HYPOCENTER RELOCATION AND MOMENT TENSOR ANALYSIS OF EARTHQUAKES IN MYANMAR: TOWARD THE INVESTIGATION OF THE BURMA SUBDUCTION-SAGAING FAULT SYSTEM

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ABSTRACT

For understanding tectonics and precise earthquake hazard assessment, the detail analysis of hypocenters and moment tensor are necessary. First, present study determined the moment tensor solutions around Myanmar using teleseismic body wave form by the inversion program by Yagi. Moment tensor solutions obtained in this study are almost consistent with the global CMT solutions. The general orientations of P-axis for shallow earthquakes are consistent with the NNE direction of the Indian plate motion with respect to the Eurasian plate. Next, we relocated hypocenters in and around Myanmar, using the modified joint hypocenter determination (MJHD) method developed by Hurukawa and Imoto. This technique allows us to relocate many events simultaneously in order to improve hypocenter location compared with ISC hypocenters; the MJHD method gave the surprisingly clear features of seismicity. Along the Burma arc, the hypocenters are concentrated on narrow inclined zone. The results show the configuration of the subduction zone. Also we clarified the features of seismicity along the inland fault zone. The Sagaing fault system is located at the area where the cut-off depth of seismicity becomes shallower and the strength of the crust is weaker. Furthermore, we found that the earthquakes are concentrated on the active spreading axis and transform fault in the southern opening region. The results give us new constraints on understanding tectonics in and around Myanmar.

Keywords: Moment tensor inversion, Hypocenter relocation, Burma subduction, Sagaing fault

INTRODUCTION

Myanmar is located at the very active tectonic area which includes the Burma oblique subduction, the Sagaing strike slip fault system and the southern opening region. For understanding the tectonic features of Myanmar, we determined the moment tensors using the body wave form inversion. The focal mechanism bears information on tectonics around the earthquake source region: plate motion and the tectonic stress which causes the earthquake. Seismic moment M_o represents the size of an earthquake. Hypocenters will be useful for determining the subduction interface. Along the Burma subduction zone, there is a high potential for occurrence of large tsunamigenic earthquakes. Therefore, we need to urgently determine the location of the subduction interfaces. The purpose of this study is to confirm the plate boundary between the Indian plate and Eurasian plate along the subduction zone and to understand the tectonic features in Myanmar.

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DATA

Moment tensor inversion

We retrieved data from the Data Management Center of the Incorporated Research Institution for Seismology (IRIS-DMC) via internet. In this study, we analyzed only teleseismic body wave (P-waves) from 54 events in the range of Latitude between 8.00° N and 30.00°N and Longitude between 90.00°E and 102.00°E with the body wave magnitude (M_b) above 5.5.

Hypocenter determination

In this study we used the earthquake phase data from International Seismological Center (ISC) catalog from January of 1980 to December of 2004. The data include the P-arrival times from worldwide stations.

THEORY AND METHODOLOGY

Moment tensor inversion

We represented the seismic source process as point source model. We can write the vertical component of the seismic waveform at the station j as

$$u_j(t) = \sum_{q=1}^{6} M_q \int G_{jq}(t-\tau, x_c, y_c, z_c) T(t) d\tau + e_o + e_m \quad \text{..................} \ (1)$$

where G_{jq} is the complete Green's function, M_q is the moment tensor at centroid of source (x_c, y_c, z_c), $T(t)$ is source time function, e_0 is observation error, and e_m is modeling error. Also we can write this equation in simple vector form as.

$$\mathbf{d} = \mathbf{G}(T(t), x_c, y_c, z_c)\mathbf{m} + \mathbf{e} \quad \text{..} \ (2)$$

where $\mathbf{d}$ is the observation waveform, $\mathbf{G}$ is the convolution Green's function with source time function and $\mathbf{m}$ is the moment tensor solution.

Moment tensor inversion needs an assumption of location of hypocenter and information of source time function (duration, shape). We determined the depth of hypocenter and duration and shape of source time function by grid search method. In this study, we used the prem-modify-model velocity structure to find the moment tensor solution. We calculated the Green's function and performed body waveform inversion using programs developed by Yagi (2004).

