kabaw fault can be traced from Latitude 27°N-longitude 96°E (Hukawng basin) to latitude16°N-longitude 94°15'E (Heingyi island) for 1100 km length in N-S direction. The northern end of the fault is approximately at 26°N-96°E, in the east of Sarameti Peak and extends to the south from west of Tamathi and Homalin, then passes between Paungpyin-Tamu and Kalemyo-Kalewa. It continues to the south along the Chin Hills and Rakhine Hills. At the latitude of Pyay, the fault gradually swings to SSW and extends along the west margin of Ayeyawady Delta basin.

Finally it ends at Heingyi Island in the south. The fault extends to the point of 16°N-94°E Heingyi Island in Myanmar territory and then continues to West Andaman fault.

2. TECTONIC SETTING

Tectonically Myanmar is made up of a mosaic of tectonostratigraphic terranes: four tectonic terranes and three accreted belts [1] (Fig. 1). Among them, the Rakhine Western Ranges is consist of Naga Hills, Chin Hills, and Rakhine Hills for 1100 km length in the western part of Myanmar.

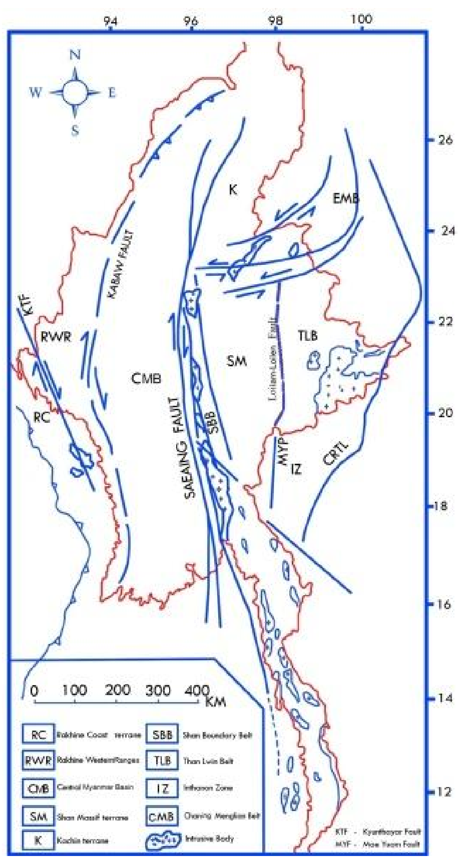

Fig. 1. Tectonostratigraphic Map of Myanmar showing 4 terranes and 3 accreted belts with their demarcating faults between each of them

The Rakhine Western Ranges (Indo-Burman mountain ranges) was produced by the collision of the India plate and the Burma plate during late Miocene and a large amount of the motion is driving the uplift of the Rakhine Western Ranges to become the boundary between the Indian and Burma plates, north of the Sumatra–Andaman subduction zone. The 1100 km length of Rakhine Western Ranges in west Myanmar region is seismically active due to continued northeastward convergence of the India plate beneath the Burma plate along the Sunda Subduction. This convergence began approximately 75 Ma [2] and was associated with the closure of Neo-Tethys Sea. Global Positioning System measurements indicate that the relative motion between the Indian and Sunda plates is 35 mm/yr [3]. The Rakhine Western Ranges are called with different name at different geographic location as: the Arakan Yoma in the south between 17°-22°, the Chin Hills in the middle between 22°-24° and the Naga Hills in the north between 24°-27°. 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 [2]. Northward and northeastward movement of India oceanic crust is the most important part for tectonics of Burma in Tertiary time.

The Rakhine Western Ranges is composed of a series of parallel ranges starting from the Patkoi Ranges in the north and continues to the south to Negrais Point. The mountain belt is broad in the north and narrows southward. The strata are folded in N-S, attaining the height of 5000-8000 feet. The highest peak is Saramati, rising 12663 feet above the sea and Mt. Victoria (Natma Taung) is 10400 feet. Structural trend swings from the NE-SW direction in the Naga Hills to NW-SE along the Rakhine Range and Chin Hills (Fig. 2).

