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SEISMICITY OF THE EARTH

BY

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AND

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INTRODUCTION

This paper is intended: (1) to give an account of the relative seismicity of various parts of the earth during the limited period for which accurate information is available, and (2) to identify and discuss the geographical and geological relationships of the principal zones and areas of seismic activity.

Maps purporting to show the distribution of earthquake epicenters have usually been based either on historical data or on the results of instrumental seismology, sometimes on both. Such maps, unless studied with critical attention, are likely to give a distorted impression of the facts. Historical macroseismic data are in general available only for land areas, and are much influenced by the present and past state of culture in the districts affected. Instrumental determinations require much careful sifting, for reasons which will become thoroughly apparent as the discussion proceeds. Many recent maps have been based on the epicenters published in the International Seismological Summary (Turner, *et al.*, 1923–1940) and similar compilations of earlier date, without any attempt to discriminate with reference to the accuracy of the determination, the magnitude of the shock, and in most cases even the focal depth. Further confusion is created by alternative epicenters suggested for poorly recorded shocks. Thus, for the earthquake of September 19, 1926, at 20^h,[1] the Summary gives the following four alternatives: 42° S. 130° E., 72° N. 2.8° W., 47° N. 10° E., 59° N. 65° E. Probably none of these is correct; the shock appears to be a deep-focus earthquake in the South Pacific. Nevertheless, these four epicenters appear as separate entries in the catalogues based on the Summary, and have appeared separately on maps. Instances of this kind are rather frequent, especially when only two alternatives are given.

There is no doubt that the International Summary is the proper basis for all investigations of this kind, including the present paper, which could hardly have been undertaken without it. The existence of inaccuracies in the Summary is no reflection on its very careful compilers but is due to a variety of causes, among which are: use in earlier years of travel time data which later research has shown to be in need of revision,—such as was adopted in the Summary for 1930 and following years; errors of inter-

[1] Times of shocks given in this paper regularly are Greenwich mean civil time (0^h to 24^h beginning at midnight) of occurrence at the seismic origin. The dates correspond to these, and may be one day earlier or one day later than the date according to local time in the country of origin. In a few cases, where this difference is likely to cause confusion, the local date has also been given.

Shocks of classes *a* and *b* are recorded at all stations; class *c* is well recorded up to 90°, class *d* up to about 45°, and class *e* in general not beyond 10°. This classification has been adhered to in mapping and in most of the tabulation. Some shocks assigned to class *b* were later found to have magnitudes slightly below 7.

In making use of the International Seismological Summary, all shocks from January 1, 1931 to March 31, 1934 have been examined critically. For this period most of the epicenters given in the Summary can be accepted as accurate within 1 degree of arc. A small number of the Summary epicenters, listed as Table 3, have been altered slightly. Shocks of class *e* have been rejected, as well as imperfectly recorded shocks, for which it was considered that the epicenters might be in error by several degrees. These latter shocks are usually qualified as very doubtful in the Summary.

Numerous shocks in areas of special interest have been selected from the International Summary for 1920–1930 inclusive. Most of the epicenters in this period call for significant revision, which has been carried out with much care. The method used has been described elsewhere (Gutenberg and Richter, 1937). The results will be found in Tables 6–20 accompanying the discussion of the seismicity of specific regions.

The International Summary has also served as a basis for another tabulation of statistical importance (Table 4). This list contains all shocks of magnitude 7 to 7.7 from January 1, 1926 to March 31, 1934. For 1926–1930 magnitudes were determined by Richter (1936) from amplitudes of earth motion as reported in various station bulletins. All origin times, epicenters and magnitudes have been carefully revised. Note that 13 larger shocks occurring in these years are included in Table 5. The following shocks mapped as of class *b* have magnitudes slightly below 7:

1931, Jan. 2	9^h	19.2° N.	107.0° W.	1931, Feb. 27	9^h	2.3° N.	127.2° E.
1931, March 19	6	18.0° N.	120.4° E.	1931, April 6	6	7.0° S.	155.0° E.
1932, Jan. 24	3	16.9° S.	168.3° E.	1932, Feb. 16	13	15° S.	180°
1932, Nov. 2	11	22.2° S.	112.2° W.	1933, March 17	19	6.5° N.	127.0° E.
1933, May 16	1	7° N.	96½° E.	1933, July 9	12	44.7° N.	150.2° E.
1933, Sept. 25	18	38.3° N.	86.8° E.	1933, Oct. 2	15	2.1° S.	81.2° W.
1933, Nov. 22	12	5.7° S.	151.8° E.	1933, Dec. 12	14	4.3° S.	153.0° E.

