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1. *Regional Study on the Characteristic Seismicity of the World.*
Part III. New Hebrides Islands Region.

By Tetsuo SANTÔ,

Earthquake Research Institute
and
International Institute of Seismology and Earthquake Engineering.

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Summary

Characteristics of the seismicity of the New Hebrides Islands region was investigated. Shallow earthquake swarms were found to be quite active. Other shallow earthquakes also contained many inductive events which follow one, two or sometimes several events closely related with the previous one both in time and space. A typical arrangement of foci which is commonly observed in the Islands-arc-trench system was disturbed in the northern part near the Torres trench, where an upper mantle earthquakes zone with the depth range from 200 km to 300 km turned eastward departing from the trend of the Islands arc.

Three earthquake nests were discovered in the upper mantle. Two of them, N1 and N2, located around 15°S near the main Islands with the depth range from 100 km to 150 km beneath the sea. N1 has several inductive events. The third one was centering at 18.6°S and 169.1°E with the depth range from 200 km to 250 km. Foci near N1 distributed around a plane with the dip of about 45° northward, while those near the other two nests N2 and N3 inclined southward at the same angle. Along an extended profile of NNW-SSE direction following the trend of the Islands arc, foci in the upper mantle, in general, have the tendency to increase their depths both northward and southward, where trenches appear respectively at the western sides.

Foci distribution along a few profiles perpendicular to the trend of the Islands arc were examined. The dips of the focal zone were found to be in all cases around 70°, which are of exceptionally large values compared with those obtained along similar profiles for other Islands arc regions.

The focal zone extended to 300 km in two profiles only containing the New Hebrides trench and the southern part of the Torres trench.

Less active depth ranges were also found to exist from 160 km to 200 km in these two focal zones.

The deep earthquakes distributed not parallel to the trend of the Islands arcs but in the direction of the Fiji Islands. A shallow seismic zone also turned toward the Fiji Islands in its southern end around 23°S, 172°E. These tendencies were compared with the epicentral distributions around Fiji Islands already studied, and it was cleared that the trends above mentioned were well connected with the seismic zones of the Tonga-Kermadec region by way of Fiji.

1. Introduction

As a continuation of Part I (Hindu Kush region)[1] and II (from Burma to the Java Islands region)[2], characteristics of seismicity in the New Hebrides Islands region were studied in the present paper as in Part III. The seismicity of this region was taken as a special study because of having an exceptional trend of deep earthquake zone, which does not run parallel to the Islands arc. Through the study, some other characterized facts have also been revealed.

The data were taken, as in previous cases, from the Earthquake Data Report and/or Preliminary Determination of Epicenter by U.S.Coast and Geodetic Survey (USCGS) during 64 months from January 1964 to April 1969.

2. Distributions of seismological stations

Just as was done in Parts I and II, the distribution of seismological stations, the data of which were almost always used by U.S. Coast and Geodetic Survey for determining the foci of smaller events of $m \fallingdotseq 4.2$ were examined for an earlier period (1964) and for later ones (1968) respectively. These stations are listed in Table 1, and locations of several nearby stations and distribution of distant ones are shown separately in Figs. 1 and 2 respectively. In Fig. 2, solid and broken arrows respectively indicate the direction of the stations, the data at which were always and sometimes available. In both periods, about 10 stations which distribute fairly well around the seismic region contribute to USCGS for determining the foci of the smaller events as m of around 4.2.

Data at south-eastern stations are desirable in order to make the determinations of foci much better. However, as these stations are too far distant in South America, the scantiness of data for small events from these directions is unavoidable.

1) T. SANTÔ, "Regional Study on the Characteristic Seismicity of the World. Part I. Hindu Kush", *Bull. Earthq. Res. Inst.*, **47** (1969), 1036-1048.

2) T. SANTÔ, "Regional Study on the Characteristic Seismicity of the World. Part II. From Burma Down to Java", *Bull. Earthq. Res. Inst.*, **47** (1969), 1049-1061.

Table 1. Seismological stations the data of which were always or sometimes (frequency of more than 50%) used by USCGS for determining the foci in the earlier period E (1964) and in the later period L (1968) respectively.
Underlined: WWSSN

	E (1964)		L (1968)	
	Station	Dist. (km)	Station	Dist. (km)
Always	PVC (Port Vila, New Hebrides)	near	The same as at left	near
	LUG (Luganville, New Hybrides)	near	The same as at left	near
	NOU (Noumea, New Caledonia)	near		
	KOU (Koumac, New Caledonia)	near		
	BRS (Brisbane, Australia)	2100	The same as at left	2100
	TFO (Tonto Forest, Arizona)	10000	The same as at left	10000
	BMO (Blue Mountains, Oregon)	10000	The same as at left	10000
Some times	CAN (Canberra, Australia)	3000	NOU	near
	<u>COL</u> (College, Alaska)	9500	The same as at left	9500
	ORV (Orcville, California)	9400	LUG	near
	<u>CTA</u> (Charters Towers, Australia)	2300	The same as at left	2300
	TOO (Toolangi Australia)	3300	<u>SPA</u> (South Pole, Antarctica)	8000
	<u>HNR</u> (Homiara, Solomon Is.)	1200	EUR (Nevada)	10000

3. Distribution of epicenters and foci

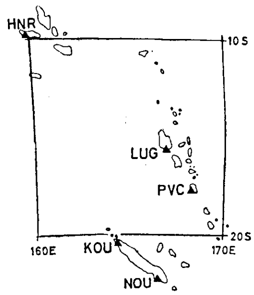


Fig. 1. Location of nearby seismological stations, the data of which were available throughout the whole period to determine the foci of smaller events ($m \fallingdotseq 4.2$).

Fig. 2 gives the epicenter distribution of the earthquakes shallower than 100 km. This seismic zone turns westward in its northern end and eastward in its southern end. The former extends to the seismic zone along the Solomon Islands region, and the latter turns north-eastward and seems to run towards Fiji Islands, which will be shown in the later part of this paper. The shallow seismic activity was found to be characterized by a lot of swarms. The epicenters of these swarms are given in Fig. 3 separating from the ordinary epicenters which are shown in Fig. 2. In Fig. 3, frequency distribution diagrams of each event in each 12 hours are attached. Numbering from S1 to S8 were made chronologically. In the time interval from 1964 to 1969 at least, they have taken place separately in the northern, central and southern parts of the zone, and no systematic emigration can be found. Depths are mostly around normal. Large shocks with CGS magnitude m of more than 6.0 are shown by double circles and the

