# Digest of PhD Thesis

## A study on crustal deformation around the southern Sagaing fault and Arakan subduction zone, Myanmar, by using GNSS data

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## 1. Introduction

The Myanmar region is situated between the active junction of the plates: India, Eurasia, Sunda plates, and Burma microplate. There are two main structural controls for active tectonics in Myanmar, the right lateral strike slip Sagaing fault and the subduction of the India plate beneath the Burma microplate in the western part of Myanmar. The possibility of earthquake occurrence in the near future is very high due to the currently locked segments along the Sagaing fault and the Arakan subduction zone in the western Myanmar. New continuous GNSS (Global Navigation Satellite System) networks were constructed to solve seismological and tectonic structural problems along the southern Sagaing fault system and subduction zone in western Myanmar. The additional campaign GNSS data are also combined to estimate crustal deformation in this study. In this thesis, we revealed the interseismic deformation and strain accumulation process along the southern Sagaing fault system, characteristic of the coseismic fault of the Thabeikkyin earthquake that occurred in the central part of the Sagaing fault in 2012, active interseismic deformation along the Arakan trench subduction zone, and seismic potential based on geodetic studies along the Sagaing fault and subduction in western Myanmar.

## 2. Interseismic deformation along the Sagaing fault

The continuous data during 2016-2019 and additional campaign data in 1998, 2000, 2005, 2016, 2017, 2018, and 2019 were analyzed to reveal the current crustal deformation and estimate locking depths and slip rates of the Sagaing (SGs), Meiktila (MTLs) and Bago (BGOs) segments by inverting obtained deformation based on the 2-D dislocation model. Both continuous and campaign data are analyzed by using the GIPSY-OASIS ver 6.4 software in ITRF 2014. The estimated slip rate is 16 – 24 mm/yr along the central and southern segments of the Sagaing fault.

The estimated slip rate in the southern segment is slower than that in the central part. The slip rate and locking depth are the largest in the central part which is in the seismic gap area of MTLs. The peak of predicted maximum shear strain and dip direction shifts to the east in SGs, while to the west in the MTLs and BGOs segments. These results imply that twisting geometry at the central section of the fault's segments where may be related to the lack of seismicity in the central part of the Sagaing fault. The estimated potential magnitudes of earthquakes for each segment as of 2021 are Mw ~ 7.4 in MTLs, and Mw ~ 7.3 in SGs and BGOs.

## 3. Coseismic fault model for the Thabeikkyin earthquake

The coseismic fault model for the 11 Nov 2012, Thabeikkyin earthquake is estimated to understand the fault characteristic at the central segment of the Sagaing fault. The coordinates of seven continuous GNSS stations (i.e., SWBO, SDWN, HAKA, GYBU, IGLE, WAAW, and SATG) before and after the earthquake are utilized to construct a rectangular fault model. Two GNSS stations, SWBO and SDWN recorded significant coseismic displacement during the earthquake. The observed coseismic displacements show an asymmetric pattern, indicating right lateral strike slip on a dipping fault. The coseismic displacements of GNSS data and prior information of fault parameters from seismological and geological information are used to construct the coseismic fault model of the Thabeikkyin earthquake by applying Okada's (1992) elastic half-space dislocation model. The fault parameters are searched by applying a non-linear inversion method of Matsu'ura and Hasegawa (1987). The estimated coseismic rectangle fault is dipping eastward, which is coherent with the model for interseismic deformation for SGs.

## 4. Interseismic deformation for subduction zone along the Arakan trench

The GNSS data of four continuous stations from January 2018 to August 2021 and fourteen campaign stations in 2017, 2018, and 2019 are utilized to reveal interseismic deformation along the subduction zone of the Arakan trench in western Myanmar. The data at station LAUN in 1998, 2000, and 2005 by Vigny et al. (2003) and Maurin et al. (2010) is also included in this analysis. The velocities with respect to the Sunda plate are calculated by utilizing the Euler pole of the Sunda plate (Panda et al., 2020). Three-dimensional velocity components (i.e., EW, NS, and UD) with respect to the Sunda plate and prior information of fault parameters are used to construct the single- and two-fault planes with back slip by applying Savage's (1983) model. The estimated fault parameters are searched by applying a non-linear inversion method of Matsu'ura and Hasegawa (1987). The fault models of the single- and two-fault planes suggested that the back slip rate of ~17 – 24 mm/yr on the gently 9° dipping plate interface based on the currently available data. The estimated locked fault planes for both models are located in offshore areas, and they roughly explain the interseismic subsidence from previous studies. This analysis suggests that the subduction is still active along the Arakan trench and a large earthquake can be expected in western Myanmar in the future. The potential magnitude of the earthquake is expected to be Mw 8.4-8.5 along the Arakan trench by using a scaling relationship for the subduction earthquake [Strasser et al., 2010] and the parameters estimated from the GNSS data.

