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50. *Regional Study on the Characteristic Seismicity of the World.*

Part II. From Burma Down to Java.

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Summary

Seismicity in Burma was studied with relation to the seismicity along Andaman, Nicobar, Greater Sunda Islands and Java as a continuation of the same seismic zone. Foci distributions of the earthquakes versus depth in the various regions from Northern Burma down to Java Island were found to be expressed by the same curve, which indicates that the continental earthquakes in Burma have the same source of generation as that of oceanic ones belonging to the trench-island arc system. Energy released by the earthquakes in Burma, however, has quite a unique action, that is, a large amount of energy has been released in the upper mantle between the depth range of 50 km and 200 km.

Special events which follow one or two other events with close relationship to the first one both in space and time have taken place in the oceanic belt. There are no such events in Burma. Earthquakes deeper than 550 km have been generating only in part beyond latitude 110°E. Extension of foci plane appears to have a close relation with the formation of trench. It was discovered that many deep earthquakes in Java Sea have the tendency to take place at the same spots with various time intervals.

Distributions of seismological stations, the data of which have often been available to U.S. Coast and Geodetic Survey for foci determination, were examined. Services from the eastern stations were found to be poor at least for detecting the smaller events.

1. Introduction

As a continuation of the previous study (Part I), foci distributions of upper mantle earthquakes in Burma were studied with relation to those in the southern seismic belt along the islands region. The data from Earthquake Data Report or Preliminary Epicenter Determination by U.S. Coast and Geodetic Survey in the period from January 1963 to

April 1969 were taken.

In northern Burma, mountains heavily folded into arcs look like having been formed by the north-eastward pressure due to the drift of Indian blocks. This feature has good similarity with the tectonics in and around Hindu Kush.

There is no such localized upper mantle seismic area, however, as was seen in the Hindu Kush region. As shown in Fig. 1, upper mantle earthquakes do not originate in a restricted area but spread along the eastern side of Patkai Hills and Arakan mountain chains. This trend is also parallel to the shallower seismic zones. The situation is similar to the general arrangement of foci distributions belonging to the Island

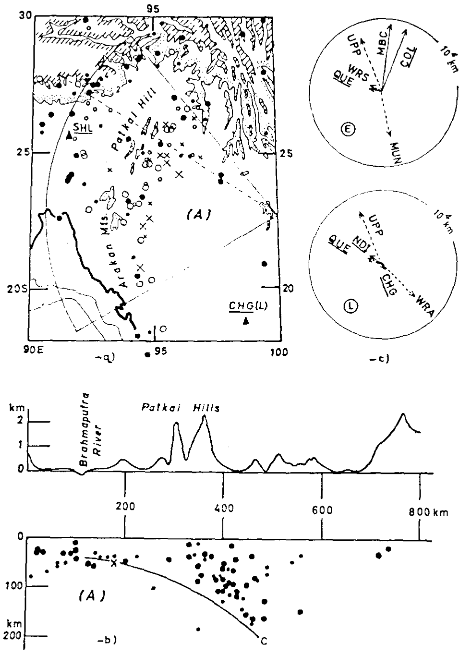


Fig. 1-a). Epicentral distribution of the earthquakes in Burma (January 1963-April 1969). Filled circles: d<50 km. Open circles: 50 km≦d<100 km. Crosses: 100 km≦d<200 km. Large circles: m≧5.0. Filled triangles: locations of seismological stations. Numerals in contour lines are the heights and/or depths in km.

Fig. 1-b). Foci distributions of the earthquakes along the radial profile inside the area (A) which is given in the epicenter map. Cross-section along the broken line in the epicenter map is shown for comparison. Curve c is the same one as those which are applied to all of the foci distributions in the later figures.

Fig. 1-c). Distributions of seismological stations given in Table 1. E: earlier period L: later period. Lengths of the arrows are taken proportional to the distances from the epicenter map.

arc-trench system. That such foci distribution exists in the continent is quite interesting.

Before examining this characteristic more deeply, distribution of the seismological stations, the data of which were used for the epicentral determination of the seismic region in Burma, will be examined in the next section.

2. Distribution of seismological stations.

As was done in the Part I, distribution of seismic stations the data of which were almost always available by U.S.Coast and Geodetic Survey for determining the epicenters and depths of smaller events ($m \leqq 4.5$) was examined for an earlier period (E)—1964—and for a later one (L)—1968.