A previous list of shocks of magnitude $7\frac{3}{4}$ to $8\frac{1}{2}$ (Gutenberg and Richter, 1936) has served as a basis for further investigation. It is believed that Table 5 contains all very large shallow earthquakes from 1904 to 1940 inclusive. Epicenters and origin times have been revised, more recent shocks have been added, and a number of shocks which proved on investigation to have deep focus have been dropped.

At present the International Summary is available only to March 31, 1934. This renders the investigation of later shocks comparatively laborious, and in a sense premature, as the data of many stations are not

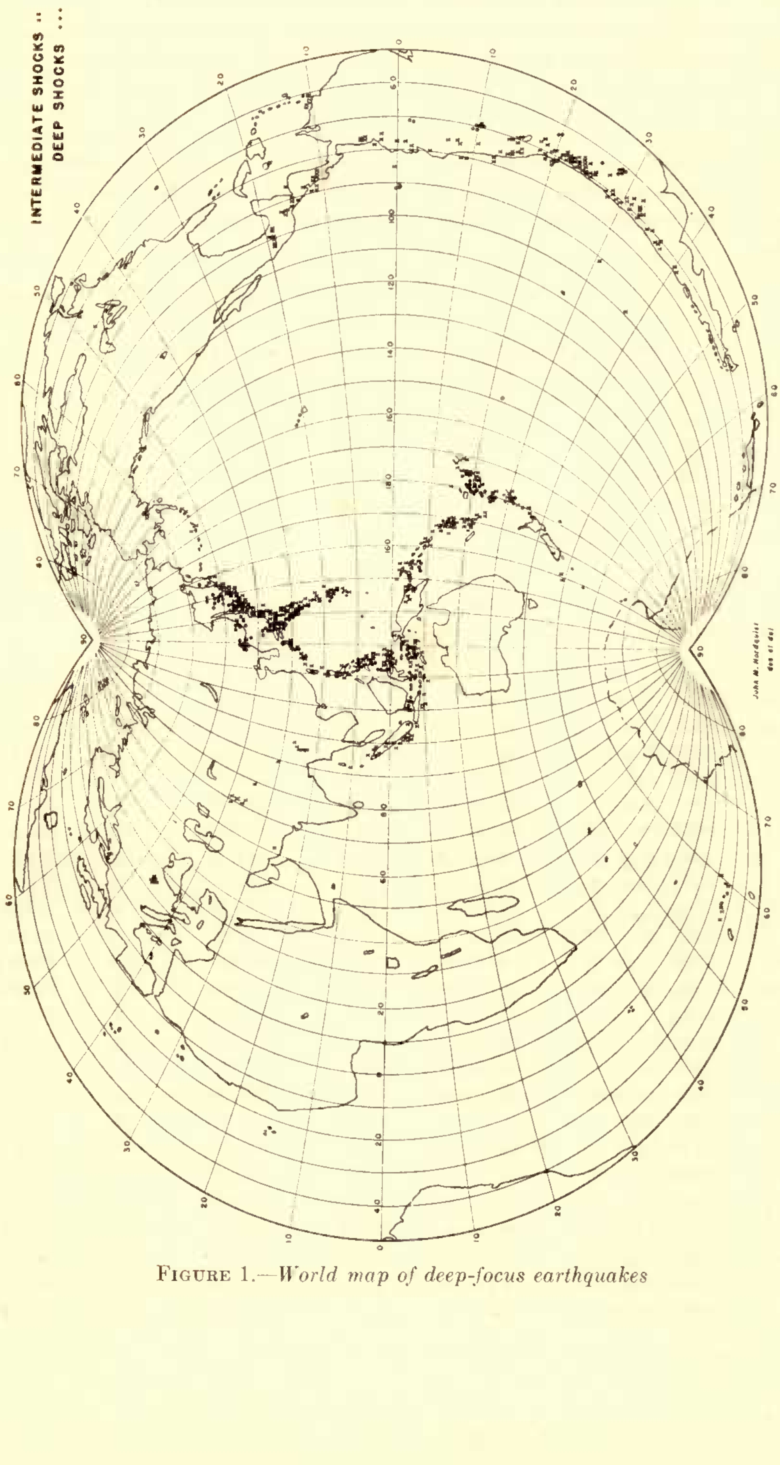

FIGURE 1.—*World map of deep-focus earthquakes*

TABLE 1.—*Continued*

No.	Date	Time hr.:min.:sec.	Latitude, degrees	Longitude, degrees	Depth, km.	Note
SOUTH AMERICA, INTERMEDIATE SHOCKS						
19 d	1938, April 24	14:10:58	23½ S.	66 W.	180	BCCh
23 e	1936, July 13	11:12:15	24½ S.	70 W.	60	ABAh
23 g	1932, April 26	07:54:48	25 S.	69½ W.	70	ABBb
23 h	1937, Oct. 12	12:50:55	25 S.	68½ W.	110	ABAh
23 k	1931, April 3	05:19:06	27 S.	65 W.	180	ABBb
23 l	1932, June 9	06:30:43	27½ S.	70½ W.	80	BCBb
23 n	1934, March 31	03:13:00	28½ S.	72 W.	60	BCAb
23 P	1939, Jan. 18	01:44:18	29½ S.	71 W.	70	BBAh
23 q	1938, Jan. 9	20:26:00	30½ S.	69 W.	120	CCBh