## 5. Discussion on earthquake potential along the Sagaing fault and Arakan trench

The probability of an earthquake is estimated for the SGs, MTLs, BGOs segments, and the Arakan trench for the next 30 years, 50 years, and 100 years by using the Brownian Passage Time (BPT) model. This probability calculation is mainly intended for a Mw >7.2 earthquake based on the previous historical records along the Sagaing fault and subduction. In this model, average recurrence, aperiodicity, and elapsed time from the most recent earthquake are considered to estimate the probability of the earthquake. An average recurrence interval is calculated from the seismic moment of the last earthquake which is divided by the moment accumulation rate estimated in this study. Aperiodicity is assumed to be 0.24 and 0.5. The calculated probability suggested that the BGOs and MTLs segments are the highest potential for a future earthquake based on the current analysis data.

## 6. Conclusions

We delineate the crustal deformation along the Sagaing fault's segments and Arakan subduction zone based on the currently available data in Myanmar. There are three main topics in this study. The following conclusions are key points of finding for the study area.

(1) This study confirms that the Shan plateau belongs to a part of stable Sunda land and the Burma microplate has its internal deformation including motion from the subduction in western Myanmar. The obtained slip rate is the highest in the central part and the lowest in

the southern segment of the Sagaing fault. The locking depth is the deepest in the central segment, MTLs which is in a seismic gap area. The peak of shear strain rate and direction of dip angle is shifted eastern side to the western side between SGs and MTLs across the seismic gap. That could be one of the reasons for the seismic gap in the central part of the Sagaing fault.

(2) The observed coseismic displacement of the 11 Nov 2012, Thabeikkyin earthquake shows an asymmetric pattern indicating that the right lateral strike slip along the Sagaing fault. It implies that this segment of the Sagaing fault may not be purely vertical. The east-dipping at SGs may be the implication of the intersection of the Sagaing fault, Momeik fault, and Shan scarp fault zone which are located on the eastern side of the Sagaing fault.

(3) The estimated back slip rate from the single and two-fault models suggests that subduction along the Arakan trench is still active with significant motion. The present study implies that some part of the motion between the India and Sunda plates along the Arakan trench has been accommodated by the India-Burma plate motion in western Myanmar. The lower edge of the locked part of the megathrust fault is located mostly offshore in both the single fault and two-fault models which is derived from the fault width estimated in this study. The expected potential magnitude of the earthquake is Mw 8.4-8.5 in the Arakan trench based on the currently available data.

Based on the key findings on the list above the following issues would be necessary to be addressed in future studies for the understanding of the crustal deformation along the Sagaing fault and subduction zone in western Myanmar.

(1) In this study, the 2D dislocation model is used for the calculation of crustal deformation along the Sagaing fault based on the available data. It is likely that several unmodeled sources affect the GNSS velocity field and add complexities. A three-dimensional model using realistic fault geometry will be carried out when data is available from a nationwide GNSS network for future studies. It is also needed to examine other geophysical data for verifying our suggested gradual 'twisting' or 'changing dip' of the fault between the SGs and MTLs segments along the Southern Sagaing fault system.

(2) The estimated slip rate in BGOs at the southernmost segment of the Sagaing fault is significantly slower than that in the central part. And estimated dip angle shows shallow

west-dipping at BGOs in this analysis. However, it is not clear where the remaining slip along the southern section is accommodated. It is still necessary to obtain additional information by constructing new stations in and around this segment.

(3) It is still needed to densify the GNSS stations along the remaining segment of the Sagaing fault's segment; Nay Pyi Taw (NPTs) and Phyu (PYUs) segments for understanding the characteristics of the fault along strike. Additional surveys and analyses are needed to improve the understanding of the behavior of the subduction along the Arakan trench in western Myanmar where effects of subduction are prevailing.

(4) The additional geophysical studies and data (i.e., microseismicity, gravity and magnetic data) are required to reveal detail along the Sagaing fault and subduction along the Arakan trench for future studies.

## Citation for published work

Results in Chapter 2 have been published as follows:

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