The results are given in Table 1, in which distance was measured from the center of the map 1-a). Group of "Sometimes" gives the stations whose data were available with the frequency ratio of more than 50%. Two nearby stations SHL and CHG are shown in Fig. 1-a) and the directions of these stations are shown by arrows (broken arrows mean the directions for the stations "Sometimes") in Fig. 1-c) in the earlier period E and in the later one L respectively. It was not obvious from when the pattern of distribution of the available stations changed from E to L.

In both periods, the data from eastern and southwestern sides are

Table 1. Seismological stations (underlined: WWSSN) the data of which were used by USCGS for determining the epicenters and depths of smaller events (m: around 4.5) in northern Burma. E: earlier period. L: later period. d: distance (ca., in km). N: range of the total number of the stations on average.

	E			L		
	Station		d	Station		d
Always	SHL	Shillong, India	—	SHL	Shillong, India	—
	QUE	Quetta, Pakistan	2800	CHG	Chiengmai, Thailand	—
	COL	College, Alaska	8300	QUE	Quetta, Pakistan	2800
	MBC	Mould Bay, Canada	8600			
Sometimes	WRS	Warsak, Pakistan	2500	NDI	New Delhi, India	1800
	MUN	Mundaring, Australia	6600	WRA	Warramunga Array, Australia	6500
	UPP	Uppsala, Sweden	7000	UPP	Uppsala, Sweden	7000
N	7∼10			7∼10		

desirable in order to make the accuracy of foci determination much better. With regard to the lacking of data from the eastern side, it is regrettable that the data at several World-Wide Standardized Stations of Mat (Matsushiro, Japan), SEO (Seoul, Korea), HKC (Hong Kong, Hong Kong), ANP (Anpu, Taiwan) and so on which are well situated locations and not so far from Burma were not available for detecting the events of $m \leqq 4.5$ at least.

3. Foci distribution

Foci along the radial profile inside the fan-shaped area, the arcs of which are taken parallel to the trend of mountain chains of Patkai Hills and Arakan mountains are plotted in Fig. 1-b). As will be explained

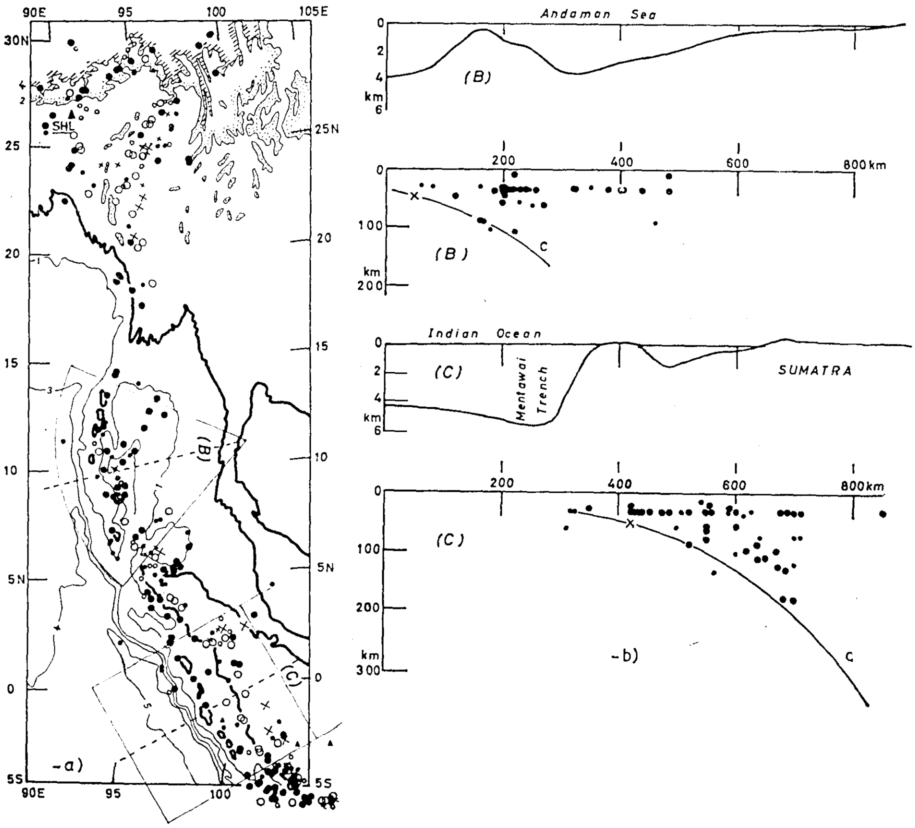


Fig. 2-a). Epicenter distributions of the earthquakes down to 5°S as a continuation of seismic belt in Burma. Crosses: d≧200 km. Other epicenter marks are the same as were used in Fig. 1-a).

