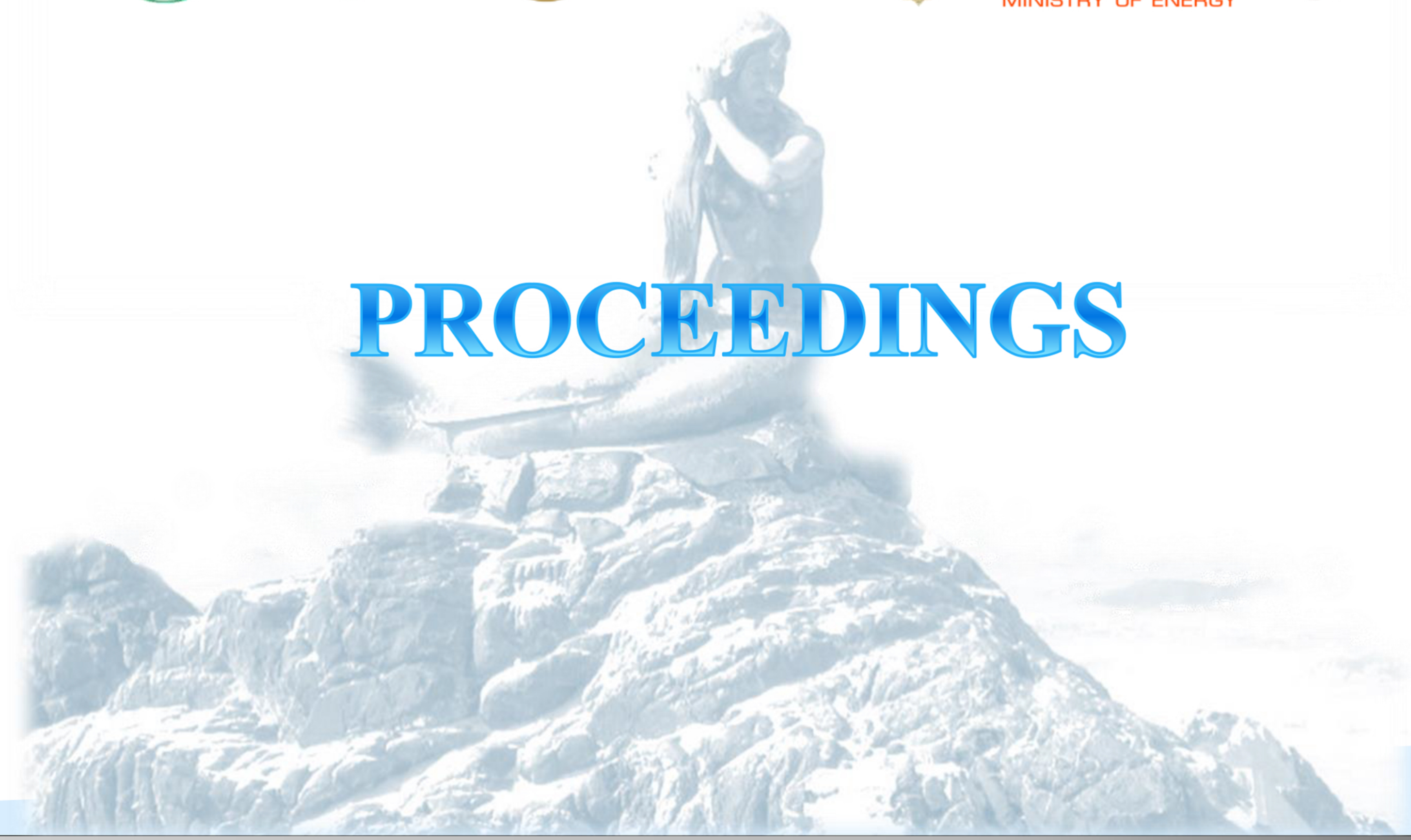
Geophysics
Songkhla, 2018

Prince of Songkla University

คณะวิทยาศาสตร์
มหาวิทยาลัยสงขลานครินทร์

The 8th International Conference on Applied Geophysics

Department of Mineral Fuels
MINISTRY OF ENERGY



PROCEEDINGS

8-10 November 2018
BP Samila Beach Hotel & Resort,
Songkhla, Thailand

Spatial Distribution of Shallow and Intermediate Earthquakes in Southern Thailand after the 26 December 2004 Sumatra – Andaman Earthquake