23 Q	1938, June 23	01:03:58	30½ S.	70 W.	70	CBAh
23 t	1933, Dec. 21	04:31:55	31 S.	69 W.	120	BBBb
24 b	1931, Aug. 17	05:05:25	32½ S.	69½ W.	120	BCBb
24 p	1937, Oct. 27	00:21:20	34½ S.	71 W.	110	BCAh
25 m	1937, Dec. 24	03:23:38	37 S.	72 W.	70	BCBh
SOUTH AMERICA, VERY DEEP SHOCKS						
36 h	1940, Sept. 23	07:15:10	23 S.	64 W.	550	BBBh
36 p	1939, Jan. 24	19:48:53	26½ S.	63 W.	580	BBAh
NEW ZEALAND						
41 c	1931, Sept. 21	13:34:25	37½ S.	178 E.	80	BCBb
41 g	1939, May 14	18:12:24	36½ S.	179 E.	80	BCBh
KERMADEC-SAMOA REGION, INTERMEDIATE SHOCKS						
41 h	1933, May 21	08:13:42	35 S.	180	100	CCCb
41 o	1933, Nov. 7	12:08:17	30 S.	177 W.	80	CCBb
41 p	1932, Oct. 20	17:36:43	30 S.	179 W.	70	CCBb
41 t	1933, June 11	13:09:12	22 S.	176 W.	80	CCBb
41 w	1934, Feb. 9	22:32:13	20½ S.	176½ W.	230	BCBa
42 a	1932, June 16	23:13:05	20 S.	176 W.	200	CCBc
44 i	1939, Oct. 30	13:12:36	16 S.	174 W.	150	BCAh
44 o	1939, June 8	20:46:53	15½ S.	174 W.	100	AAAh
KERMADEC-FIJI REGION, VERY DEEP SHOCKS						
50 d	1931, May 15	07:41:58	29 S.	180	500	CCCc
51 a	1940, Aug. 1	12:39:38	26 S.	180	500	BBAh
54 m	1939, May 21	20:21:53	22½ S.	179 W.	600	BCAh
55 a	1939, July 5	22:41:04	22 S.	180	650	CBBh
55 c	1939, July 20	02:23:00	22 S.	179½ W.	650	CCCh
58 d	1939, Nov. 17	18:39:30	21½ S.	178 W.	600	BBBh
59 m	1934, Jan. 18	03:21:05	21 S.	179 W.	580	CCCa