Fig. 2-b). Foci distributions of earthquakes along the radial and band profiles (B) and (C) shown in Fig. 2-a) respectively. Topographies along the broken lines in Fig. 2-a) are also shown for comparison.

later, the general tendency of the underthrusting of the foci is quite the same throughout any of that along the profile which is taken perpendicular to the continuing seismic zone down to Java. This suggests that the earthquakes in Burma may generate due to the same mechanism as those along the Island arc-trench system near Sumatra and Java. In other words, they may generate due to the underthrusting of the lithosphere layer caused by the convection current in the upper mantle, though the underthrusting appears to be disappearing or weakening, for some reasons, in Burma deeper than 200 km.

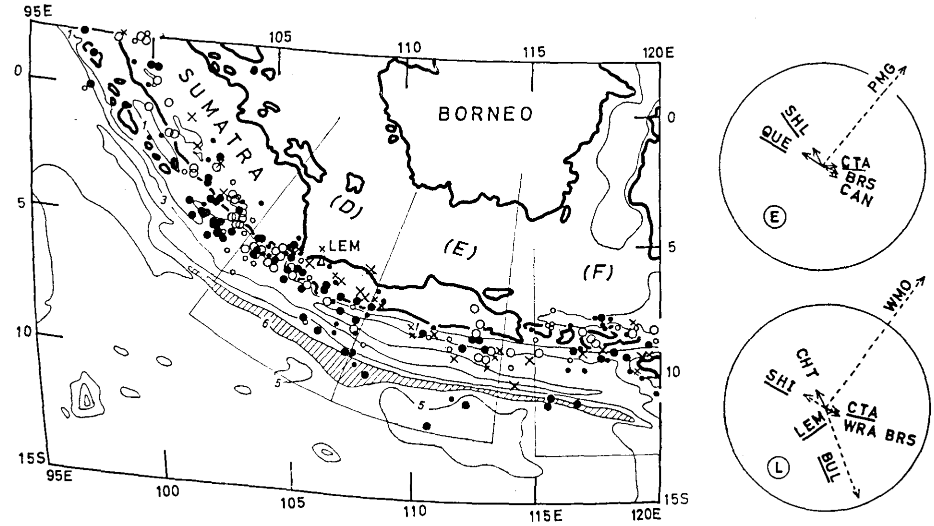
4. Foci distributions along the Andaman Islands, Nicobar Islands, Greater Sunda Islands and Java.

Geographically, the mountain chains of the Patkai Hills and Arakan mountains in Burma continue to the Nicobar Islands and Andaman Islands in the Bay of Bengal. Foci distributions of the earthquakes in and around these Islands are really found to be of exactly the same character as in Burma too. Two of them are shown in Fig. 2-b) along the profiles (B) and (C), both being taken as perpendicular to the trend of the Islands. Along these two profiles, the deepening of the foci are, as in the case of Burma, stopped to a depth shallower than 200 km.

As for the eastern extension of the seismic zone, foci distributions around Java along the profiles (D), (E) and (F) (Fig. 3-a) perpendicular to the Islands were also studied, the results of which are shown in Fig. 4. In Fig. 3-b) showing the epicentral distribution of the earthquakes deeper than 200 km it will be recognized that deeper events, especially those deeper than 550 km, appear from 110°E. This was also the case in the epicenter map presented in "Seismicity of the Earth" by using the data in older period.[1] Another characteristic fact is that there are several couples or groups of deep events which have the same epicenters. In Table 2, 13 events out of 16 are classified into 5 groups in each of which events took place almost at the same spot. Taking into account of rather poor accuracy in the depth determinations, each of them may have occurred at almost the same spot in the depths between 500 km–600 km. What does this mean is quite difficult to answer at the present stage.