Hypocenter determination

The equation which is used in the determination of hypocenters is as follows.

$$(O-C)_{ij} = (t_{ij} - To_{oj}) - T_{ij} = \frac{\partial t_{ij}}{\partial x_j} dx_j + \frac{\partial t_{ij}}{\partial y_j} dy_j + \frac{\partial t_{ij}}{\partial z_j} dz_j + dTo_j + dS_i \quad \text{..............} \ (3)$$

where t_{ij} and T_{ij} are the arrival times and the calculated travel time of the j-th event at the i-th station, respectively. dS_i is a correction of a station correction at the i-th station. To is the origin time. O is the observed travel time. C is the calculated travel time. dx, dy, dz ant dTo are the corrections to the trial hypocenter

Due to the heterogeneous earth's structure, when the station coverage is not good, the JHD solutions become unstable and unreliable because of the trade–off between station corrections and focal depths of earthquakes. For this reason, Hurukawa and Imoto (1990, 1992) developed a modified joint hypocenter determination (MJHD) method using the constraints below.

$$\sum_{i=1}^{n} S_i D_i = 0 \qquad \sum_{i=1}^{n} S_i \cos\theta_i = 0 \qquad \sum_{i=1}^{n} S_i \sin\theta_i = 0 \qquad \sum_{i=1}^{n} S_i = 0 \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \text{(4)}$$

where S_i is the station correction at the i-th station, D_i is the distance between the i-th station and the center of the region, θ_i is the azimuth to the i-th station from the center of the region, and n is the number of stations.

RESULTS

Moment tensor inversion

In this study, we determined moment tensors to understand various behavior of tectonic and related effect in the region near the subduction and active fault area. We analyzed the 54 events for moment tensor inversion and compared our results (Figure 1) with those from global CMT. Also we used the grid search method developed by Yagi (2004) to find out the best depth and source duration with the minimum variance. Generally almost all the results of moment tensor inversion are consistent with the global CMT results. But some of the results are different in depth and seismic moment from those of global CMT. One of the reasons is that we used the body wave although global CMT is determined using long-period wave. We found that the focal mechanism solution from moment tensor inversion is in agreement not only with global CMT solution but also with the previous studies for regional tectonic setting. According to the generation orientation of P-axis from focal mechanism solution, the direction of P-axis is the same as the Indian plate motion (Figure 2). So this result is consistent with the other results of the Indian plate motion.

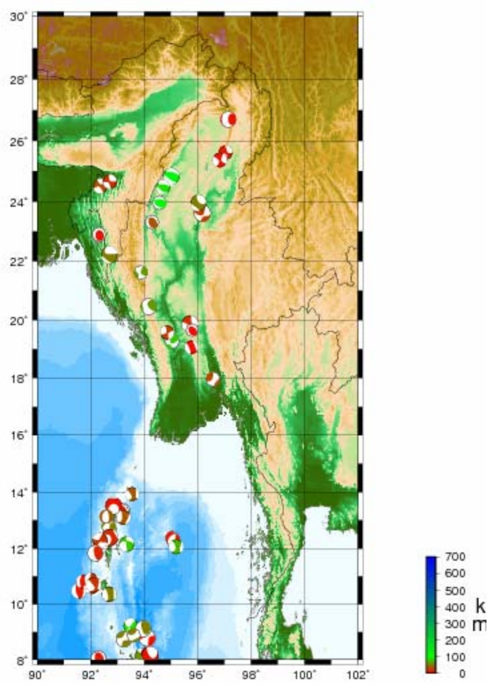

Figure 1. The results of moment tensor inversion.

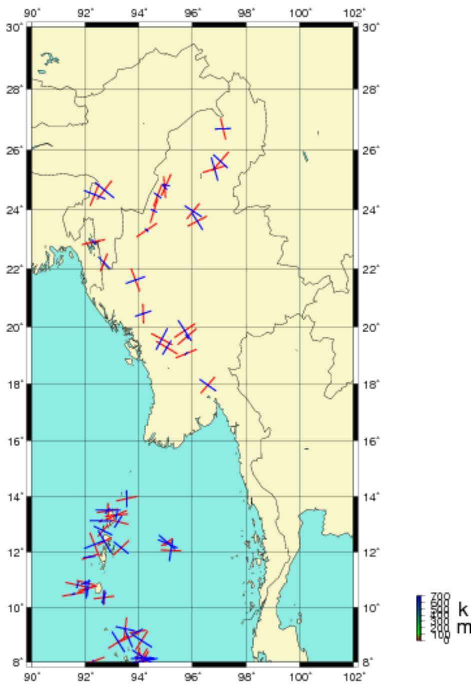

Figure 2. General orientation of P-axis and T-axis.