TABLE 1.—*Continued*

No.	Date	Time hr.:min.:sec.	Latitude, degrees	Longitude, degrees	Depth, km.	Note
CELEBES AND MINDANAO, SHOCKS WITH DEPTHS BETWEEN 100 KM. AND 400 KM. —*Continued*						
125 d	1932, June 6	06:26:21	2 N.	122½ E.	280	CCCa
127 d	1932, July 9	20:23:54	5½ N.	126½ E.	120	BCBb
127 m	1932, June 10	20:21:20	5½ N.	127 E.	80	ABBb
128 d	1933, Sept. 7	17:53:38	6½ N.	126 E.	150	BCCb
128 g	1933, Sept. 28	00:27:58	7 N.	127 E.	100	CCCb
128 m	1932, June 8	14:54:38	8 N.	126 E.	100	BBBb
CELEBES TO MINDANAO, VERY DEEP SHOCKS						
131 h	1940, June 18	13:52:33	5½ N.	123½ E.	570	BBBh
132 b	1940, Sept. 22	22:51:56	8 N.	124 E.	680	BBBh
132 p	1941, Feb. 4	14:03:12	9 N.	124 E.	600	BBBh
LUZON TO KIUSHIU						
133 g	1933, Sept. 20	23:33:40	13 N.	121 E.	100	BBBb
133 i	1932, July 18	05:02:05	14 N.	120 E.	100	BCCb
133 k	1940, March 28	15:48:52	14½ N.	120 E.	200	ABAh
135 x	1932, June 14	05:59:38	18½ N.	120¼ E.	80	ABBb
136 g	1932, Oct. 9	12:49:49	23½ N.	122½ E.	130	BBCb
136 k	1933, Feb. 19	04:26:11	25 N.	123 E.	120	ABCb
138 p	1911, June 15	14:26:00	29 N.	129 E.	160	BCCh
MARIANNE ISLANDS-JAPAN-KAMCHATKA, INTERMEDIATE SHOCKS						
141 p	1931, Nov. 3	02:35:55	17 N.	147 E.	100	CCCb
141 x	1933, Nov. 7	06:39:58	18 N.	146 E.	70	CCBb
142 d	1930, Jan. 26	12:20:30	18½ N.	146½ E.	190	BCBb[5]
143 m	1932, Jan. 5	11:22:25	20 N.	148 E.	130	CCCb
144 t	1931, July 2	03:38:50	24 N.	142½ E.	120	BCCb
147 d	1923, Sept. 17	03:39:32	31 N.	140 E.	150	CCCb
147 m	1926, Sept. 26	01:00:39	32 N.	140 E.	200	CCCb
147 w	1933, Nov. 19	01:33:39	32½ N.	139 E.	230	AABak
148 d	1938, Jan. 11	15:12:00	33 N.	135½ E.	70	ABBh
148 m	1933, Sept. 15	13:53:45	33 N.	141¼ E.	120	AABa
150 g	1933, Sept. 6	14:05:20	34½ N.	137¾ E.	280	AABak
150 n	1934, Feb. 1	00:15:59	35¼ N.	139¼ E.	90	AAAhk
151 q	1931, May 25	06:48:55	38½ N.	141 E.	100	AABb
151 u	1933, July 20	23:14:05	38½ N.	144½ E.	100	AAAa
153 d	1934, Oct. 29	17:23:04	42 N.	141 E.	100	BCBhk
153 m	1931, Jan. 6	03:22:46	42½ N.	142¾ E.	100	AABbk
156 g	1931, Jan. 21	08:58:04	43¼ N.	146 E.	120	ABBbk
158 k	1933, Aug. 28	08:47:42	44 N.	147½ E.	130	BCBb
161 d	1938, Aug. 17	01:45:35	45 N.	148 E.	100	BCChk
162 d	1936, Nov. 12	20:04:46	46 N.	148 E.	150	BBBhk

[5] Pasadena has iP at 12:32:43 and pP 48 seconds later.

TABLE 1—*Concluded*

No.	Date	Time hr.:min.:sec.	Latitude, degrees	Longitude, degrees	Depth, km.	Note
			HINDU KUSH			
231 d	1909, July 7	21:37:50	36½ N.	70½ E.	230	CCCh
243 p	1931, Jan. 7	03:49:42	36½ N.	71 E.	200	CCCb
245 m	1931, Sept. 14	03:32:16	36½ N.	70½ E.	220	ABBb
246 d	1932, Feb. 9	02:19:44	36½ N.	70½ E.	220	CCCb
246 h	1932, April 30	10:52:41	36¾ N.	70½ E.	250	ABBb
247 m	1933, May 21	17:53:43	36½ N.	70½ E.	220	CCCb
247 t	1933, July 25	13:38:23	39 N.	72 E.	250	BCCb
250 k	1939, Nov. 21	11:01:50	36½ N.	70½ E.	220	AAAh
250 m	1940, Sept. 21	13:49:03	36½ N.	70½ E.	230	BBBh
			SOUTHEASTERN EUROPE			
251 m	1941, Jan. 20	03:37:07	35 N.	34 E.	100	BBBh
252 q	1934, March 29	20:06:51	45¾ N.	26½ E.	150	ABBh
252 r	1939, Sept. 5	06:02:02	45¾ N.	26½ E.	150	BBBh
252 s	1940, Oct. 22	06:37:00	45¾ N.	26½ E.	150	AAAh
252 t	1940, Nov. 10	01:39:10	45¾ N.	26½ E.	150	AAAh
			SOUTH ATLANTIC			
254 d	1937, Sept. 8	00:40:01	57 S.	27 W.	130	BBBh
256 a	1932, Feb. 23	00:13:54	60 S.	12½ W.	150	BCCb