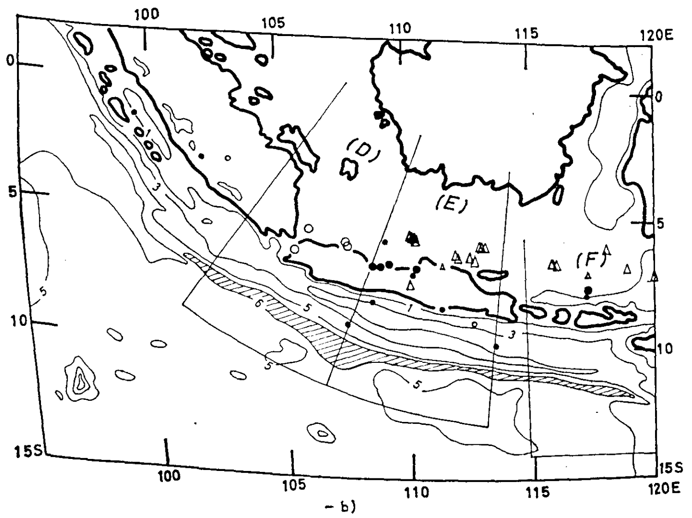
Distribution of the seismological stations, the data of which were used by U.S.Coast and Geodetic Survey for determining the foci around

1) B. GUTENBERG and C. F. RICHTER, *Seismicity of the Earth and Associated Phenomena*, (Princeton Univ. Press 1954), p. 63.



-a)

Fig. 3-a). Epicenter distribution of the earthquakes (d<200km) in and around Java. Epicenter marks have the same meanings as were used in Figs. 1-a) and 2-a). Attached figures show distributions of seismological stations in two periods E (1964) and L (1968) which are given in Table. 3.



- b)

Fig. 3-b). Epicentral distribution of deeper earthquakes (d≧200 km) in and around Java. Filled circles: 200 km≦d<300 km. Open circles: 300 km≦ d<400 km. Open triangles: d≧500 km.

Java, was examined. The results are listed in Table 3 and their directions against the center of the map in Fig. 3-a) are shown by the attached figure for the earlier period E and the later period L respectively. The data at near stations towards NW (South Asia) and SE (Australia)

Table 2. List of deep (>500 km) earthquakes along the seismic zone from northern Burma to Java (January 1963—April 1969)

Date			Origin Time (G.M.T.)			Epicenter		d (km)	m	Intervals (month)
{Jan.	24	1963	09h	29m	21.0	6.1°S	112.9°E	611	5.0	34.3
{Dec.	03	1965	03	03	34	6.2 S	112.9E	574	5.0	
{June	22	1963	16	12	14.0	6.0E	113.1E	594	5.2	40.6
{Nov.	10	1967	07	28	53.7	5.9 S	113.1E	555	5.2	17.7
{Apr.	15	1969	22	15	09.6	5.9 S	113.2E	575	5.6	
{Apr.	29	1965	15	48	57.1	5.6 S	110.2E	504	6.0	22.2
{Feb.	03	1967	12	30	53.0	5.6 S	110.5E	569	5.1	0
{	〃			48	09.2	5.6 S	110.5E	560	5.4	26.5
{Mar.	13	1969	20	40	12.5	5.5 S	110.4E	502	5.2	
{Mar.	24	1967	09	00	19.5	6.0 S	112.3E	600	6.0	0
{	〃		11	46	13.9	6.0 S	112.3E	600	5.3	
{Mar.	26	1968	00	41	56.9	6.6 S	116.1E	520	5.9	0.3
{Apr.	04	1968	18	04	07	6.6 S	115.8E	511		
Feb.	16	1963	10	46	24.8	7.0 S	117.4E	606		
Dec.	30	1968	04	24	43.1	7.2 S	119.9E	601	5.2	
May	24	1968	15	43	54.2	6.8 S	118.9E	609	6.0	

Table 3. Seismological Stations (underlined one: WWSSN) the data of which were used by USCGS for determining the epicenters and depths of smaller events (m: around 4.5) in and around Java. L: later period. E: earlier period. d: distance (ca., in km). N: range of the total number of the stations on average.

	E			L		
	Station		d	Station		d
Always	CTA	Charters Towers, Australia	1900	WRA	Warramunga Array, Australia	1500
	BRS	Brisbane, Australia	2200	CTA	Charters Towers, Australia	1900
	SHL	Shillong, India	3700	BRS	Brisbane, Australia	2200
	QUE	Quetta, Pakistan	5000	CHT	Chittagang, Pakistan	3500
Sometimes	CAN	Canberra, Australia	1900	SHI	Shiraz, Iran	6100
	PMG	Port Moresby, New Guinea	11000	BUL	Bulawayo, Rhodesia	8400
				WMO	Wichita Mountains, Oklahoma	16000
				LEM	Lembang, Java	near
N	6 ~ 12			10 ~ 14		