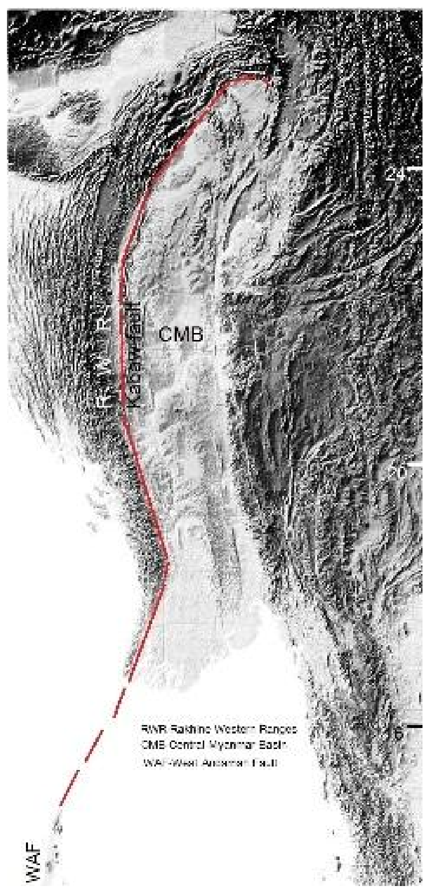

Fig. 2. A topographic satellite image showing physiographic features of Myanmar and the Kabaw fault at the eastern base of Rakhine Western Ranges, which demarcate from Central Myanmar Basin

3. GEOLOGICAL BACGROUND

The interpretation of satellite imagery, topographic map and aerial photograph has been carried out to better understand the relation between seismicity and tectonics. To better understand the seismic hazard of the fault, the surface trace of the fault has been mapped by interpretation of Landsat TM images and shaded relief map. Myanmar is composed of seven tectonic terranes in which Rakhine Western Ranges defines the western parameter of western Myanmar with 1100 km length. These ranges strike NE-SW in the north, N-S in the middle and NNW-SSE in the south. A major fault zone which was given a name as the Kabaw fault between the Rakhine Western Ranges and Central Myanmar Basin has been running along the eastern foot of Rakhine Western Ranges. The fault zone run from a region of East Himalayan Syntaxis and then extend southward passing through the Kabaw Valley between Kale and Kalewa. The elongated shape of Kabaw valley follows the fault trace from Thannan to Gangaw for 360 km with major rivers of Maw, Myitha, and Yu Rivers (Fig. 3).

Previous workers have mapped this distinct lineament both in the field and on satellite images as a major fault. Dr. L.D. Stamp (1922) first noticed the existence of a great line of dislocation at the foothills of Rakhine ranges (Arakan Yoma) [4]. Images of 2D and 3D seismic profiles acquired in the western highland area of Myanmar between latitude 19° to 21°30’N and longitude 94° to 94°30’E, revealed that the Kabaw Fault presents as a high angle reverse fault zone which includes discontinuously distributed with four major reverse faults namely Handauk reverse fault in the west, Dudawdaung reverse fault in the center and west Ngahlaingdwin fault and east Ngahlaingdwin fault in the north [5]. Recent seismicity data provides on deformation of the Kabaw fault. Location of earthquake epicenters and focal mechanism solution indicate that the movement of the Kabaw fault gives oblique reverse faulting with a right lateral strike-slip component (Table 1). In the north of Rakhine Western Ranges, the Kabaw fault seems to correspond to the Western Naga Fault [6].

4. THE SUBDUCTION - INDUCED STRIKE-SLIP EARTHQUAKE

An earthquake with magnitude 5.9 occurred in the east of Falam on 16th April, 2020 at 11:45:23 (UTC). The epicenter is situated at latitude 22.789°N, longitude 94.025°E, 38 km ESE of Falam, at the depth of 10 km (Fig. 4). Focal mechanism solution for this event is normal faulting. Detailed investigation of recent earthquake activities associated with the down-going India slab was carried out by drawing a cross-section across the Myanmar region with surface profile and the focal mechanism solution of seven significant earthquake events are plotted (Fig. 5).

Fig. 3. Google Earth Map showing Kabaw Valley associated with Kabaw fault and the valley appears to represent the fault zone. The Maw, Myitha and Yu Rivers are flowing along the trace of the fault in the valley

Fig. 4. Google Earth map showing epicentral location of Falam earthquake (yellow pin)