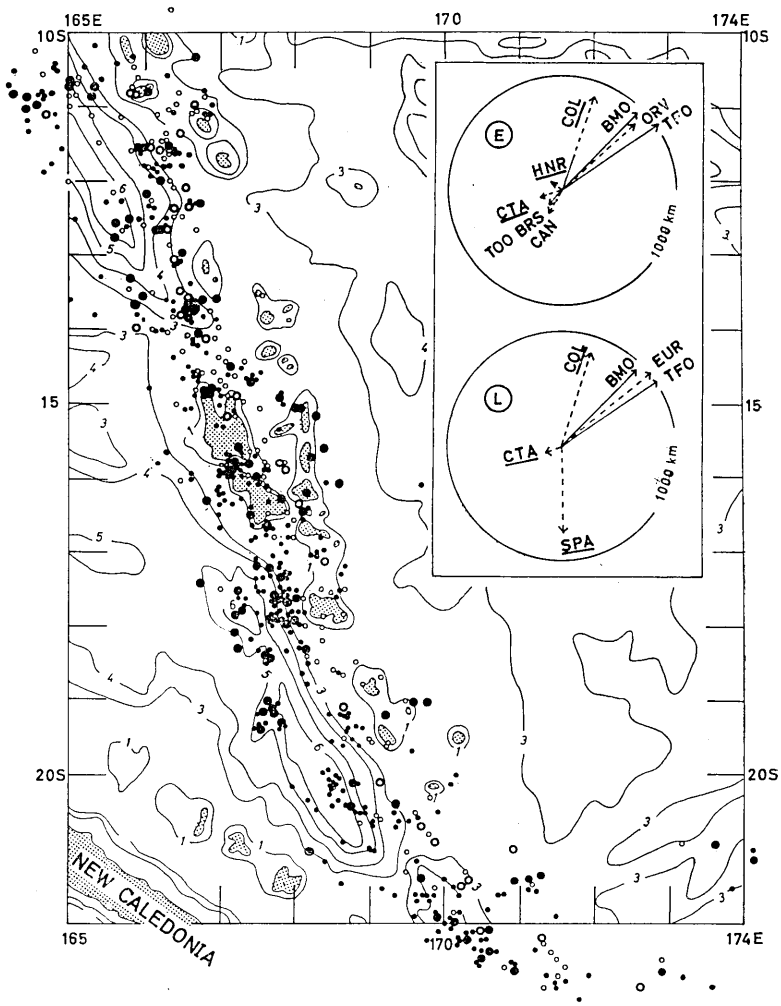


Fig. 2. Distribution of epicenters of earthquakes shallower than 100 km. Epicenters of swarms are omitted. Solid circles: $d<50$ km. Open circles: $50 \leqq d < 100$ km. Large circles: $m \geqq 5.0$. Dotted area: Islands. Numerals on the contour lines indicate the sea depth in km. Attached figures—Directions of seismological stations the data of which were available by USCGS to determine the foci of smaller events ($m \fallingdotseq 4.2$) in the earlier period E (1964) and in the later period L (1968). The difference of solid and broken arrows is explained in the text. Length of arrow is proportional to the distance of the stations from the center of the epicenter map.

locations of their occurrences in time scale are given by solid circles in frequency diagrams respectively.

The northernmost shock group A1 is considered to be the aftershocks associated with a main shock of $m=6.4$ on January 7, 1969. Though the decay of activity of S3, S4 and S7 shows more or less the nature of

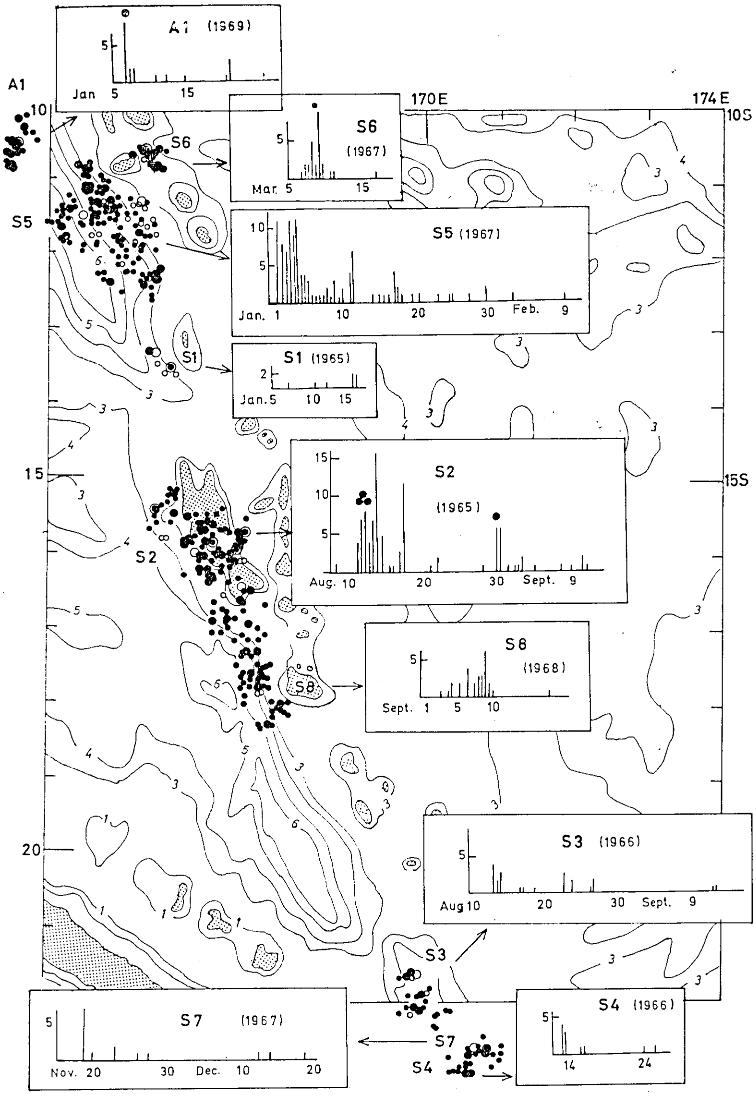


Fig. 3. Epicentral distribution of swarms (S1~S8) and aftershocks (A 1), and their frequency variations in every 12 hours. Swarms are numbered chronologically. Solid circles in frequency diagram show the time when large events with $m \geqq 6.0$ took place. In the epicenter map, solid circles: $d<50$ km. Open circles: $d \geqq 50$ km. Small circles: $m \leqq 5.0$. Large circles: $m \geqq 5.0$. Double circles: $m \geqq 6.0$

aftershocks, they do not contain any remarkable shock at the beginning, because of which they were ranked into the swarm.

These swarms of course contain many inductive events which are closely related with each other both in time and in space. Frequency of such inductive events in each 0.5°×0.5° mesh is given in Fig. 4. Besides these inductive events in swarms, it was also found that the