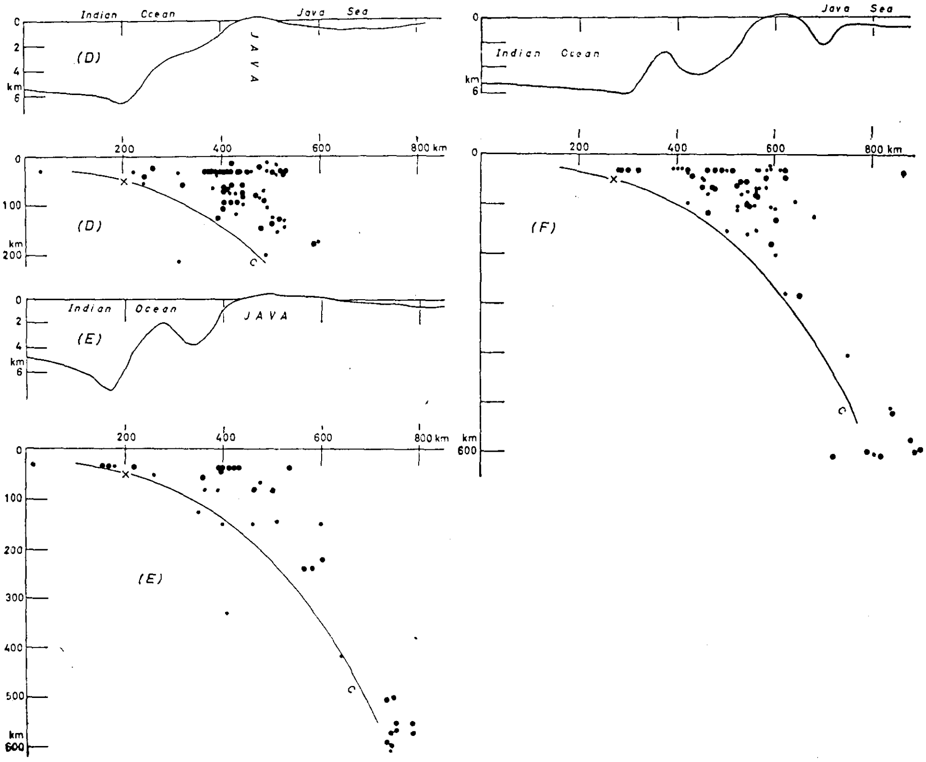


Fig. 4. Foci distributions of the earthquakes along the three profiles (D), (E) and (F) which are shown in Figs. 3-a) or 3-b). Topographies along the broken lines in the profiles in Fig. 3 are shown for comparison. The curve c which was drawn to represent the general trend of underthrusting the foci distribution down to the depth of 600 km in the profile (E) was used in all other figures of foci distributions.

were extensively used. However, the detections of the weaker events at some moderately distant stations in the Far East, in Japan, Korea, Hong Kong, Philippines, for instance, are desirable to improve the accuracy of the foci around Java.

For the foci distribution along the profile (E) including the foci deeper than 500 km, a curve c can be drawn which represents the general tendency of the deepening of foci towards Java Sea. (Fig. 4). A noticeable fact is that exactly the same curve can be suitable for any other foci distribution along other profiles from (A) to (F) through the long seismic zone from Burma down to Java only by shifting the curve horizontally. The curves presented in foci diagram from (A) to (F) are all the same curve c which was used in the profile (E). There is only one important difference, however, that deep foci appear only along the profiles (E) and (F) around Java posessing a trench nearby. The extension of foci plane, therefore, seem to be connecting with the formation of the trench, which is also quite an interesting fact.

The above evidences may indicate that the earthquake generation in Burma belongs to the same system as those along such trench-Island arc system as around Andaman, Nicobar, Greater Sunda Islands and Java. They may tell, further, that the effect of the convection current which underthrusting the lithosphere into the upper mantle may still be more active around Java, in the southeastern part of the long zone, which may form a deep trench there.