No. 138 p was originally in the list of great shocks, presumed to be at normal depth. A note by Mr. H. O. Wood in the Bulletin of the Berkeley station for 1911, referring to peculiarities in the seismogram, suggested that the shock was deep. Inspection of the original Berkeley seismograms, kindly lent by Professor Byerly, showed very small surface waves and a pP-P interval of 40 seconds.

Intermediate shocks in the Hindu Kush region have continued, the most recent large shock of the series having occurred on September 21, 1940. The total number of known shocks from practically the same epicenter and depth in the last 20 years is at least 40.

No. 251 m was destructive on Cyprus.

No. 252 t was very destructive in Roumania.

No. 256 a is a new epicenter in the South Atlantic, lying well to the east of the active structure loop of the southern Antilles.

No. S 14 i, north of the Fiji Islands, falls in an otherwise large gap in the line of epicenters. Owing to the early date of this shock, the location and determination of depth are not precise.

No. S 10 m, on the south island of New Zealand, is well established from both macroseismic and microseismic data. The location on that side of the island remote from the Pacific is important.

No. S 5 m is reasonably well located, about midway between the Galápagos Islands and the coast of South America. It is most probably at intermediate depth, although the data for determining this depth are not as satisfactory as those for the epicenter;

TABLE 3.—*Revised epicenters of earthquakes*

January 1931–March 1934 with depths of less than 60 km. *See* text for "quality" and "class."

Day	Time	Latitude, degrees	Longitude, degrees	Quality	Class
1931					
Feb. 10	01:22:54	25.5 N.	96 E.	B	d
24	17:28:24	9.5 S.	117 E.	C	d
March 11	05:58:51	7 S.	131 E.	C	d
April 16	21:35:00	8 S.	158 E.	C	d
24	02:15:10	3 S.	103 W.	C	d
May 10	19:24:45	25 S.	116 W.	B	c
June 9	12:14:11	50½ N.	159 E.	C	c
	13:52:12	14 S.	174 W.	B	c
July 7	03:54:12	14 N.	96 W.	C	c
Sept. 15	21:08:50	45 S.	168 E.	B	d
Nov. 2	00:32:11	16 N.	96½ W.	A	c
26	2 shocks	61 S.	150 E.	C	d
Dec. 7	18:51:57	59 S.	148 E.	C	d
25	03:04:24	52 S.	141 E.	B	c
1932					
Jan. 17	07:45:05	12 S.	160.0 E.	C	c
18	13:12:33	45 N.	32.0 W.	C	d
22	00:48:56±	33 N.	47 E.	C	d
Feb. 16	13:48:50	15 S.	180	A	b
17	16:06:57	12 N.	73½ W.	A	d
21	13:20:57	4 N.	63 E.	C	d
March 5	01:40:54	36½ S.	178 E.	C	d
15	04:32:14	11 N.	144½ E.	A	c
	07:44:34	41 N.	45 E.	B	d
23	12:08:02	37 S.	99 W.	C	c
27	08:44:40	24½ N.	92 E.	B	d
28	00:35:34	8 S.	98½ E.	C	c
April 29	17:30:45	7 N.	127 E.	C	c
May 6	05:35:04	0	124 E.	C	d
31	08:37:24	7 N.	38 W.	B	d
June 6	11:49:56	19.6 N.	76.5 W.	B	c
14	11:20:15	18 N.	120 E.	B	c
July 11	08:21:31	12½ N.	124½ E.	B	c
Aug. 2	04:25:34	2.0 N.	126.0 E.	A	c
Sept. 9	06:46:25	1½ S.	128½ E.	B	d
Oct. 3	04:37:40	1 S.	91 W.	C	d
Nov. 27	03:37:28	29½ N.	143 E.	B	d
Dec. 16	07:14:24	7 N.	127 E.	B	c
1933					
Jan. 17	15:59:56	40 N.	97 E.	C	d
	18:47:47	34½ S.	59 E.	C	c
18	08:37:45	32 S.	19 W.	C	c
27	22:36:35	16 S.	172 W.	B	c