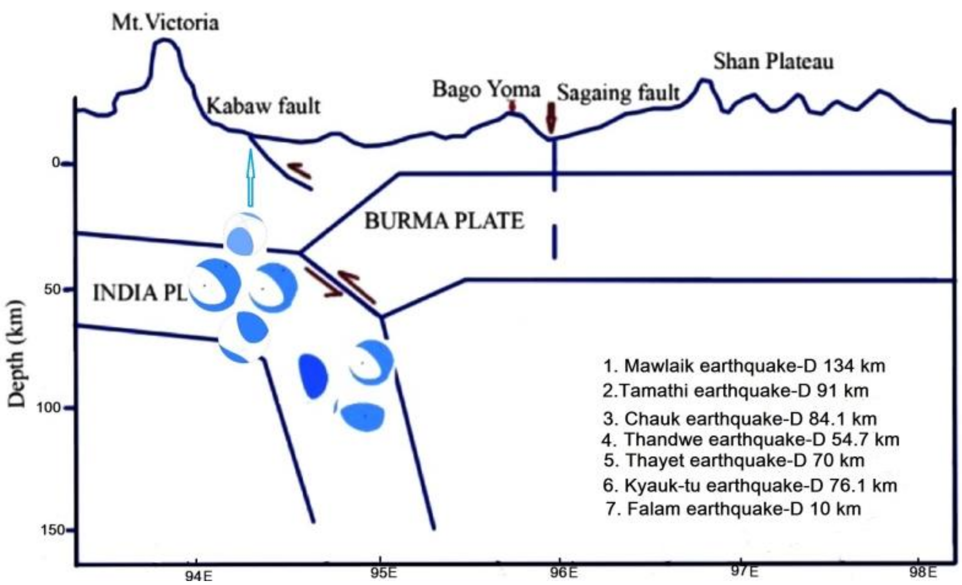

Fig. 5. A cross-section along latitude 21°N showing relation between forearc area of overriding plate and outer rise area of India-Burma subduction zone with focal mechanism of significant earthquakes and geometry and structure India-Burma subduction zone

When plotted the epicentral location of this Falam earthquake on the Google Earth map, it is found in the Kabaw Valley (Fig. 4). The focal depth of the event is 10 km. In the geometry and structure of the India-Burma subduction zone [7], it is found that the Kabaw fault is high-angle reverse fault and it terminates at shallow depth (20-30 km) against the subduction zone interface. The Kabaw fault is a right-lateral strike-slip fault along which Rakhine Western Ranges shifted towards the north as a result of the Indian plate motion [6]. The Kabaw Fault appears locally very steep in attitude, but in most places it dips moderately to the east as indicated by the broadly arcuate, but highly irregular on finer scale, course and by local imbricate structures [8]).

Table 1. Shows parameters of recent earthquake events: date, time, epicenter location, magnitude, depth and their focal mechanism solution