5. Double or triple events.

The present author has discovered in South America that there were many double and/or triple events in which events were closely related

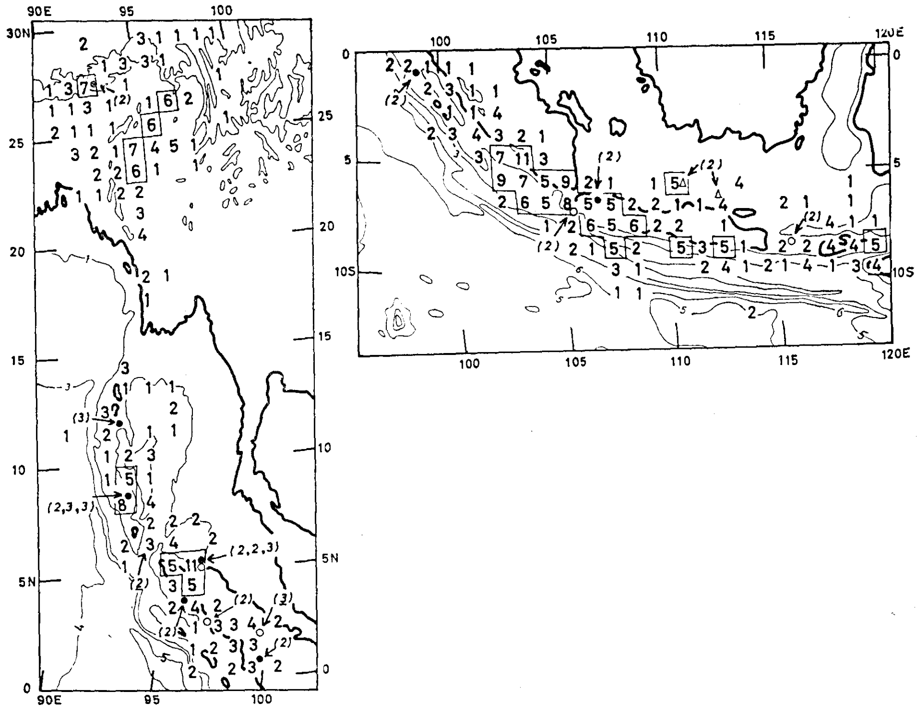


Fig. 5. Frequency distributions of earthquakes (all depths) in each 1°×1° mesh along the whole seismic zone from Burma to Java. Active area with the frequency of more than 5 are fringed. Locations of double (2) or triple (3) events listed in Table 4 are shown by arrows and epicenter marks. Filled circles: normal depth. Open circles: below Moho. Triangles: deeper than 550 km. Numerals in the contour lines mean the heights (in the land) and/or depth (in the sea) respectively in km.

Table 4. List of the double and/or triple events which are closely related with each other both in time and space.

Date			Origin Time (G.M.T)	Epicenter		d	*m*	Time diff.	Foci diff.		
				λ	φ			ΔT	Δλ	Δφ	Δd
1963	Feb.	21	19h 43m 52.3s 52 27.2	6.3°S 6.3S	106.7°E 106.8E	38 33		00h 08m 34.9s	0.0°	0.1	05km
	Apr.	18	12 20 34.4 13 03 35.8	8.2S 8.3S	115.6E 115.7E	65 69		00 43 01.4	0.1	0.1	04
1965	May	20	14 00 50 06 55.6 35 53	1.2N 1.8N 2.3N	99.6E 99.1E 99.5E	75 73 75	 4.8 4.4	00 06 05.6 00 28 57.4	0.4 0.5	0.5 0.4	02 02
	July	07 08	23 00 06.8 02 58 51.2	6.9S 6.8S	105.6E 105.5E	109 92	5.8 5.1	04 58 44.4	0.1	0.1	17
		19	09 07 16 09 40.3	3.0N 3.0N	97.1E 97.1E	59 33	4.9 5.2	00 02 24.3	0.0	0.0	26
1966	Apr.	04	02 17 18.1 51 39.0 06 42 13.9	11.8N 12.0N 12.1N	92.6E 92.7E 92.7E	33 33 33	5.0 5.0 5.0	00 34 20.9 03 50 34.9	0.2 0.1	0.1 0.0	00 00
	Sept.	26	05 10 59.1 06 03 48	27.5N 27.6N	92.6E 92.7E	33 33	5.6 4.2	00 50 48.9	0.1	0.1	00
1967	Feb.	03	12 30 53.0 48 09.2	5.6S 5.6S	110.5E 110.5E	569 560	5.1 5.4	00 17 16.2	0.0	0.0	09
		24	09 00 19.5 11 46 13.9	6.0S 6.0S	112.3E 112.3E	600 600	5.0 5.3	02 45 54.4	0.0	0.0	00
	Apr.	12	04 51 40.2 05 11 14.1 06 03 37 19 33 47.3	5.3N 3.5N 3.3N 5.2N	96.5E 96.7E 96.6E 96.7E	55 33 33 56	6.1 5.7 5.1 5.2	00 19 33.9 00 52 22.9 13 30 10.3	0.2 0.2 0.1	0.2 0.1 0.1	22 00 23
		21 22	16 28 38 13 07 38.1	5.3N 5.1N	96.8E 96.4E	72 42	4.8 5.4	20 39 00.1	0.2	0.4	30
1967	July	01	06 42 34 07 28 67.6	0.8S 0.8S	98.8E 98.7E	33 26	4.4 5.5	00 46 33.6	0.0	0.1	07
		02	07 03 52.9 14 09 37.6 18 36 19	8.7N 8.5N 8.6N	93.8E 93.8E 93.8E	33 36 33	5.7 5.2 4.5	07 05 44.7 04 26 41.4	0.2 0.1	0.0 0.0	03 03
	Aug.	21 22	07 33 00.6 07 32 57	3.6N 3.6N	95.8E 96.2E	33 24	5.9	23 59 56.4	0.2	0.4	09
1968	July	18	17 20 29 43 24	8.9N 8.8N	93.9E 93.8E	33 33	4.8 4.8	00 22 55	0.1	0.1	00
		19	04 56 27.2 06 07 22 16 42 15.9	8.7N 8.9N 8.7N	93.6E 93.8E 93.7E	33 33 8	5.4 4.8 5.1	01 10 54.8 10 34 53.9	0.2 0.2	0.2 0.1	00 25