TABLE 3—*Concluded*

Day	Time	Latitude, degrees	Longitude, degrees	Quality	Class
1933					
Dec. 2	05:17:18	52 S.	161 E.	C	c
	20:05:09	51 S.	50 W.	C	c
9	07:52:21	36½ N.	69½ E.	B	d
24	10:46:01	1 S.	150 E.	C	c
1934					
Jan. 16	04:59:27	27 N.	84 E.	C	d
20	17:56:08	41 N.	108 E.	B	c
29	12:34:43	37½ N.	144¼ E.	A	d
Feb. 12	11:30:47	19 N.	101 E.	B	c
20	03:18:50	4 S.	105 W.	C	d
March 4	11:17:30	55 N.	164 E.	B	c
8	02:56:53	34 N.	26½ E.	B	d
	23:02:20	28 S.	68½ E.	C	d
9	14:02:23	65 N.	173 E.	C	d
21	03:39:50	35 N.	139½ E.	B	d

with the International Seismological Summary. It must be emphasized at once that the period of 36 years represented by Table 5 is extremely short from the geological point of view. In Table 3 the class designations are the same as those already given.

All shocks in Table 4 are of class *b*; those in Table 5 are of class *a*. In these tables, and throughout the paper, the letter given under "Quality" has the following meaning:

A epicenter probably located within 1 degree of arc.
B within 2 degrees.
C within 3 degrees.

In general, shocks which it did not appear possible to locate within 3 degrees have been omitted. However, in remote areas, particularly in the southern hemisphere, this tolerance has been extended somewhat, and such epicenters are also graded as of quality C.

The magnitudes given in Tables 4 and 5 are calculated from the amplitudes of surface waves at various stations. In general, the values thus found are accurate within ±0.4. (See Gutenberg and Richter, 1934, Fig. 6, p. 120.) Many shocks in Tables 4 and 5 have been made the subject of special investigations; references to these are given in footnotes to the tables. There may be others which have escaped our notice.

In adapting Table 5 from the previous list of large shocks (Gutenberg and Richter, 1936), several shocks have had to be omitted. Two of these are definitely established instances of deep focus—1911 June 15 (No. 138 p) and 1919 January 1 (No. 143). 1910 November 9 has been omitted

TABLE 4.—*Concluded*

Day	Time	Revised epicenter		Quality	Magnitude
		Latitude, degrees	Longitude, degrees		
1930, Oct. 24[8]	20:15:11	18½ N.	147 E.	A	7.0
1930, Nov. 25[9]	19:02:47	35 N.	139 E.	A	7.0?
1930, Dec. 3[10]	18:51:44	18 N.	96½ E.	A	7.2
1931, Jan. 27	20:09:21	25.4 N.	96.8 E.	A	7.6
1931, Jan. 28	21:24:10	11.1 N.	145.0 E.	A	7.4
1931, Feb. 10[11]	06:34:32	5.3 S.	102.5 E.	A	7.1
1931, March 9	03:48:57	40.5 N.	142.5 E.	A	7.3
1931, March 18[12]	08:02:25	32.8 S.	71.3 W.	B	7.2
1931, March 18	20:13:42	5.6 N.	126.3 E.	A	7.0
1931, April 24	17:22:18	6.6 S.	155.2 E.	B	7.0
1931, Aug. 7	02:11:37	3.0 S.	143.5 E.	B	7.2
1931, Aug. 27[13]	15:27:25	29.8 N.	67.3 E.	A	7.0
1931, Sept. 25[14]	05:59:52	5.1 S.	102.7 E.	A	7.3
1931, Oct. 3[14]	19:13:19	10.6 S.	161.7 E.	A	7.6
1931, Oct. 10[14]	00:19:59	9.9 S.	161.4 E.	A	7.4
1931, Nov. 2	10:03:09	32.4 N.	132.1 E.	A	7.4
1932, Jan. 29	13:41:18	6.2 S.	155.0 E.	B	7.0
1932, June 22	12:59:32	19.1 N.	104.5 W.	A	7.0
1932, Sept. 15[15]	13:54:55	39.2 S.	178.2 E.	A	7.0
1932, Dec. 4	08:11:19	2.4 N.	121.0 E.	A	7.1
1932, Dec. 21[16]	06:10:12	38.7 N.	117.9 W.	A	7.3
1932, Dec. 25	02:04:31	39.2 N.	96.4 E.	B	7.7
1933, Jan. 21	19:21:14	34.0 S.	57.0 E.	B	7.0
1933, Feb. 23	08:09:19	20.0 S.	70.2 W.	A	7.2
1933, April 27	02:36:11	61.2 N.	150.9 W.	B	7.0
1933, June 18	21:37:36	38.5 N.	142.8 E.	A	7.3
1933, June 24	21:54:51	5.0 S.	104.2 E.	B	7.3
1933, Aug. 25	07:50:33	31.7 N.	103.4 E.	A	7.3
1933, Aug. 28	22:19:40	59.5 S.	25 W.	B	7.3
1933, Nov. 20[17]	23:21:38	73.3 N.	70.7 W.	A	7.4
1934, Feb. 24	06:23:47	22.8 N.	143.9 E.	A	7.1
1934, March 5[18]	11:46:19	40.4 S.	175.6 E.	B	7.3
1934, March 24	12:04:34	9.9 S.	161.4 E.	B	7.0