Hypocenter determination

We relocated the hypocenters for all the events that occurred in and around Myanmar and were obtained from ISC data catalog from 1980 to 2004 including all of the depth range. In this method, to make accurate location, it is better to take a small region with no significant variations in structures. If there is any strong variation in the velocity structures, the station correction strongly depends on the location of events. Therefore, we selected the several small regions for the analysis (Figure 3). Mainly, there are three regions: the Burma subduction zone, the region from the Burma subduction zone to Sagaing fault zone, and the Southern opening region.

Based on the two criteria, we selected the stations and events for each region. These two criteria are minimum number of stations (MSTN) and minimum number of events (MEVN). We remove phase data of which travel time residuals are larger than 2 seconds. To obtain the precise hypocenters, the epicentral distances of nearby stations were checked. There are valuable nearby stations for all events. Therefore absolute locations are reliable for all regions. The station corrections for all of events are almost same.

Seven regions from (A) to (G) are selected for the Burma subduction zone. The region between Latitude from 15.00°N to 24.00°N and Longitude 90.00°E to 96.00°E was included. Figure 4 shows the result in region (A). Before relocation all of events are scattering. (Figure 4a). But after relocation using the MJHD method some of the events are concentrated along the subduction zone and some are related with in inland earthquakes. In Figure 4b, the dotted line are represented the possible plate boundary which are in between Longitude around 91.0°E for this region. However, MJHD method gave the significant of the tectonic features for all regions.

Region (H), (I) and (J) are included in the area from the Burma subduction zone to the Sagaing fault. The tectonic features for those regions are similar each other. Figure 5 illustrates the result in region (I). In this region, we found that the earthquake clusters which seem to be foreshocks and aftershocks for a large event. Before relocation these events are generally at a depth of approximately 10 km and concentrated in horizontal distribution. But after relocation this earthquake cluster appeared at a depth between 0-50 km and down dip direction to the west. The epicenters are much concentrated in around the center of the cross section and seem to be distributed vertically. We can assume that this earthquake cluster seem to be the Taungdwingyi earthquake (M_w 6.6) which occurred at Latitude 19.90°N and Longitude 95.73°E on September 21st 2003. Moreover, four shallow earthquakes occurred just on the Sagaing fault.

The regions (K) and (L) are included in the Southern opening zone. In these regions the earthquakes clusters occurred systematically along the spreading axis and transform fault respectively. Figure 6 show that the MJHD hypocenter distribution for region (L).

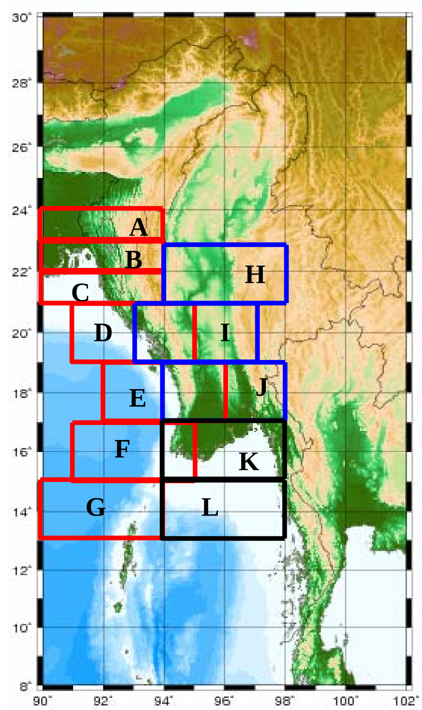

Figure 3. Map showing the 12 sub regions. The rectangulars (A-G) with red color include the Burma subduction zone, the rectangulars (H-J) with blue color include the Burma subduction zone to Sagaing fault and the rectangulars (K-L) with black color include the Southern opening zone.