with each other both in time and space.[2] In the seismic zone from Burma to Java, the same double or triple events were also found as are listed in Table 4. The locations are presented in Fig. 5 by arrows. Excepting one doublet in another seismic zone along Himalaya, they are taking place in the marine seismic zone only. In South America, the occurrence of double or triple events was predominant in the upper mantle. In the present case, almost all of them take place around the normal depth of 33 km. As most of their epicenters (see Fig. 5) locate the areas which are supposed to have more or less transitional crustal thickness of around 30 km, most of these special events generate around or just below the Mohorovičić discontinuity. Two of them, however, have occurred in such deep spots as nearly 600 km, which must be noted.

6. Frequency and the energy released with relation to depth.

Distributions of frequency and energy released by earthquakes versus

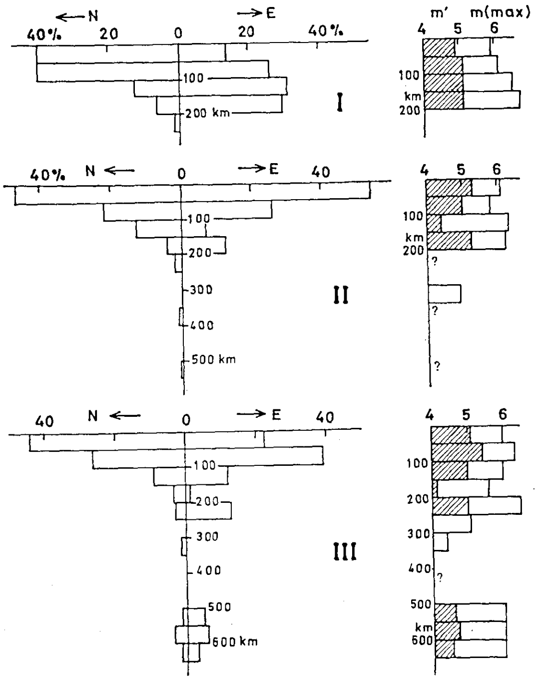


Fig. 6. Left: Frequency (N) and energy (E) distributions versus depth in three regions I (Burma), II (Andaman Islands, Nicobar Islands and Greater Sunda Islands regions) and III (Southern Sumatra and Java regions).
Right: Comparisons of the magnitudes of equivalent earthquake (m') and the largest one (m(max)) in different depth ranges for three regions.

2) T. SANTÔ, "Characteristics of Seismicity in South America", *Bull. Earthq. Res. Inst.*, **47** (1969), 635-672.

depth were studied in three regions I (Burma), II (Andaman Islands, Nicobar Islands and Greater Sunda Islands regions) and III (Java Island region). In the region I, the earthquakes along and around Himalaya were excluded, because they belong to another seismic zone. In the energy estimation, the events with m of more than 5.0 were used.