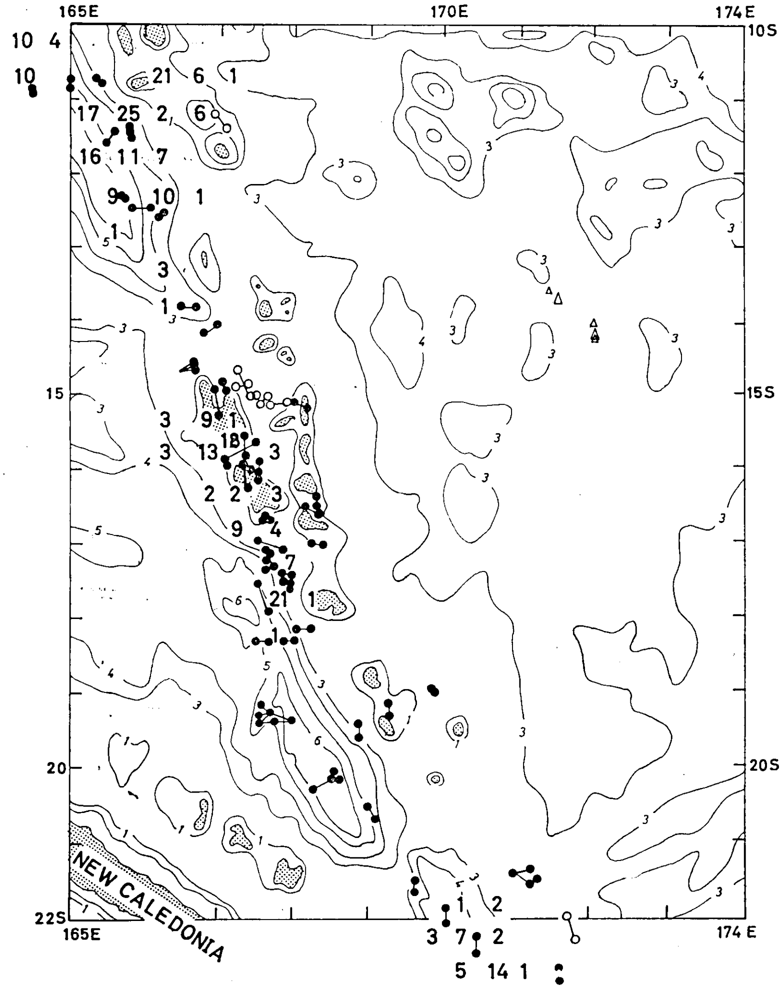


Fig. 4. Frequency distribution of the inductive shocks in the swarms in each 0.5°×0.5° mesh which are followed by other shocks closely related with each other both in time and in space. The pair or the group of similar inductive events which are not included in swarms are also shown by combined solid circles ($d<50$ km), open circles ($50\,\mathrm{km} \leqq d < 100$ km) and triangles (deeper than 550 km respectively.

shallow earthquakes zone in Fig. 2 contained many inductive events as are listed in Table 2. The location of these multiplets are plotted in Fig. 4 by circles. Altogether, activity of the inductive shallow

Table 2. List of the events which are closely related both in time (less than 24 hours) and space (less than 50 km).

Date	Origin Time (G.M.T.)	Epicenter λ	Epicenter φ	d km	Mag. m	Time diff. ΔT	Focal diff. Δλ	Δφ	Δd
d	h m s					h m s			
1964 Aug. 29	12 49 58.3	13.3S	172.4E	33	4.9	00 35 27.6	0.4	0.2	00
	13 25 25.9	13.7S	172.6E	33	5.0				
Dec. 16	03 57 17.2	21.6S	169.6E	44	4.3	08 23 16.0	0.1	0.0	23
	12 20 33.2	21.7S	169.6E	21	4.3				
May 31	07 15 26.8	13.6S	172.1E	73	4.7	10 00 00.0	0.0	0.0	00
	17 15 26.8	13.6S	172.1E	73	5.0				
1965 Jan. 06	09 51 09.0	22.7S	171.5E	64	4.5	15 49 32.0	0.2	0.0	31
07	05 40 41	22.9S	〃	33	4.5				
18	15 57 18.9	18.3S	167.5E	33	4.6	00 18 42.1	0.0	0.2	00
	16 16 05	18.3S	167.7E	33					
30	17 32 12.3	13.0S	169.4E	647	5.7	00 34 08.9	0.1	0.1	02
	18 06 21.2	12.9S	169.5E	649	5.4				
June 10	11 54 15	10.9S	164.6E	16		00 26 12.9	0.0	0.0	05
	12 30 27.9	10.9S	164.6E	21	4.0				
Aug. 16	02 56 51	17.1S	167.6E	33		11 47 57	0.3	0.1	13
	14 44 48	17.4S	16.77E	20	4.8				
Sept. 21	00 26 24	22.5S	170.4E	30	4.3	04 38 03.0	0.2	0.0	03
	05 04 27	22.3S	170.4E	33	4.3				
Oct. 15	11 55 19.8	12.5S	166.1E	41		00 06 39.0	0.0	0.3	08
	12 01 58.8	12.5S	165.8E	33	5.9				
Nov. 04	01 09 08.4	17.0S	167.5E	23	4.8	02 50 19.7	0.1	0.4	19
	03 59 28.1	17.1S	167.9E	42	4.9	03 56 58.9	0.3	0.3	09
	07 56 27	17.4S	167.6E	33					
14	03 26 39	20.3S	163.2E	33	4.5	14 13 17	0.2	0.3	14
	17 39 56	20.1S	168.5E	19	4.1				
1966 Jan. 20	04 27 44.9	15.1S	168.0E	28	5.5	01 07 0.2	0.1	0.2	05
	05 34 45.1	15.2S	168.2E	33	4.7				
28	05 42 16.4	17.1S	168.4E	24	5.7	01 10 30.6	0.1	0.3	09
	06 52 47	17.2S	168.7E	33	4.6	17 17 56.5	0.2	0.4	00
29	00 10 44.5	17.0S	168.3E	33	4.7	01 02 25.5	0.0	0.1	00
	01 13 15	17.0S	168.2E	33	4.5	05 11 57.7	0.1	0.2	00
	06 24 22.7	16.9S	168.4E	33	4.9				
30	11 05 02.3	22.1S	170.0E	46	5.3	19 03 00.7	0.2	0.0	13
31	06 08 03	21.9S	〃	33		02 25 29	0.2	0.0	02
	08 33 42	22.1S	〃	35					
Feb. 16	03 18 27.2	17.7S	167.9E	31	6.5	02 02 51.8	0.0	0.0	15
	05 21 19	〃	〃	16	4.8				
Mar. 07	19 58 51	13.8S	166.4E	33		08 14 51.0	0.1	0.2	04
08	01 13 42.3	13.9S	166.6E	37	5.8				
30	23 09 38	17.3S	167.9E	32		05 56 16.7	0.0	0.1	12
31	05 05 54.7	17.3S	16.88E	34	5.4				
Apr. 06	19 45 46	22.3S	171.7E	113	5.3	00 00 05	0.3	0.1	45
	51	22.0S	171.6E	158	5.2				
30	04 53 41	16.2S	167.0E	37		01 31 11	0.3	0.0	06
	06 24 53	15.9S	167.0E	43	4.5				
June 15	20 49 21	11.4S	167.1E	151	4.7	01 54 17.2	0.2	0.1	44
	22 43 38.2	11.2S	167.0E	107	4.9				

(to be continued)

Table 2. (continued)