Dony Adriansyah Nazaruddin[1*], Helmut Duerrast[1]
[1]*Geophysics Research Center, Department of Physics, Faculty of Science, Prince of Songkla University, THAILAND*
(E-mail: donyadriansyah2704@gmail.com, helmut.j@psu.ac.th)

ABSTRACT- The observation of seismicity in Southern Thailand has been actively conducted in the aftermath of the 26 December 2004 Sumatra – Andaman Earthquake. In this study, seismogram records of 172 earthquakes were collected during 2005 to 2017 from two sources: A temporary seismological network operated by the Geophysics Research Center – Prince of Songkla University (GRC–PSU) in collaboration with the Department of Mineral Resources (DMR) with 111 earthquakes recorded by at least 3 stations in the region during January to April 2005; and Some permanent local stations of the Thai Meteorological Department (TMD) installed in the region recorded 61 events during 2010 to 2017. Some previous studies have analyzed earthquake data in the region to determine earthquake source parameters; however not the focal (hypocentral) depths. Therefore, the purpose of this study was to determine the focal depths and the spatial distribution of earthquakes in Southern Thailand. All available digital seismograms were processed and interpreted following standard procedures by using SEISAN software to produce information on source parameters (origin times, locations, magnitudes, and focal depths). Focal depths were obtained by using the software through iterations with the starting/trial depth of 15 km; then this depth was used to give the best fit to the data. All recorded earthquakes are considered local earthquakes which occurred onshore and offshore of Thai Peninsula within an area between 7°00'N to 10°45'N and 97°30'E to 100°45'E with local magnitudes ML -0.2 to 4.8 (micro to light earthquakes), including earthquake swarms in Phuket Island in 2012. This study also reveals that the hypocenters (focal depths) are located between 0 – 80 km deep where most of the events are categorized as shallow earthquakes and only a few as intermediate earthquakes. The lateral distribution of shallow-depth events within this region is scattered in and around two major fault zones in Southern Thailand, which are the Ranong and Khlong Marui Fault Zones; whereas intermediate-depth events are clustered in the western part of the region.

Keywords: Earthquakes, 2004 Sumatra–Andaman Earthquake, Southern Thailand, focal depth

1. INTRODUCTION

Southern Thailand, one of four regions and the southernmost part of Thailand, is surrounded by the Andaman Sea and the Gulf of Thailand in the west and the east respectively forming a part of the Thai Peninsula which extends south to the border with Malaysia. This region is tectonically located intraplate of the Eurasian Plate and regionally close to the Sumatra-Andaman Subduction Zone (about 600-800 km between the coast line to the plate boundary), which is the regional source of earthquakes. For local setting, there are a series of active fault zones mainly the Ranong and the Khlong Marui Fault Zones (RFZ and KMFZ) which, according to Duerrast et al. (2007), were considered as dormant by Thailand's Department of Mineral Resources (DMR) before the Mw 9.2 Sumatra-Andaman Earthquake on 26 December 2004.

Before the 2004 great earthquake, there was no or little awareness on seismic hazards in Southern Thailand until the region experienced the impact of the 2004 earthquake. Since then until now, seismic hazards and the potential for the movement and reactivation of existing faults and fault zones in the region have been studied. As stated by Morley et al. (2011), since the occurrence of the 2004 Sumatra-Andaman Earthquake, the two major faults and fault zones (RFZ and KMFZ) have attracted much attention from geologists, seismologists, and people from other related fields because of their increasing reactivation. Duerrast et al. (2007) conducted an earthquake study in the region and revealed that after the 26 December 2004 earthquake, the existing faults zones might be reactivated in a compressional stress regime, increasing the probability of higher magnitude earthquakes. Sutiwanich et al. (2012) concluded that Southern Thailand or Thai Peninsula is not tectonically stable anymore as had previously thought. Some other researchers have also analyzed earthquake data from this region to identify source parameters including origin times, locations, and magnitudes. However, there is still no study on the determination of earthquake focal depths (depths of hypocenters) in this region after the 2004 earthquake.

This study observed the seismicity in Southern Thailand from 2005 to 2017. Digital seismograms from 172 earthquake events in the region have been processed and interpreted according to standard procedures using the freely available SEISAN (Seismic Analysis) software to produce earthquake source parameters which include origin times, locations, magnitudes as well as focal depths. This paper also emphasized the determination of focal depths and their spatial distribution in this region.