Serial	Name	Date	Time (UTC)	Epicenter	Focal Mechanism	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	Falam	19.5.2016	23:10:24 UTC	28 km SE of Falam		4.8	42km
4	Mawlaik 2	26.5.2018	11:42:23 UTC	23.004°N 94.608°E		4.5	95.3km
5	Mawlaik 3	24.4.2018	4:08:35 UTC	22.923°N 94.804°E	Thrusting	5.2	105.9km
6	Mawlaik 4	20.1.2018	10:00:06 UTC	23.89°N 94.702°E		4.2	85.5km
7	Thandwe 2	20.1.2018	4:00:05 UTC	18.24°N 94.06°E		4.0	
8	Monywa	3.12.2018	9:47:14 UTC	22.361°N 94.504°E		4.7	96.8km
9	Pyay	14.2.2018	7:14:01 UTC	18.724°N 95.251°E		4.7	81.4km
10	Chauk	29.4.2018	5:58:57 UTC	21.124°N 94.435°E		4.5	89.6
11	Monwya 2	26.6.2016	12:00	22.209°N 95.034°E		4.6	21.8km
12	Taunggup	27.3.2019	11:00:18 MST	18.88°N 94.14°E		4.5	10km
13	Haka	25.1.2019	4:06:03 MST	23.12°N 94.08°E		4.2	
14	Paung Pyin	17.3.2019	1:53:40 MST	24.02°N 94.59°E		4.8	84km
15	Chauk 2	24.8.2016	5:05 MST	20.919°N 94.579°E	Thrusting	6.8	84.1km
16	Mawlaik 5	13.4.2016	8:25 MST	23.133°N 94.900°E	Thrusting	6.9	134km
17	Kyauk-tu	19.11.2018	12:07 MST	21°30'N 94°23'E	Normal fault	4.9	76.1km
18	Thandwe 2	18.8.2019	03:38:15 UTC	18.486°N 94.609°E	Normal fault	4.7	54.7km
19	Thandwe 3	18.8.2019	03:24:23 UTC	18.487°N 94.511°E		5.3	40.3km
20	Shibweyan	26.8.2019	2:49:15 UTC	26.523°N 96.090°E		4.7	93.5km
21	Chauk 3	6.9.2019	10:09:49 UTC	21.189°N 94.650°E		4.8	98.9km
22	Bagan(Pagan)	8.7.1975	12:04:38 UTC	21.48°N 94.04°E	Thrusting	6.8	112km
23	Min Kin	10.10.2019	07:10:47 MST	22.75°N 94.47°E		4.1	84km
24	W. Thayet	26.11.2019	11:05:57 UTC	19.227°N 94.938°E	Normal fault	5.3	70km
25	W. Thayet	26.11.2019	9:36:12 UTC	19.263°N 95.024°E		4.7	76.48km
26	Homelin	29.1.2020	20:13:04 UTC	24.55°N 95.01°E		4.2	114km
27	Minbya	23.1.2020	9:48:05 MST	20.437°N 93.378°E		4.9	31.8km
28	NW.MKNa	28.6.2004	08:18:32 UTC	26.45°N 96.56°E		4.7	82.6km
29	Nagaland	3.6.2004	13:01:21 UTC	25.248°N 95.149°E		5.0	100km
30	W. Pathein	3.3.2020	18:54 UTC	17.612°N 94.290°E		4.7	35.5km
31	W. Pakokokku	6.9.2019	10:09:49 UTC	21.248°N 94.754E		4.7	101.6km
32	SW. Thayet	26.11.2019	09:38 UTC	19.2065°N 95.0277E		4.7	78.2km
33	ESE Falam	16.4.2020	11:45:25 UTC	22.789°N 94.025°E	Normal fault	5.9	10km
34	SE Gangaw	18.3.2019	16:54:30 UTC	21.97°N 94.51°E		4.6	60km
35	Tamathi	10.11.2016	7:30:15 UTC			4.8	91km
36	Homelin	7.1.2018	01:17:14 MST	24.756°N 94.9132°E	Thrusting	5.5	22km
37	W.Pathein	6.1.2018	22:56:57 UTC	17.715°N 94.380°E		4.1	35.1km

Deformation of the forearc region above subduction zones is impacted by the subduction process. Earthquakes that occurred within the forearc region, could be more destructive than the larger earthquakes on the subduction interface because of their shallow depth. Oblique subduction is qualitatively related to internal forearc deformation in the form of strike-slip faults, block rotation and along-arc extension or compression. Stress changes from individual subduction earthquake are ephemeral, their cumulative effects in the pattern of lithospheric deformation in the forearc region are significant [9].

A significant contribution to Coulomb stress increase on the strike-slip faults in the back region of the forearc comes from unclamping of the fault, reduction in normal stress due to reverse faulting on subduction outer-rise area. Unclamping the fault would have locally lowered the resistance to sliding. A reduction in normal stress on part of a fault could have increased the subsequent slip by lowering the fault friction [10].

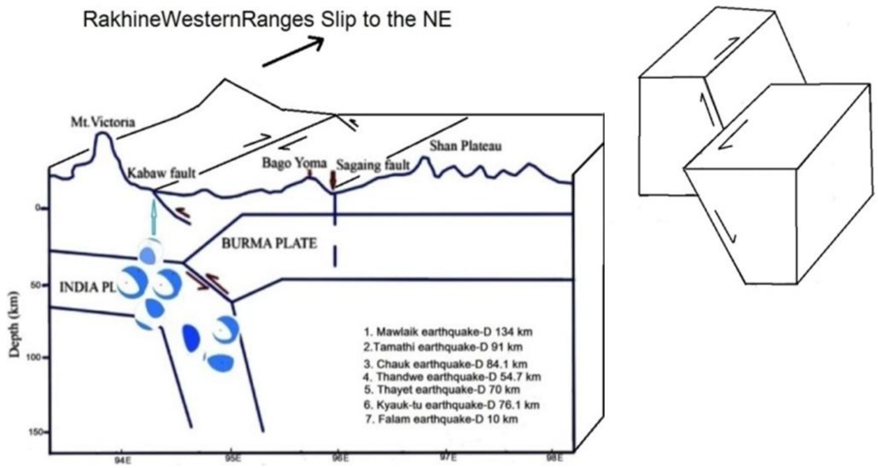

Fig. 6. Block diagram show structure and geometry of India-Burma subduction zone with surface features associated with tectonics of Rakhine Western Ranges.Mechanism of Falam earthquake has been shown with block diagram explaining compression and shearing by Kabaw fault movement