Date	Origin Time (G.M.T.) h m s	Epicenter λ	Epicenter φ	d km	Mag. m	Time diff. ΔT h m s	Focal diff. Δλ	Δφ	Δd
July 28	01 05 39	17.3S	167.6E	19		00 12 43.3	0.1	0.1	02
	18 27.4	17.2S	167.7E	17	5.3				
	09 42 36.8	14.9S	167.3E	141	5.0	02 49 52.2	0.0	0.0	29
	12 32 29	14.9S	167.3E	112	4.1				
Aug. 08	22 37 42	20.1S	168.5E	37	4.1	02 35 31	0.1	0.0	08
09	01 13 13	20.2S	168.5E	29					
Nov. 05	02 30 15.0	19.2S	169.2E	25	5.3	03 13 01.0	0.1	0.0	17
	05 43 16	19.3S	169.2E	8					
12	18 45 01.0	15.6S	167.3E	40	5.2	10 52 21.0	0.2	0.0	22
13	05 37 22	15.8S	167.3E	18	4.9				
23	02 19 13.8	14.0S	166.9E	48	5.6	06 02 47.2	0.1	0.1	26
	08 21 01	14.8S	166.8E	22					
1967 Feb. 01	06 19 55.7	15.9S	167.0E	21	4.6	00 04 40.3	0.1	0.1	14
	24 36.0	16.0S	167.1E	7		23 18 27.8	0.1	0.1	07
02	05 43 03.8	15.9S	167.0F	14	4.5	07 01 27.2	0.2	0.5	23
	12 44 31	15.7S	167.5E	37					
Mar. 21	19 06 30.3	11.5S	165.6E	39	4.9	05 04 19.4	0.2	0.1	06
22	00 10 51.7	11.7S	165.5E	33	4.8				
27	10 01 42.0	16.5S	168.1E	11	5.5	10 13 02.0	0.1	0.2	10
	20 14 44	16.6S	168.3E	21	4.9				
29	12 49 16	16.4S	168.2E	10	4.7	00 23 37	0.1	0.0	23
	13 12 53	16.5S	168.2E	33	4.9	14 21 51	0.1	0.0	15
30	03 34 44	16.4S	168.2E	17	4.7				
Apr. 1	15 39 32	16.7S	167.7E	18	4	00 16 35.4	0.0	0.1	03
	56 07.4	16.7S	167.6E	10	4.7	00 12 45.6	0.0	0.0	18
	16 08 53.0	16.7S	167.6E	28					
17	11 18 19.3	12.5S	166.3E	45	4.9	01 16 17.2	0.2	0.5	12
	12 34 36.5	12.7S	165.8E	33					
28	07 18 57.1	11.3S	165.8E	37	4.7	00 25 39.9	0.2	0.0	07
	44 37	11.5S	165.8E	30	4.7	00 00 17	0.1	0.0	26
	54	11.4S	165.8E	56	3.6				
May 05	17 03 30	14.0S	167.0E	58	4.9	00 26 24.4	0.1	0.2	10
	29 54.4	14.1S	166.8E	48	4.7				
22	13 34 24	16.0S	167.4E	60		05 03 24	0.1	0.1	27
	18 37 48	16.1S	167.5E	33					
June 06	09 29 54.3	10.9S	165.4E	27	4.8	00 00 32.4	0.1	0.1	06
	30 26.7	10.8S	165.3E	33	5.1				
13	00 17 15.6	17.5S	167.5E	9	4.8	14 23 50.4	0.4	0.2	08
	14 43 06.0	17.9S	167.7E	17	4.5				
Aug. 24	03 21 40	15.3S	167.0E	42		07 11 12.6	0.4	0.1	19
	10 32 52.6	14.9S	166.9E	23	5.3				
31	10 47 30.4	18.7S	169.1E	234	4.9	22 08 06.2	0.2	0.3	08
Sept. 1	08 55 36.6	18.9S	169.4E	242	4.9				
12	12 37 18	19.2S	167.5E	9	4.9	10 23 42	0.1	0.1	14
	23 01 00	19.3S	167.6E	23	4.7				
13	00 05 55.3	19.4S	167.5E	17	5.0	00 09 06.6	0.0	0.2	15
	15 02.4	〃	167.7E	33	4.3	00 20 22.3	0.0	0.3	00
	35 24.7	〃	168.0E	33		00 03 50.3	0.1	0.5	23
	39 15	19.3S	167.5E	10	4.6				

(to be continued)

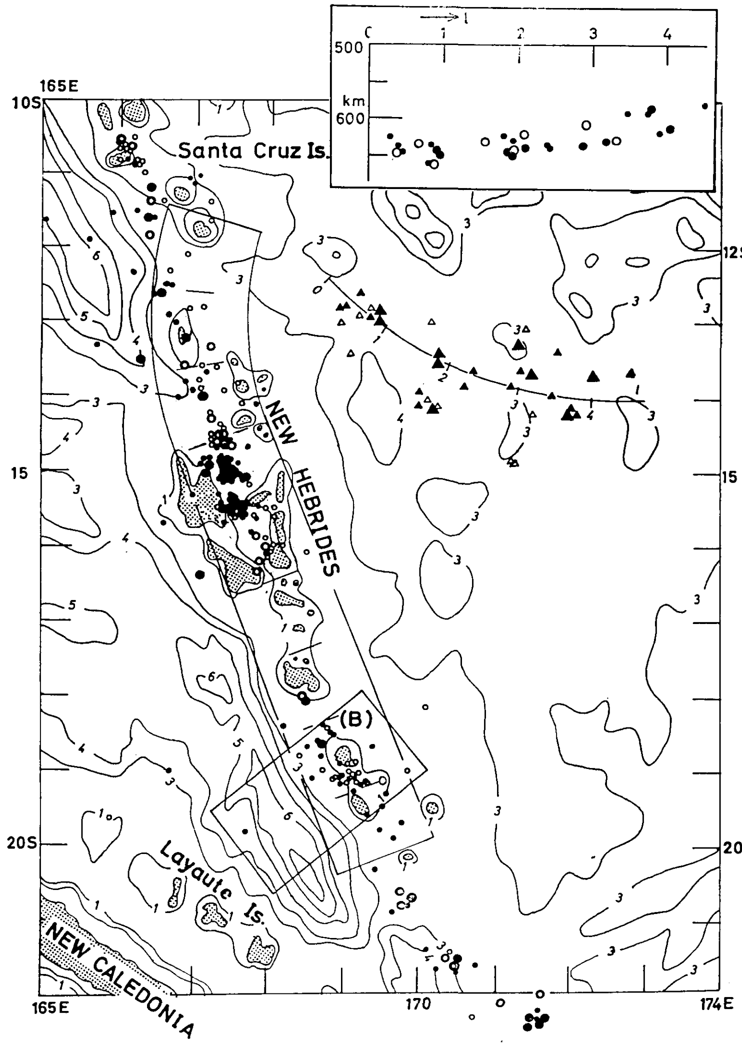
Table 2. (continued)