2. TECTONIC SETTING AND GENERAL GEOLOGY

Southern Thailand is regionally affected by the interaction of the plate boundary between the India Plate and Burma Microplate (considered a part of the larger Eurasian Plate), one of most seismically active plate boundaries, mainly in the Andaman Sea. In local tectonic setting, the RFZ and KMFZ which cross the Thai Peninsula from Andaman Sea to the Gulf of Thailand in the relatively NNE-SSW direction are two prominent fault zones that have long and complex history extending back to Paleozoic Era (Morley et al., 2011; Figure 1a).

Geologically, the southern part of Thailand consists of a succession of Paleozoic and Mesozoic sedimentary and metamorphic rocks, intruded by Late Paleozoic to Mesozoic igneous rocks, and covered by Cenozoic sedimentary rocks or sediments. It has the main chain of granitic mountains which continues north into the Gulf of Thailand where it formed some islands. It has also a number of scattered and less linear granitic bodies (Ridd et al., 2011; Figure 1b).

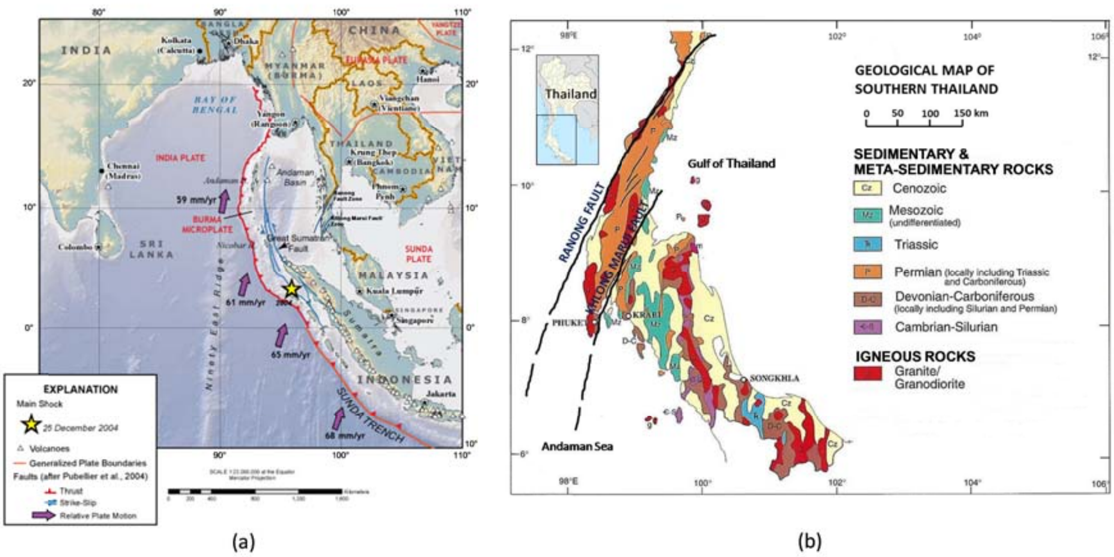


Figure 1. (a) Regional tectonic setting of Sumatra–Andaman subduction zone showing relative motion between the India Plate and the Burma Microplate, major fault zones, and location of the 26 December 2004 earthquake (Source: http://walrus.wr.usgs.gov/tsunami/sumatraEQ/tectonic.html); (b) Geological Map of Southern Thailand (Modified from Ridd et al., 2011)

3. DATA AND METHODOLOGY

3.1 Datasets

In total, there are 172 local earthquake events were used in this study and can be categorized into two datasets based on their sources. The first dataset was collected from a temporary seismological network comprising four short-period (SP) three-component (Z, N, and E) seismometers operated by GRC-PSU and DMR from January to June 2005 in Phang Nga (2 stations), Phuket (1 station), and Krabi (1 station). From numerous earthquakes recorded during the six-month monitoring, only those recorded by at least 3 seismic stations were selected for this study, which are 111 local earthquakes occurred between 14 January and 11 April 2005. The second dataset was taken from 10 permanent local stations in Southern Thailand operated by TMD. This dataset contains 61 local earthquakes occurred during 2010 – 2017 in the region. This study was carried out in Southern Thailand region, situated between latitude of 5°30’-12°30’N and 97°30’-102°30’E. Locations of all seismic stations used in this study are given in Table 1 and shown in Figure 2.