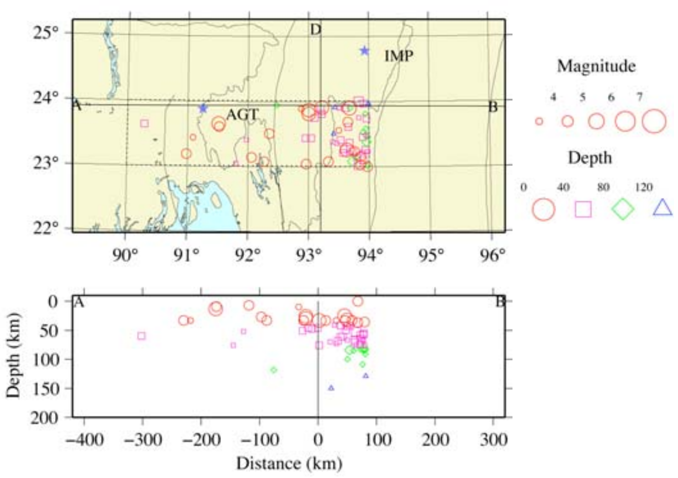

Figure 4a. ISC hypocenter in region (A). The epicenter distribution and two vertical cross sections along A-B and C-D lines are illustrated. A dotted rectangular in epicentral map indicates the epicentral area of selected earthquakes. The size of the symbols represents the magnitude of the events. The color and shape of the symbols denotes the depth range of the events

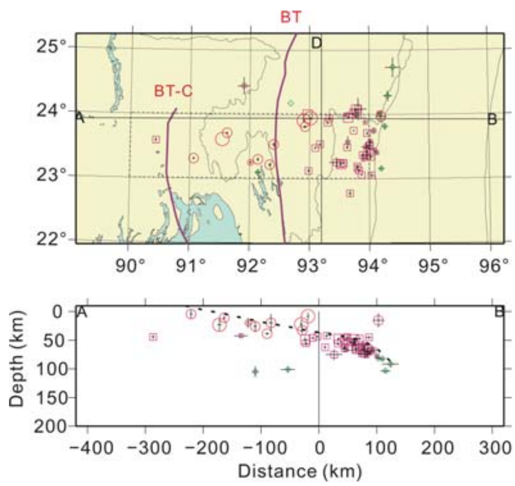

Figure 4b. Relocated hypocenters by the MJHD method in region (A). Cross represent the standard errors of hypocenters. The symbols are the same as in Figure 4a.

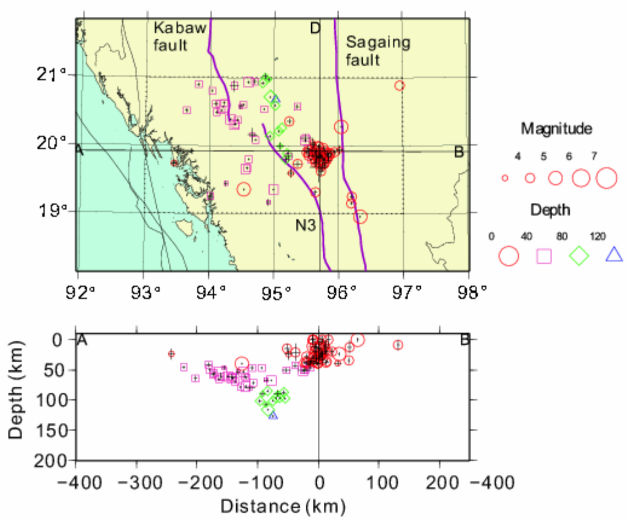

Figure 5. The relocated hypocenters by the MJHD method for region (I). The symbols are the same as in Figure 4b.

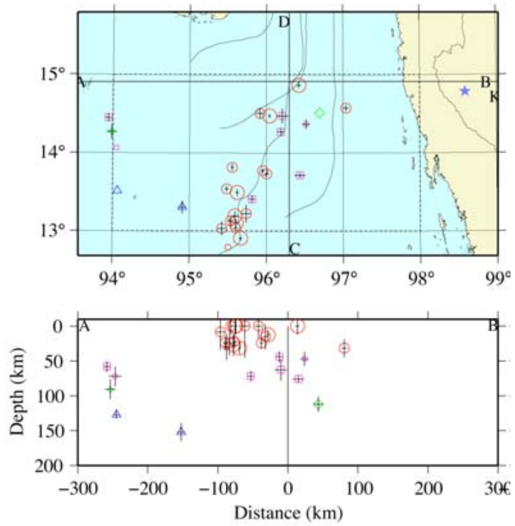

Figure 6. MJHD hypocenters for region (L). The symbols are the same as in Figure 4b.