Date	Origin Time			Epicenter		d	Mag.	Time diff.			Focal diff.		
	(G.M.T.)			λ	φ	km	m	ΔT			Δλ	Δφ	Δd
d	h	m	s					h	m	s			
Oct. 18	23	35	11.0	13.9S	166.5E	87	5.0	07	51	54.0	0.0	0.2	42
19	07	27	05	〃	166.7E	45							
23	04	57	40.0	15.0S	167.4E	115		20	40	22.7	0.2	0.2	06
24	01	38	12.7	14.8	167.2	109	4.3						
Nov. 21	17	45	48.0	12.7S	166.3E	43		02	13	44.4	0.1	0.0	05
	19	59	32.4	12.6S	166.3E	48	4.5						
Dec. 17	10	56	48	20.5S	168.9E	32		09	56	13.0	0.2	0.1	01
	20	53	01.0	20.7S	169.0E	33	4.2						
20	03	48	52.3	15.1S	167.6E	129	5.1	08	38	56.8	0.0	0.3	06
	17	07	49.1	〃	167.9E	135	5.1						
1968 Jan. 08	03	17	12.6	13.7S	171.5E	630	5.2	00	19	37.7	0.1	0.2	01
		36	50.3	13.6S	171.3E	631	4.2						
13	04	22	13.9	12.3S	165.7E	38	4.5	22	22	52.0	0.0	0.0	10
14	02	45	05.9	〃	〃	48	4.6	23	17	12.0	0.3	0.1	07
15	02	02	17.9	12.6S	165.6E	41	5.0						
25	21	36	30	19.5S	168.8E	33		00	41	57	0.1	0.1	00
	22	13	27	19.6S	168.9E	33							
22	12	55	48.2	12.6S	167.0E	215	5.0	02	18	25.5	0.4	0.0	34
	15	14	13.7	12.2S	167.0E	249	4.6						
Feb. 09	18	52	11	12.4S	167.8E	33		21	14	55.8	0.2	0.1	02
10	16	07	06.8	17.6S	167.9E	31		00	15	47.0	0.1	0.1	09
		22	63.8	17.5S	167.8E	22	4.2						
	19	31	07.2	14.6S	166.7E	34	4.3	00	34	26.7	0.1	0.0	12
	20	05	33.9	14.7S	166.7E	22	4.1	00	03	07.0	0.0	0.2	09
		08	41.6	〃	166.5E	13	4.7	01	28	56.4	0.1	0.2	20
	21	47	38	14.6S	166.7E	33		00	04	23.4	0.0	0.0	08
		52	11.4	14.6S	166.7E	41	4.4						
Mar. 16	03	39	12	15.0S	167.6E	121		13	16	48	0.1	0.1	06
	16	56	00	15.1S	167.5E	127							
May 12	18	39	10.8	19.0S	169.8E	16	5.1	00	17	12.0	0.0	0.0	09
	18	56	22.8	19.0S	169.8E	5	4.6						
June 15	12	05	44.0	13.3S	167.8E	12		01	28	30.4	0.0	0.0	11
	13	34	14.4	18.3S	167.9E	11	5.5						
27	10	37	04.6	15.9S	167.3E	27		13	07	18.6	0.4	0.0	19
	23	44	25.2	16.3S	167.3E	8	4.6						
Aug. 06	01	23	14.0	16.0S	167.5E	57		05	22	53.8	0.2	0.4	43
	06	46	07.8	15.8S	167.1E	14	4.5						
18	16	44	20.4	12.5S	166.3E	16	4.6	01	24	14.9	0.2	0.1	18
	18	08	35.3	12.7S	166.2E	34	5.2	00	20	46.5	0.1	0.1	04
		29	21.8	12.6S	166.3E	38	4.7						
Sept. 06	14	02	00.6	10.8S	165.0E	28	5.3	00	38	24.9	0.1	0.0	01
		30	25.5	10.9S	165.0E	29							
17	14	23	57.7	16.1S	167.7E	39	4.6	21	12	16.3	0.1	0.3	05
18	11	36	14.0	16.0S	167.4E	44							
Nov. 04	09	07	38.5	14.2S	172.0E	585	5.8	01	28	42.8	0.1	0.0	06
	10	36	21.3	14.1S	172.0E	591	4.8	00	10	09.9	0.1	0.0	24
		47	12.2	14.2S	172.0E	615	4.2						
07	17	09	52.5	14.0S	166.8E	56		18	33	01.3	0.0	0.1	15
08	12	42	53.8	14.0S	166.7E	41							

(to be continued)

Table 2. (continued)

Date	Origin Time (G.M.T.)	Epicenter λ	Epicenter φ	d km	Mag. m	Time diff. ΔT	Focal diff. Δλ	Δφ	Δd
d	h m s					h m s			
Dec. 28	01 11 55.7	18.2S	168.2E	37	4.4	01 37 00.1	0.0	0.2	12
	08 48 55.8	18.2S	168.0E	25					
29	04 35 53.9	14.7S	167.2E	100		03 05 04.4	0.5	0.3	21
	07 41 02.3	15.2S	167.5E	121					
1969 Feb. 25	13 33 58.3	15.0S	167.4E	125	5.0	01 08 32.1	0.0	0.0	07
	14 42 30.4	15.0S	167.4E	132	5.0				
Mar. 18	03 25 31.8	21.4S	171.1E	15	5.5	00 07 19.0	0.0	0.2	18
	03 32 50.8	21.4S	170.9E	N	5.5				
	07 46 48.6	21.5S	171.1E	N	3.9	04 13 21.7	0.0	0.1	16
	13 20 06.3	21.5S	171.2E	49	4.3				



events is quite high in the New Hebrides region, which must be counted as one of the remarkable characteristics. After K. Mogi's

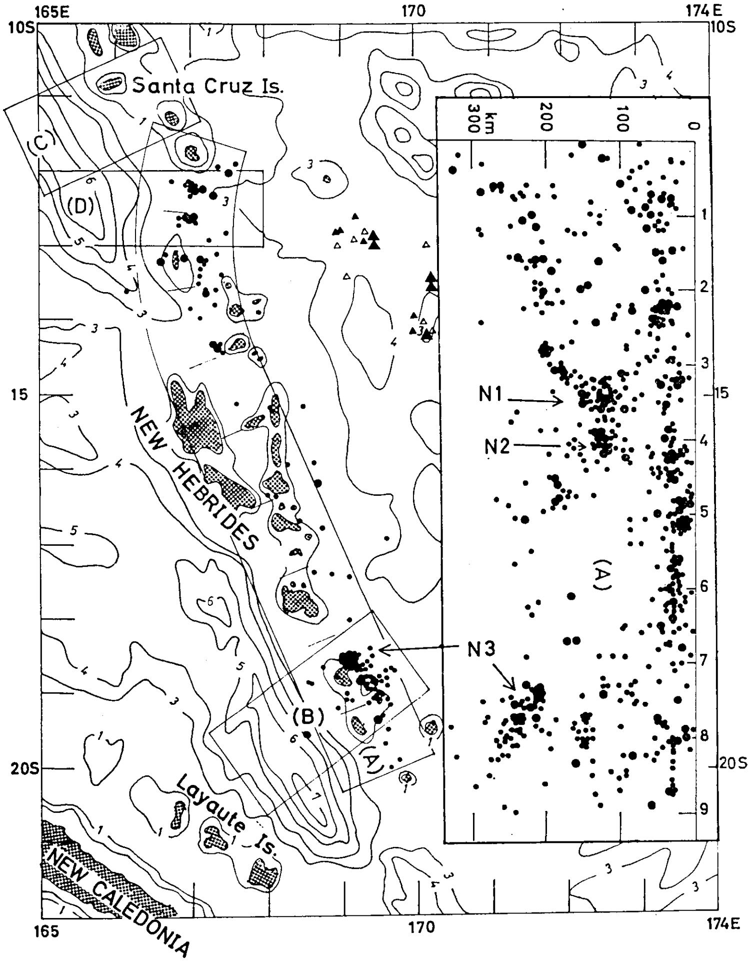


Fig. 6. Distribution of the epicenters of earthquakes deeper than 200 km. Epicenters of deep ($d>550$ km) events are also partly represented. Attached figure—Foci distribution of all the events along the profile (A). N1, N2, N3: earthquake nests. Horizontal scales are taken in degree.