Table 1. Information on Seismic Stations for Earthquake Monitoring in Southern Thailand during 2005–2017 (for this study)

Data-set	Station No.	Station Code	Lat.	Long.	Location
1	1	PSUHY	8°26’3.48”N	98°30’24.48”E	Muang District, Phang Nga Province
1	2	PNG2	8°33’27.36”N	98°39’37.44”E	Thap Put District, Phang Nga Province
1	3	PSUNM	7°53’28.90”N	98°21’3.96”E	Prince of Songkla University, Phuket Campus, Khatu District, Phuket Province
1	4	TBK	8°23’20.28”N	98°44’10.46”E	Tanbokkoranee National Park, Ao Luek District, Krabi Province
2	5	KRAB	8°13’17.40”N	99°11’49.92”E	Krabi Province
2	6	PHET	12°54’47.92”N	99°37’36.30”E	Phetchaburi Province
2	7	PKDT	7°53’31.20”N	98°20’6.00”E	Phuket Province
2	8	PRAC	12°28’21.47”N	99°47’34.37”E	Prachuap Kirikhan Province
2	9	RNTT	9°23’25.44”N	98°28’40.08”E	Ranong Province
2	10	SKLT	7°10’24.60”N	100°37’7.68”E	Songkhla Province
2	11	SRIT	8°35’43.76”N	99°36’7.06”E	Nakhon Si Tammarat Province
2	12	SURA	9°9’58.82”N	99°37’46.02”E	Surat Thani Province
2	13	SURT	8°57’27.72”N	98°47’42.00”E	Surat Thani Province
2	14	TRTT	7°50’10.32”N	99°41’28.32”E	Trang Province

Reference: Duerrast et al. (2007), Vanichnukhroh (2013)

3.2 Methodology

In seismogram analysis, the first step was to identify the seismic phases associated with each earthquake and to determine their arrival times. Seismic phases for local earthquakes (mainly P and S waves) and their arrival times, and maximum amplitudes (from horizontal components: N and E) have been measured. Information of earthquake source parameters consists of origin time, location (epicentral coordinates), magnitude and focal depth; focal depth has not been determined in the earlier study (Duerrast et al., 2007). Seismogram analysis was done by SEISAN, open-source software developed by Havskov and Ottemöller (1999) which can be downloaded at: ftp://ftp.geo.uib.no/-pub/seismo/SOFTWARE/SEISAN/. For this study, SEISAN version 10.4 (the latest version) was used.

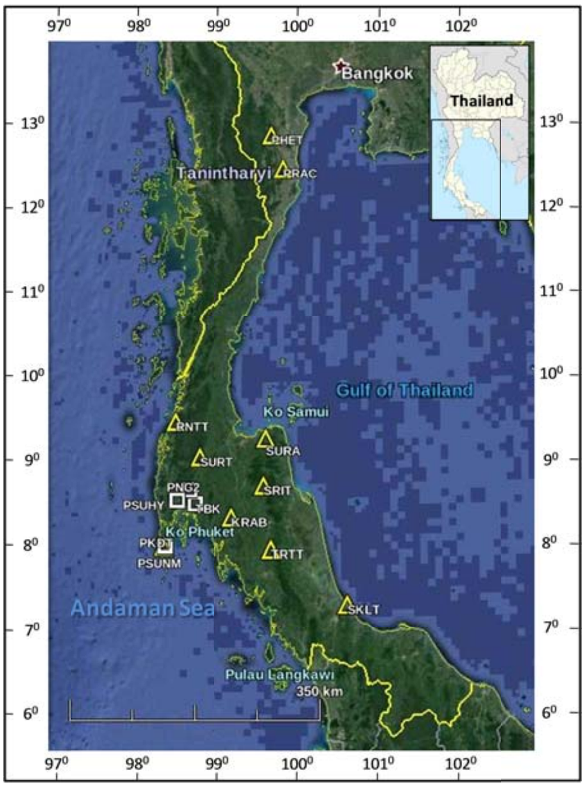


Figure 2. Location map of all seismic stations used in this study to monitor earthquakes in Southern Thailand during 2005–2017. The squares indicate the temporary network/stations (operated by GRC-PSU and DMR for data collection in 2005) and consist of 4 stations (PSUHY, PNG2, PSUNM, and TBK) and the triangles show permanent local stations (operated by TMD for data collection in 2010 - 2017) and consist of 10 stations (KRAB, PHET, PKDT, PRAC, RNTT, SKLT, SRIT, SURA, SURT, and TRTT)

Since the velocity of different layers within the earth is known, travel times as a function of epicentral distance (distance from station to epicenter) and origin times (time of the event occurrence) can be calculated. This study used the IASP91 velocity model (Kennett and Engdahl, 1991). Origin times and locations (epicenters) were determined by using differences between S and P arrival times from at least three different stations. Time differences between both arrival times, called 'delta time' (Δt), was used to determine the distance between the seismic event and the station. The earthquake hypocenter is expressed by latitude, longitude, and depth while its projection on the surface (expressed only by latitude and longitude) is the epicenter. The local magnitude (ML) was determined by using the IASPEI standard ML (Bormann et al., 2013) with:

$$ML = \log_{10}(A) + 1.11 \log_{10}R + 0.00189*R - 2.09 \quad \text{(1)}$$

where A is the maximum trace amplitude (in nm) that is measured from horizontal components (N and E) of a Wood-Anderson seismogram, and R is the hypocentral distance (in km).