5. DISCUSSION AND CONCLUSION

To investigate the tectonic setting around Myanmar, we obtained moment tensor solutions in and around Myanmar using the teleseismic waveform inversion code developed by Yagi (2004). We analyzed 54 events and compared the results with the solutions from global CMT. Some differences are seen in centroid depth and seismic moment between our result and global CMT solution. Those differences may be due to the difference in method for determining moment tensors. The P-axis determined in the present study is consistent with the NNE motion of Indian plate relative to Eurasian plate.

Since the subduction zone at the shallower part is not clear at the northern segment of the Burma trench. Depth ranges of seimicity become narrower after the relocations by MJHD. It's difficult to judge exactly where the plate boundary is. Around the deformation front suggested by Cummins (2007), seismic activity is quite low. Deformation front seems to exist on the east side of the suggested deformation front. The previous study by Khan (2005) analyzed the hypocenter distribution along the subduction zone using the ISC data between 1964 and 1999. Since the hypocenter distribution was very scattered, they could not get exact images of seismicity along the subduction zone. Our study got much improved hypocenter distribution which is useful for understanding the tectonics in Myanmar.

In the Burma subduction zone to the Sagaing fault, the hypocenters are relocated very well. There are two groups of earthquake hypocenter distributions. One is representing the subduction zone earthquakes, and the other one is related to the Kabaw and Sagaing faults. According to depth distribution of earthquakes, subduction zone earthquakes are located on intermediate depth. On the other hand, earthquakes near the Kabaw and Sagaing faults are located on the shallow depth. Before relocation, we can not clarify the accurate depth of earthquakes clusters. But after relocation, all of these earthquakes clusters are concentrated very well. These events seem to be aftershocks of the Taungdwingyi earthquake which occurred at Latitude 19.90°N and Longitude 95.73°E on September 21st 2003.

As to the Southern opening zone, before relocation, hypocenters of ISC are rather scattering. After relocations, hypocenters are clustering. To clarify the cause of seismic activity around this zone, we compared seismicity with the fault lines which are related with the Sagaing fault (Nielsen, 2004; Curry, 2005). We found that the two seismic activities occurs around Latitude 16.00°N and Longitude 95.70°E, and Latitude 15.00°N and Longitude 95.70°E and these are close to the fault lines drawn by Nielsen (2004). Hypocenters distribution from Latitude 13.00°N to 15.00°N follows systematically the active spreading axis and the transform fault which is the southern extension of the Sagaing fault, which is supported by Curray (2005).

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REFERENCES

Bhattacharya, P.M., Pujol, J., Majumdar, R.K. and Kayal, J. R., 2005, Current Science, 89, 1404-1413.
Cummins, P. R., 2007, Nature, 449, doi: 10.1038/nature06088.
Curray, J. R., 2005, Journal of Asian Earth Sciences 25, 187-232.
Hurukawa, N. and Imoto, M., 1990, J. Seism. Soc. Japan, Ser. 2, 43, 413-429.
Hurukawa, N. and Imoto, M., 1992, Geophys. J. Int., 109, 639-652.
Khan, P. K, 2005, Geo. Scie. Journal, 9, 227-234.
Nielsen, C., Chamot-Rooke, N., Rangin, C and the Andaman Cruise Team, 2004, Geology, 209, 303-327.
Rao, N.P., and Kalpna, 2005, Geophys. Res. Lett. , 32, L05301, doi: 10.1029/2004GL022034.
Sahu, V. K., Gahalaut, V. K, Rajput, S., Chadha, R. K., Laishram, S. S. and Kumar, A., 2006, Current Science, 90, 1688-1692.
Socquet, A., Vigny, C., Chamot-Rooke, N., Simons, W., Rangin, C. and Ambrosius, B., 2006, J. Geophys. Res., 111, B05406, doi: 10.1029/2005JB003877.
Yagi, Y., 2004, Earth Planets Space, 56, 311-316.
Yagi, Y., 2006, IISEE Lecture Note 2007-2008, IISEE, BRI.