Fig. 5. Distribution of epicenters of the upper mantle earthquakes shallower than 200 km and deep earthquakes. Filled circles: $100\text{ km} \leqq d < 150\text{ km}$. Open circles: $150\text{ km} \leqq d < 200\text{ km}$. Solid triangles: $d > 550\text{ km}$. Large marks; $m \geqq 5.0$. Open triangles: Deep earthquake data by R. L. Sykes.[5] Attached diagram: Foci distribution of deep earthquakes being projected on a curved section l. Open circles mean the data by R. L. Sykes.[5]

study[3], this characteristic may suggests that the degree of fracturing beneath the region in question shallower than 50 km is high, which also leads to the suggestion that the possibility of the occurrence of large shallow earthquakes may be small. B. Gutenberg and C. F. Richter[4], in a summary of large shocks before 1956, did not report any great shallow earthquakes with M larger than 7.9 in the region in question.

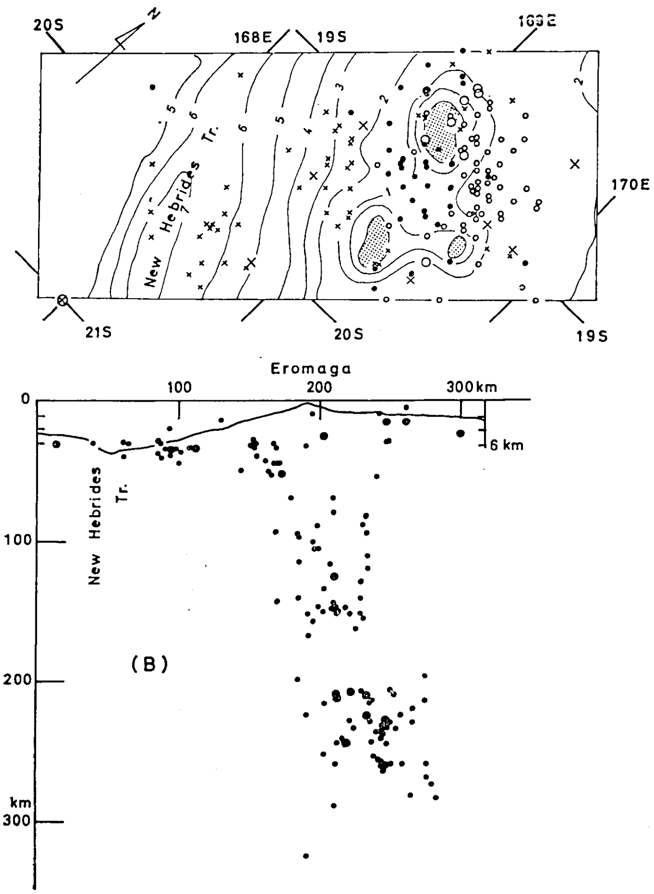


Fig. 7. Above: Detailed distribution of epicenters in the area (B) in Fig. 5. Solid circles: 100 km $\leqq d < 200$ km. Open circles: $d \geqq 200$ km. Crosses: d < 100 km. Large marks: $m \geqq 5.0$
Below: Foci distributions in the area (B) being projected on the longer central axis. The data of the swarms S2 (see Fig. 3) are excluded for avoiding the complexity of the figure.

Distributions of the epicenters of upper mantle events with the depth range from 100 km to 200 km are shown in Fig. 5. They run a little to the eastern side of the shallower seismic zone (refer to Fig. 2). Two compact groups of epicenters N1 and N2—earthquake nest as they are called—are seen around 15°S between Islands. Another group N3 with deeper depth range from 200 km to 300 km is also seen in the next Fig. 6 around 19°S. This deeper group, together with other neighbouring epicenters in the same depth range, distribute parallel to the shallower epicenters (compare with Figs. 5 and 2), and foci in the area B at least become deeper northeast-

3) K. MOGI, "Regional Variation of Aftershock Activity", *Bull. Earthq. Res. Inst.*, **45** (1967), 711-726.

4) B. GUTENBERG and C. F. RICHTER, "*Seismicity of the Earth and Associated Phenomena 2nd ed.*, (Princeton Univ. Press 1954).

ward against the trench. This is a typical arrangement of the foci distribution in the Islands-arc system. An exceptionality, however, was discovered concerning the dip of the focal zone, which was measured of being approximately 70° (Fig. 7). This value is the largest one obtained for focal zones shallower than 300 km in the regions belonging to the Islands-arc-trench system. Existence of a less seismic depth range from 160 km to 200 km must also be noticed (refer to Part I).[5]

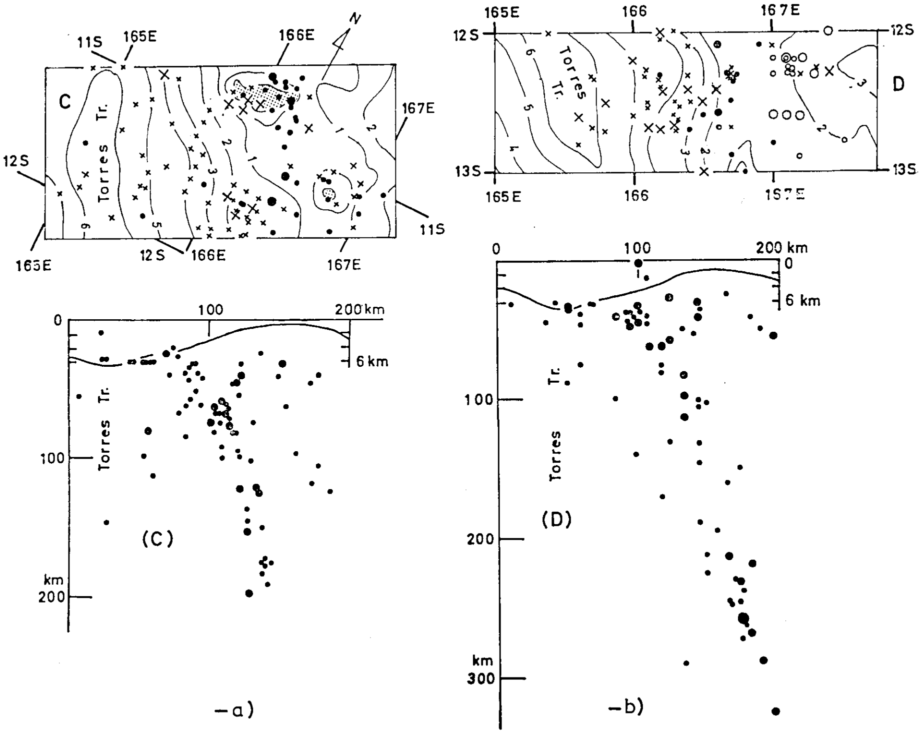


Fig. 8 —a). Detailed distribution of epicenters in the area (C) in Fig. 5. Solid circles: $100 \leqq d < 200$ km. Crosses: $d < 100$ km. Large marks: $m \geqq 5.0$. Below: Foci distribution in the area (C) being projected on the longer central axis.
—b). Detailed distribution of epicenters in the area (D) in Fig. 5. Solid circles 100 km $\leqq d < 200$ km. Open circles: $d \geqq 200$ km. Crosses: $d < 100$ km. Large marks: $m \geqq 5.0$. Below: Foci distribution in the area (D) being projected on the longer central axis.

Another thing to be remarked upon in Fig 6 is that the trend of the epicenters in the northern part does not follow the typical feature of the Island-arc trench system. That is, they change their trends eastward separating from the trend of arc as if they are pulled by the deep events with the depth of more than 550 km.