Based on Rafferty (2018), earthquakes can be categorized into six classes based on the magnitude (Richter scale): micro (less than 1.0 – 2.9), minor (3.0 – 3.9), light (4.0 – 4.9), moderate (5.0 – 5.9), strong (6.0 – 6.9), major (7.0 – 7.9), and great (8.0 and higher).

3.3 Focal (Hypocentral) Depth

Spence et al. (1989) divided the earthquake focal depths into three zones: shallow earthquakes (0-70 km deep), intermediate earthquakes (70 - 300 km deep), and deep earthquakes (300 - 700 km deep). In this study, focal depths were obtained by using SEISAN software through iterations with the starting/trial depths adjusted to all events. The starting depth is usually a fixed parameter and adjusted to the most likely depth for the region which is around 10-20 km for the local earthquake (Havskov and Ottemöller, 2010). In this study, the software/program first iterated with the depth fixed to the starting depth of 15 km and then used this depth to give the best fit to the data.

4. SPATIAL DISTRIBUTION OF EARTHQUAKES

This study revealed that, during 2005 – 2017, the earthquake locations are distributed in a relatively NNE-SSW trend following the direction of the two major faults in Southern Thailand, the Khlong Marui and Ranong Faults. Many epicenters are located in or parallel to these fault lines and many others are within the areas of the fault zones (KMFZ and RFZ). There was also a cluster of relatively N-S-trending epicenters in Nakhon Si Thammarat and Trang provinces which, according to the detailed map of the Thai Peninsula showing those fault zones (Watkinson et al., 2008), can be interpreted due to the existences of some faults in granitic bodies in the areas. During this period, the earthquakes in Southern Thailand occurred mainly on land in some provinces of the region, i.e. Chumpon, Ranong, Surat Thani, Phang Nga, Nakhon Si Thammarat, Krabi, Phuket, and Trang. However, there are also clusters of epicenter in the Andaman Sea and the Gulf of Thailand, scattered in many locations offshore of Trang, Krabi, Phang Nga, Phuket, and Ranong, and a few locations in Surat Thani, Nakhon Si Tammarat, and Songkla. There was also a cluster of earthquake swarms in the northern part of Phuket Island, where the island experienced sequences of many earthquakes striking in a relatively short period of time in April – May 2012.

Most of local earthquakes occurred during 2005 - 2017 have their local magnitude (ML) between 0.1 to 1.0 which are concentrated in the fault lines of the Khlong Marui and Ranong Faults and within the areas of the fault zones. Earthquakes with minimum magnitudes (ML -1.0 to 0.0) are concentrated in some areas in Krabi, Phang Nga, and Phuket. The maximum magnitudes are ML 4.8 located near Phuket and Ko Yao Yai islands in the western part of Thai Peninsula.

In term of the focal depth, most of the recorded earthquakes in Southern Thailand have very shallow depths (depth = 0.0 – 20.0 km, symbolized by white circles in the following maps) scattered in and around the fault zones. Epicenters with the depth of 21.0 – 35.0 km (symbolized by yellow circles) are distributed randomly in the fault zones and its surroundings. Deeper hypocenters with 35.0 – 70.0 km depth (indicated by blue circles) and the deepest category (depth = 70.0 – 80.0 km, symbolized by red circles) are all located in the western part of Thai Peninsula, mainly in Phang Nga and Phuket provinces.

Figure 3 and 4 shows the maps of lateral distribution of epicenters in Southern Thailand region and Phuket Island area respectively during 2005 – 2017 in relation to the magnitude and depth. The vertical distribution of epicenters is represented by some depth profiles in Figure 5.

5. CONCLUSION

The results of this study have shown that after the 26 December 2004 Sumatra-Andaman Earthquake, the increasing numbers of earthquake events occurred in Southern Thailand. Based on the distribution of epicenters during 2005 - 2017, it can be interpreted that most of the recorded earthquakes are related to the existing faults and fault zones, mainly the Ranong and Khlong Marui Fault Zones. The 2004 devastating earthquake has reactivated the fault zones in this region with subsequent earthquake occurrences.