In region, earthquakes are generated in response to the bending of the lithosphere as it begins its descent. Bending, downward flexure of the lithosphere, puts the upper surface of the plate into tension and the normal faulting associated with this stress regime give rise to the earthquake which occurred to depths of up to 25 km [11]. Many major earthquakes that occur in the oceanic lithosphere near subduction zones are usually bending-related outer rise normal faulting earthquakes [12]. It is a result of a stress transfer from subduction zones into outer rise regions. However in some cases when plate motion is oblique to the trench, a forearc sliver moves separately from the overriding plate. This effect, called slip partitioning, makes earthquake slip vectors at the trench trend between the trench-normal direction and the predicted convergence direction, and causes strike-slip motion between the forearc and the stable interior of the overriding plate [13].

The epicenter of the Falam earthquake is located 38 km ESE of Falam in alluvial area of Kabaw Valley and the valley lies at the east of mountainous area of Rakhine ranges. The fault accommodates a mix of reverse and strike-slip fault motion during compressional earthquake movement. This is caused by a combination of shearing and compressional forces. This mechanism is a subduction-induced strike-slip faulting due to stress transfer from the subducting India plate to the overriding Burma plate (Fig. 6). The seismic waves have been amplified in the soft sediments leading to the strong shaking over much of the area. The Falam earthquake of 16th April, 2020 was very severe with heavy shaking near Falam and its neighboring cities. The shock was sharp and severe, lasted almost a minute. It was preceded by a loud sound and felt by cities of Gangaw, Kalae, Kalewa, Mandalay, Kyauk-se, Monywa, Gangaw. The houses rocked considerably and most of the pagodas were badly damaged. A few aftershocks of magnitude >3.5 followed the main shock. The earthquake spread a wide area along Rakhine Yoma and Myanmar lowland area. The investigation of field survey from social media was found that the event reaches Modified Mercalli Intensity scale VIII based on people's perception, indoor effects, and damaged buildings.

5. DISCUSSION AND CONCLUSION

Myanmar region has been tectonically active due to reorganization and interaction between India, Burma, Eurasia, Indochina and Australia plates. Recently the region has been experiencing subduction earthquakes in the Rakhine ranges and its environs as the India plate is obliquely subducting beneath the Burma plate. As shown in Table 1, several earthquakes with magnitude ≥4.5 and significant subduction earthquakes are occurring lately in western part of Myanmar. Among these events, on April 13th 2016, at 8:25 (Local Time) an earthquake of magnitude 6.9 (CMT determination) occurred at depth of 134 km, the moment tensor gives oblique reverse faulting. The 6.8 magnitude earthquake occurred on 24th August 2016 at deep depth of 84.1 km and focal mechanism solution of this event is gives compressional faulting in subducting slab of India plate. The main surface rupture zone of Mawlaik earthquake on the Tripura segment of the India-Burma subduction zone is approximately (250) km in length and the Chauk earthquake on Arakan segment is approximately (180) km, respectively. The 1975 M 6.8 Bagan earthquake occurred on 8th July 1975, with the depth of 112 km (ISC) and focal mechanism is thrusting. The January 2018 M 5.5 Homelin earthquake occurred on 7th January 2018, at the depth of 22.8 km. This event presents a thrust focal mechanism solution. The January 2018 Homelin earthquake is an interplate earthquake between subducting India oceanic plate and overriding Burma continental plate that occurred at shallow depth of 22.8 km. This event ruptured the Naga segment for a length of 200 km approximately. 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. An earthquake with magnitude 5.9 occurred in the east of Falam on 16th April, 2020, 38 km ESE of Falam, at the depth of 10 km. Focal mechanism solution for this event is normal faulting in outer rise region and oblique reverse faulting with a component of strike-slip faulting in forearc area. Due to the normal faulting mechanism in outer rise region of the down-going India oceanic plate, the stresses have transferred upward to forearc area of the overriding Burma plate. As a result, it has unclamped the pre-existing Kabaw fault to trigger the 2018 M 5.9 Falam earthquake with a strike-slip movement. Various advanced technologies and geophysical investigations are greatly needed to assess the future seismic potential for Myanmar region.

COMPETING INTERESTS

Author has declared that no competing interests exist.

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