Comparing Fig. 6 with Fig. 5, it is also noticed that the depth of the upper mantle events are deeper both in the northern and southern

5) *ibid.*, 2)

parts and shallow in the central part of the Islands arc. This feature is clarified by the attached figure in which foci distribution of the events along the (A) profile is presented including the shallow foci. As far as the upper mantle foci deeper than 100 km are concerned, they have a tendency to underthrust towards the northern and southern directions with similar dips of around 45° containing two earthquake nests N1 and N2 in the top. In must be noticed that the trenches existing in the western side of the two terminals of the profile (A) seem to have deepened the foci. N1 contains several inductive events which are closely related with each other both in time and space (see open circles in Fig. 4).

Foci distributions along the profiles (C) and (D) in the northern part near the Torres trench were examined, these being shown in Fig. 8. Along the profile (D) which is almost perpendicular to the trend of the trench, foci distribution shows the dip of around 70°, which is the same as along the profile (B) which was taken perpendicular to the New Hebrides trench. Seismic activity along the focal zone is rather poor in the depth range from 160 km to 200 km, which is also the same feature as the previous focal zone along the profile (B). Another profile (C) was taken from the Torres trench to Santa Cruz Islands, where a seismic zone with the depth range from 200 km to 300 km has already turned eastward escaping from the general trend of a shallower zone. The focal zone along this profile also shows a similar dip as in the previous two cases. It does not, however, have a less seismic depth range.

Foci distributions along other profiles perpendicular to the trend of the Islands arc in the central part where the trench is missing were also examined. The focal zones had also dips of around 65°.

In general, the focal zone extended to 300 km in two profiles only, one containing the New Hebrides trench and the other the southern part of the Torres trench. As mentioned in Part II, the formation of the trench looks like having a close relation with the extension of focal zone, that is, the underthrusting of the lithosphere slab.

Twenty-six deep earthquakes were reported by USCGS (Table 3), the epicentral distribution of which is shown in Fig. 5 by solid triangles. Data observed by L. R. Sykes[6] during the period from 1957 to 1963 are also added by open triangles. Quite different from the feature which is always observed in the Islands-arc trench system, they do not distribute parallel to the Islands-arc but extend towards Fiji Islands (refer to Fig. 10). Such a peculiar trend of deep earthquake zone against the trend of the trench was also observed in South America[7]. In South

6) L. R. Sykes, "Deep-Focus Earthquakes in the New Hebrides Region", *J. Geophys. Res.*, **69** (1964), 5353-5355.

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

America, foci were gradually deepened against the trench. In the present case, on the contrary, foci gradually become shallower eastward against the trench (see the upper-right diagram in Fig. 5). Though the data are still poor, the foci also look like becoming shallower in a western direction too. It is not difficult, therefore, to suppose that the deep seismic zone we are dealing with now may be connected to the seismic zone with the depth range from 200 km to 300 km which turns eastward at its northern end.

Seismic activities of all the events deeper than 100 km in each 25 km range are shown in Fig. 9. Seismicity deeper than 550 km is completely separated from that of shallower than 300 km. In the upper mantle, frequency shows a minimum around 175–200 km.

Table 3. List of deep earthquakes in the northeastern part of the New Hebrides Islands region. (January 1964—April 1969.)

Date	Origin Time (G.M.T.) h	m	s	Epicenter		*d* km	Mag. *m*
1964 Mar. 14	15	05	54.4	14.7S	172.3E	611	5.1
June 21	13	10	28.9	12.6S	169.4E	648	4.9
Sept. 17	15	06	14.8	12.8S	168.9E	622	4.5
1965 Jan. 21	21	37	26.2	12.8S	169.0E	639	4.5
25	01	11	54	14.8S	171.2E	635	4.3
30	17	42	12.3	13.0S	169.4E	647	5.2
	18	06	21.2	12.9S	169.5E	649	5.4
Apr. 10	22	53	04.8	13.4S	170.3E	644	6.2
19	17	01	10.5	13.5S	170.3E	647	3.9
June 29	02	07	18.1	13.8S	170.6E	636	
Sept. 12	19	11	34	13.9S	172.7E	590	3.7
Oct. 01	13	22	28.5	20.0S	174.4E	533	6.2
Dec. 13	16	50	16.8	14.1S	170.2E	638	5.0
1966 Apr. 24	03	28	50.5	12.8S	169.5E	660	4.6
June 04	08	35	15.4	14.8S	171.2E	660	4.6
1967 Feb. 14	05	02	38.4	13.3S	171.3E	635	5.6
Mar. 16	17	33	07.5	13.6S	170.7E	637	4.8
May 12	01	59	31.6	13.9S	170.0E	620	4.1
Aug. 25	09	09	15.3	14.1S	170.0E	629	4.0
1968 Jan. 08	03	17	12.6	13.7S	171.5E	630	5.2
		36	50.3	13.6S	171.3E	631	4.2
Feb. 17	19	49	22	13.6S	172.8E	577	4.5
Nov. 04	09	07	38.5	14.2S	172.0E	585	5.8
	10	36	21.3	14.1S	172.0E	591	4.8
		47	12.2	14.2S	172.0E	615	4.2
1969 Jan. 02	15	47	55.4	12.9S	169.1E	635	4.7

4. Trend of Seismic zones in New Hebrides Islands region with relation to those around Fiji-Tonga-Kermadec Islands region

As has been described, the epicentral distribution of deep earthquakes is not parallel to the trend of the New Hebrides Islands but rather directed to Fiji Islands. The upper mantle earthquakes zone of deeper than 200 km changes its direction eastward at the northern end. The trend of the shallow earthquake zone also turns north-easterly in its southern end. These situations can well be clarified by examining their relations to the epicenter distributions in the region between New Hebrides Islands and Fiji Islands or much further to Tonga Islands. L. R. Sykes *et al.*[8] relocated

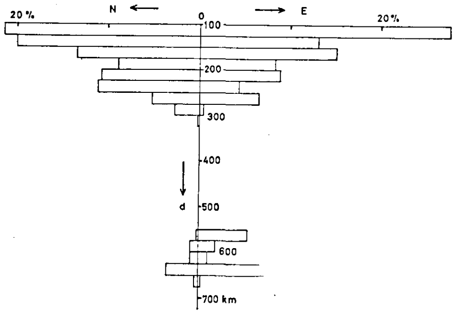


Fig. 9. Frequency (N) and Energy (E) distribution versus depth (d) of the upper mantle earthquakes with the depth of more than 100 km.