Most recorded earthquakes are categorized as microearthquakes (ML≤2.0) and mostly have very shallow depth of sources (0.0 – 20.0 km). This study revealed that the number of earthquakes decreased with the increasing of the focal depths. Most of shallower earthquakes occurred on land, meanwhile most of deeper events occurred offshore of the study area.

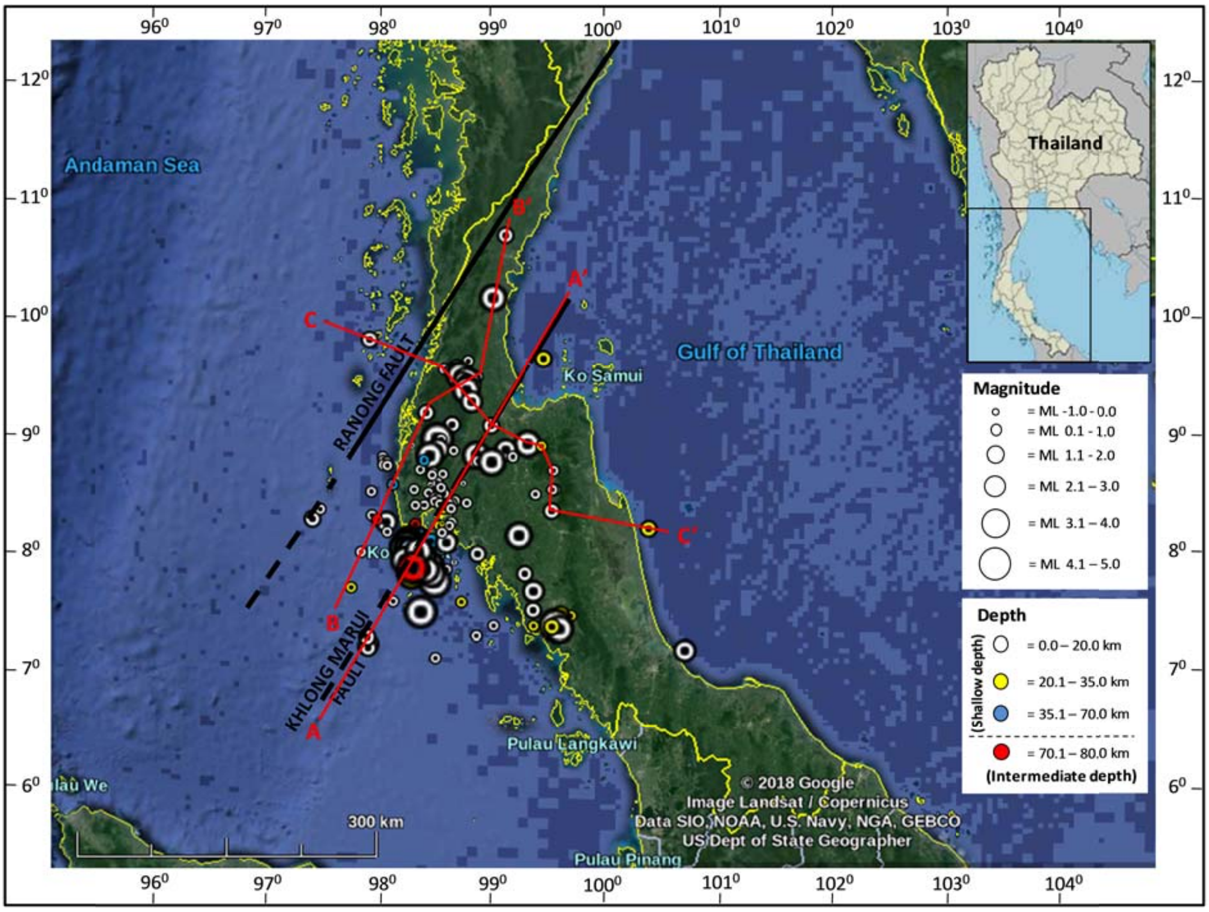


Figure 3. Epicenter Map of Southern Thailand Showing the Distribution of Earthquakes during 2005 - 2017 with Different Magnitudes and Depths. Red lines (A – A', B – B', and C – C') indicate the lines of cross section (see Figure 5 a-c)

ACKNOWLEDGEMENT

Authors thank following institutions or agencies for providing seismological data for this study: firstly, the Geophysics Research Center (GRC) in Department of Physics, Faculty of Science, Prince of Songkla University and Thailand's Department of Mineral Resources (DMR) for monitoring period in early 2005, and secondly to Thai Meteorological Department (TMD) for monitoring period of 2010 - 2017. Authors are also grateful to our colleagues, Sutamas Veerarattragul from GRC-PSU and Patinya Pornsopin from TMD for their great assistance and guidance in using SEISAN software. This study was supported by the Higher Education Research Promotion and the Thailand's Education Hub for Southern Region of ASEAN Countries (TEH-AC) Project Office of the Higher Education Commission.