The results are given in the left diagrams of Fig. 6, from which we can see a remarkably unique character in the seismicity of Burma in the energy distribution versus depth. That is, in Burma, actually more than 86% of the seismic energy has been released in the upper mantle with the depth range from 50 km to 200 km. The total amount of seismic energy released from this depth range is approximately equal to the monthly occurrence of the earthquake with m of around 5.1 (see right diagram in Fig. 6).

In Table 5, released energy in the total period is compared for three regions. Energy averaged for one earthquake is largest in the region I, Burma.

Table 5. Comparative table on seismic activities in three regions. $\bar{m}$: magnitude of the earthquake with energy equal to $\sum E/\sum N$.

Region	Length of zone	Total Energy $\sum E$ (erg.)	Total No. $\sum N$	$\sum E/\sum N$	$\bar{m}$
I	13°	59.93×10^{21}	80	7.49×10^{20}	4.8
II	25°	47.80×10^{21}	140	3.42×10^{20}	4.4
III	15°	98.54×10^{21}	198	4.98×10^{20}	4.6

7. Conclusions.

Burma has upper mantle earthquakes. They spread along the eastern side of a curved mountain trending in a north-south direction and is also parallel to the shallower seismic zones. Though the depth is less that 220 km, foci distribution along the profile perpendicular to the mountain chain show a similar character as those along the profiles perpendicular to the trench-island arc system in the ocean. Together with the geographical feature, the seismic zone in Burma is considered to be the northern extension of the trench-islands arc system which is running along Java, Sumatra, Nicobar Islands and Andaman Islands regions.

Seismicity in Burma, however, has other characteristics quite different from the oceanic seismic zone in the following two points.

1. Ratio of the amount of energy released by upper mantle earthquakes to the total one is quite large. The above ratio in the depth range from 100 km to 200 km, especially, is counted as about 50%,

though the corresponding ratio is only 20% in frequency (Fig. 6).

2. A minimum of energy released along the oceanic zone is revealed between 100 km—150 km in the region II and between 150 km—200 km in the region III respectively, while it exists in the crust in Burma.

3. In the oceanic zone, double or triple events which are closely related with each other both in time and in space occur here and there. Such events are, however, nothing in Burma (Fig. 5).

Seimicity along Java also differs from the northern Islands regions. Earthquakes with the depth of more than 300 km begin to appear from the Java region. Deep earthquakes of more than 550 km depth, especially, begin to appear in the eastern part, from the latitude of around 113°E (Fig. 3-b)). These facts indicate that the extension of the foci plane has close relation with the formation of the trench. Further, many of these deep earthquakes originate at almost the same epicenter of previous one with various intervals (Fig. 3-b) and Table 2).

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50. 世界の特殊な地震地域の活動について

(その二) Burma から Java 島まで

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Burma 北方の褶曲の状態は，前篇で取扱つた Hindu Kush 周辺のそれとよく似ているにかかわらず，ここでの上部マントル地震には，前篇でのべたようなかたまりはみられず，かえつて Burma 西部の国境沿いに南北に走る弓形の山脈に沿つて起こつており，明らかに南の Sunda-Nicobar-Andaman 諸列島沿いに北上する島弧系の地震帯が，そのまま大陸内に延長されたものと見なせる．このことが，震源分布をしらべた結果一層はつきりした．

そこで，北は Burma から南は Java 島に至る長い地震系列について，地域別にそれぞれの地震活動を比較してみた．

最も注目されることは，系列に直角な切口でみた震源分布のすべてに同一の曲線があてはめられること，つまり，Burma の地震が島弧系のものであることと，この震源面の伸びが海溝の形成と深いつながりをもつていそうなことであつた (第1-b), 2-b), 4図)．即ち，海溝のある Java 島付近では，震源面は 600 km 前後の深さまで伸びているのに，海溝のない Sanda 列島から Burma までのそれは，せいぜい 300 km どまりである．

この他

1. Java 海底で起こる深発地震は，同じ場所でくり返し起こる傾向が著しい (第3-b) 図および第2表)．
2. 列島周辺のモホ不連続面の直下あたりでは，誘発性の地震がところどころで起こつているのに，Burma ではそれがない (第5図)．
3. 列島周辺の地震に比べて，Burma に起こる地震が放出したエネルギー量は，マントル上部で特に著しく大きい．また，列島周辺では放出エネルギー量の少ない深さが 100 km から 200 km の間にあるのに，陸地の Burma ではそれが地殻内にある (第6図)，などの諸点が目についた．