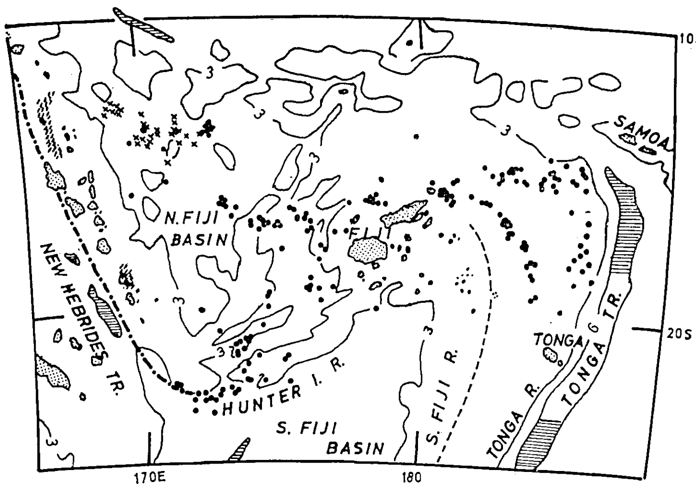


Fig. 10. Schematical presentation of the seismic zones in the New Hebrides Islands region with relation to those around the Fiji and Tonga Islands regions. Thick dash-dotted line through New Hebrides Islands: axis of the seismic zone shallower than 100 km. Areas with short oblique bars: seismic areas with depth deeper than 200 km. Crosses: deep seismic zone. Solid circles: local events observed by L. R. Sykes *et al.* Broken curves near South Fiji Ridge: representative contour lines of deep earthquakes in the Tonga-Kermadec Islands region by L. R. Sykes *et al.*[8]

8) L. R. SYKES, B. L. ISACKS and J. OLIVER, "Spatial Distribution of Deep and Shallow Earthquakes of Small Magnitudes in the Fiji-Tonga Region," *Bull. Seism. Soc. Amer.*, **59** (1969), 1093–1113.

the hypocenters in the region between Fiji and New Hebrides by computer in the period of 1920–1965. Their data which are given in Fig. 10 by filled circles are quite helpful for this investigation. Most of them are shallow ones excepting a group of fourteen events gathering in their southernmost portion, which have depths between 50 km and 100 km.

We can see that four shallow seismic zones connect the New Hebrides Islands and Tonga Islands regions, which gather at the northern part off the coast of Fiji Islands by sinistral curves. As has been pointed out by B. Gutenberg and C. F. Richter[9] or by L. R. Sykes[10] from the seismological view point and by H. H. Hess and J. C. Maxwell[11] from the geological and bathymetrical data, Fig. 10 well indicates the close tectonical connection between New Hebrides Islands and Tonga Islands through Fiji Islands.

The sea floor spreading hypothesis demands six main plates which separately grow up from the ridges and disappear beneath the trenches[12]. Taking this model into account, trenches off the western coast of New Hebrides Islands and a shallow seismic zone connecting the southern part of New Hebrides arc and the northern part of the Tonga-Kermadec arc through Fiji Islands might be caused by the north-eastern drifting of the Indian plate against the Pacific plate. The above supposition is supported by L. R. Sykes *et al.*,[13] who observed that three shallow earthquakes along the zone from Fiji to the southern end of the New Hebrides arc are characterized by a left-lateral strike-slip motion being generated by the transform fault. Isacks *et al.*[14] also reported the same mechanism for an earthquake between Fiji and the northern end of the Tonga trench. Survey on a geomagnetic pattern of the ocean floor in both sides of this zone is requested for providing better and more direct evidence.

With regard to the existence of another shallow seismic zone which also crosses the ocean floor between the northern part of the New Hebrides arc and the Tonga arc through Fiji Islands, it is still hard to offer any suggestion at the present moment without obtaining some other kinds of geophysical evidences.

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9) *ibid.*, 4)

10) *ibid.*, 6)

11) H. H. HESS and J. C. MAXWELL, "Major Structural features of the Southwest Pacific: A Preliminary Interpretation of H.O. 5484, Bathymetric Chart, New Guinea to New Zealand- 7th Pacific Sci. Congress, New Zealand, 2 (1953) 14–17.

12) X. LE PICHON, "Sea-Floor Spreading and Continental Drift," *J. Geophys. Res.*, **73** (1968), 3661–3697.

13) L. R. SYKES, "Mechanism of Earthquakes and Nature of Faulting on the Mid-Ocean Ridges, "*J. Geophys. Res.*, **72** (1967), 2131–2153.

14) B. L. ISACKS, L. R. SYKES and J. OLIVER, "Focal Mechanisms of Deep and Shallow Earthquakes in the Tonga-Kermadec Region", *Bull. Geol. Soc. Amer.*, **80** (1969), 1443–1470.

1. 世界の特殊な地震地域の活動について

(其の三) New Hebrides 諸島周辺

地　震　研　究　所
国際地震・地震工学研修所　三　東　哲　夫

New Hebrides 諸島北東部の海洋底に分布する深発地震の震央分布は，島弧にも海溝にも平行せずに，Fiji 島に向つて斜めに分布している．これがこの周辺を特殊な地震地域の一つに取り上げた理由である．

島弧にそつて起こつている浅い地震は，多くの小規模な群震を含んでいるばかりでなく，一般に誘発性を帯びている (第 3, 4 図，表 2)．茂木の考え方を借りれば，このことは，この周辺の浅い部分の構造に破砕度が高く，従つて大きな地震は起こりにくいことを予測させるが，事実，Gutenberg-Richter の "Seismicity of the Earth" をみても 1953 年以前に於てもこの地区では $M \geqq 7.9$ の浅い地震は一つも報告されていない．

マントル上層部では，100 km～150 km の深さに 2 つ，200 km ~250 km の深さに 1 つ地震の巣がある．いずれも島弧の中央部付近に位置し，島弧ぞいのマントル上層部地震の震源は，これらの巣を中心として島弧の南北両端にむけて次第に深まる傾向を見せる (第 6 図)．そしてちょうどその深まるあたりの西側に海溝ができていることが注目される．そしてこれらの海溝の軸に直角な面内での震源分布は，約 70° という他の島弧ではみられない大きな傾斜で深さ 300 km 前後まで達している (第 7, 8 図)．前篇でも述べたように，この場合にも震源面の没入する深さは海溝の生成と関連がありそうである．また，これも前篇でふれたと同じく，ここでも地震活動が比較的弱まる深さが，160 km から 200 km にかけて認められる (第 9 図)．

L. R. Sykes らは Fiji 島周辺から New Hebrides 諸島にかけての海域で，1920 年から 1965 年までの間に起こつた地震の震源を決め直したが，その結果とこんどのそれとを引き合わせてみるとたいへん面白い．即ち，New Hebrides 諸島の南端で方向を北東に変えてわん曲する浅い地震帯は，Tonga-Kermadec の北端でこれまた逆に南西に方向転換する浅い地震帯と Fiji 島北部でつながるし，これとは別に，これも Fiji 島付近から別のもう 1 本の浅い地震帯がほぼ東西にのび，東の方へのびた帯は，ゆるやかに南に転じて Tonga 島をめざす一方，西にのびたものは途中で切れるが，その先は，New Hebrides 東北部を逆に Fiji 島に向う深発地震帯と合流している (第 10 図)．最近話題になつている海洋底拡大説に従うならば，上にのべた第一の帯，つまり New Hebrides 諸島南端と Tonga 諸島北端とを結ぶ浅い地震帯は，インド大陸や Australia をのせた "Indian plate" が，Fiji-Tonga 諸島を北東におしやつたその境目の tramsform fault に生じた地震帯と考えられる．この考えを直接実証するためには，この地震帯をはさむ海底の地磁気の縞模様の調査が必要だけれども，Isacks や Sykes らが調べた発震機構の研究結果は，上にのべた考え方を裏付けている．また，太平洋から見れば大陸側に存在するという点で例外的な New Hebrides 諸島西側の海溝も，この "Indian plate" が "Paciffc plate" の下にもぐりこんだためにできた海溝だということで説明がつく．また，海溝は plate が比較的深くもぐれた場所にだけできるのであろう．