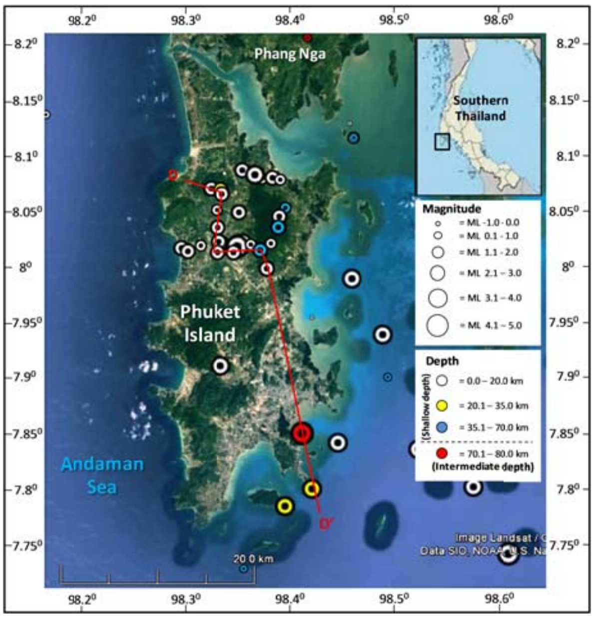


Figure 4. Epicenter Map of Phuket Island and Its Surroundings during 2005 - 2017 with Different Magnitudes and Depths. Earthquake swarms in 2012 can be seen in the northern part of the island. The red line (D – D') shows the line of cross section (see Figure 5d)

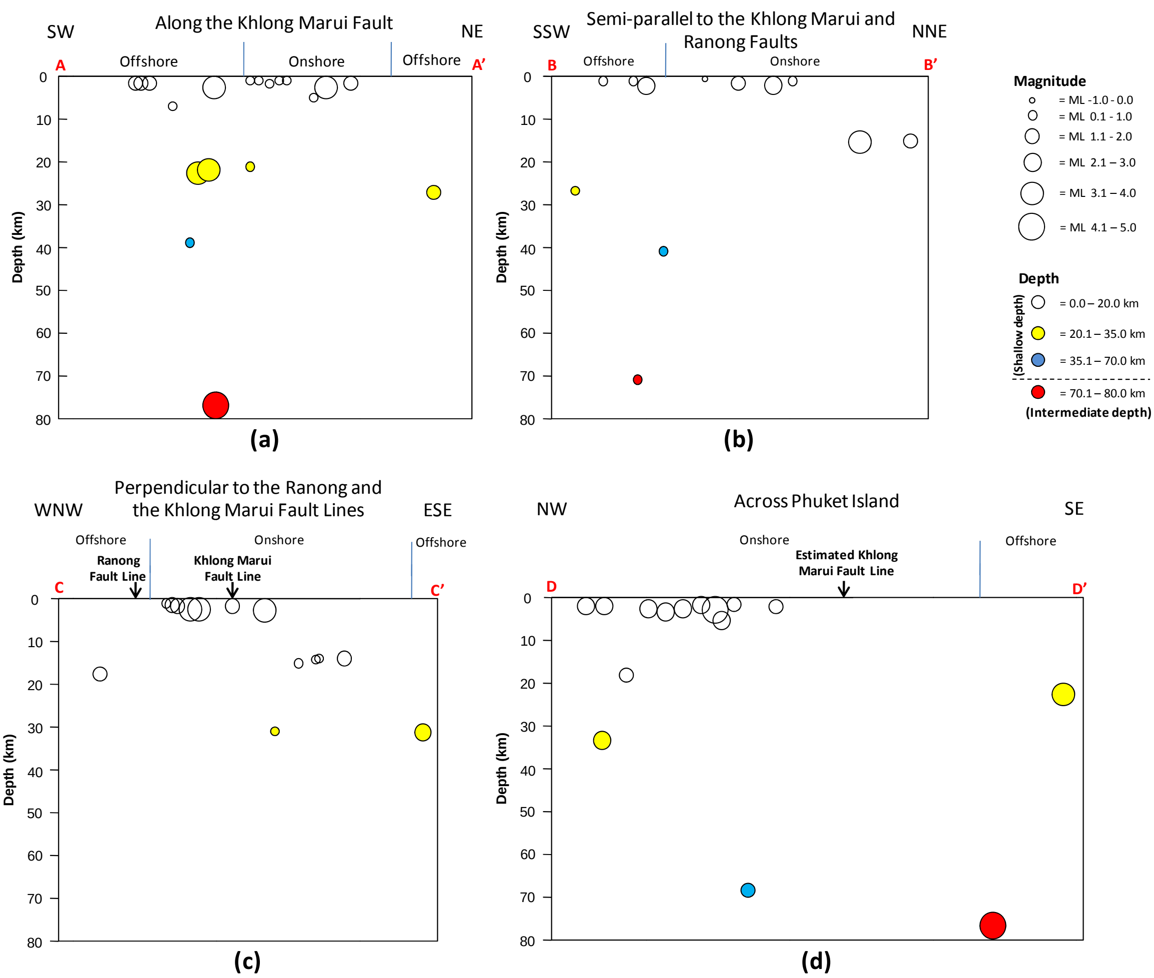


Figure 5. Vertical sections (depth profiles) of seismicity in Southern Thailand during 2005 – 2017 from some lines: (a) Along the Khlong Marui Fault, (b) Semi-parallel to the Khlong Marui and Ranong Faults, (c) Perpendicular to the Ranong and the Khlong Marui Fault Lines, and (d) Across Phuket Island

REFERENCES

Bormann, P., Wendt, S., DiGiacomo, D. (2013). Seismic Sources and Source Parameters. In: Bormann, P. (Eds.), New Manual of Seismological Observatory Practice 2 (NMSOP2), Potsdam : Deutsches GeoForschungs Zentrum GFZ, pp. 1 – 259. http://doi.org/10.2312/GFZ.NMSOP-2_ch3.

Duerrast, H., Dangmuan, S., and Lohawijarn, W. (2007). Khlong Marui and Ranong Fault Zones in Southern Thailand Re-activated by the 26 December 2014 Mw 9.3 Sumatra-Andaman Earthquake? GEOTHAI'07 International Conference on Geology of Thailand: Towards Sustainable Development and Sufficiency Economy, 141-144.

Havskov, J. and Ottemöller, L. (1999). *SeisAn* Earthquake Analysis Software. Seismological Research Letters, 70 (5), 532-534.

Havskov, J. and Ottemöller, L. (2010). Routine Data Processing in Earthquake Seismology. Springer. 347p.

Kennett B.L.N. and Engdahl E.R. (1991). Travel Times for Global Earthquake Location and Phase Association. Geophysical Journal International, 105:429-465.

Morley, C.K., Charusiri, P., and Watkinson, I.M. (2011). Structural Geology of Thailand During the Cenozoic. In: Ridd, M.F., Barber, A.J., and Crow, M.J. (Eds). The Geology of Thailand. The Geological Society, London, 273 – 334.

Rafferty, J.P. (2018). Richter scale. Encyclopedia Britannica. https://www.britannica.com/science/Richter-scale#accordion-article-history.

Ridd, M. F., Barber, A. J., & Crow, M. J. (2011). Geological Map of Thailand (as the attachment). In: Ridd, M. F., Barber, A. J., & Crow, M. J. (Eds). The Geology of Thailand. London: Geological Society.

Spence, W., Sipkin, S.A., Choy, G.L. (1989). Determining the Depth of an Earthquake. Earthquakes and Volcanoes, 21:1, https://earthquake.usgs.gov/learn/topics/determining_depth.php.

Sutiwanich, C., Hanpattanapanich, T., Pailoplee, S., and Charusiri, P. (2012). Probability Seismic Hazard Maps of Southern Thailand. Songklanakarin J. Sci. Technol., 34(4), 453-466.

Vanichnukhroh, P. (2013). Seismic Observations of Thailand. 2013-2014 Global Seismological Observation Course, Seismological Bureau, Meteorological Department, Thailand, 7 p.

Watkinson, I., Elders, C., and Hall, R. (2008). The Kinematic History of the Khlong Marui and Ranong Faults, Southern Thailand. Journal of Structural Geology, 30: 1554-1571.