[8] Lehmann and Plett (1932) have studied seismograms of this shock; they have taken 0 = 20:15:11, with an epicenter at 18.4° N., 146.8° E.

[9] A summary of observations with references has been published by Davison (1936, p. 246–265). Among these note especially papers by Imamura (1931) and Kunitomi (1931).

[10] *See* Brown and Leicester (1933).

[11] *See* Gutenberg and Richter (1934).

[12] *See* Bobillier (1933).

[13] *See* West (1934).

[14] *See* Gutenberg and Richter (1934).

[15] *See* Hayes (1937).

[16] *See* Byerly (1935).

[17] *See* Lee (1937); Rajko and Linden (1935). Amplitudes of surface waves depend much on the azimuth of the station, causing differences in the calculated magnitude by about ± 1.

[18] *See* Bullen (1938).

TABLE 5.—*Shocks of magnitude $7\frac{3}{4}$–$8\frac{1}{2}$, 1904–1940*

Day	Time	Epicenter		Magnitude	Quality	Region
		Latitude, degrees	Longitude, degrees			
1904, June 25[1]	21:00.5	52 N.	159 E.	8	C	Kamchatka
1905, April 4[2]	00:50.0	33 N.	76 E.	$7\frac{3}{4}$	B	Kangra, India
1905, July 9[3]	09:40.4	49 N.	99 E.	8	C	SW. of Lake Baikal
1905, July 23[3]	02:46.2	49 N.	98 E.	8	C	SW. of Lake Baikal
1906, Jan. 31[4]	15:36.0	1 N.	$81\frac{1}{2}$ W.	$8\frac{1}{2}$	B	Colombia-Ecuador
1906, April 18[5]	13:12.0	38 N.	123 W.	$8\frac{1}{4}$	B	San Francisco
1906, Aug. 17[6]	00:10.7	51 N.	179 E.	8	C	Aleutian Islands
1906, Aug. 17[6]	00:40.0	33 S.	72 W.	$8\frac{1}{4}$	C	Chile
1906, Sept. 14[7]	16:04.3	7 S.	149 E.	8	C	New Guinea
1907, Jan. 4[8]	05:19.2	2 N.	$94\frac{1}{2}$ E.	8	B	Sumatra
1907, April 15[9]	06:08.1	17 N.	100 W.	$7\frac{3}{4}$	B	Guerrero, Mexico
1911, Jan. 3[10]	23:25.7	$43\frac{1}{2}$ N.	$77\frac{1}{2}$ E.	$8\frac{1}{2}$	B	Tien-Shan
1911, Feb. 18[11]	18:41.1	40 N.	73 E.	$7\frac{3}{4}$	B	Pamir
1911, Aug. 16[12]	22:41.4	9 N.	138 E.	8	C	Caroline Islands
1912, May 23[13]	02:24.1	21 N.	97 E.	8	C	Burma
1912, Aug. 9[14]	01:29.0	$40\frac{1}{2}$ N.	27 E.	8	B	Turkey
1914, May 26	14:22.7	3 S.	138 E.	8	C	New Guinea
1915, Oct. 3[15]	06:52.8	$40\frac{1}{2}$ N.	$117\frac{1}{2}$ W.	$7\frac{3}{4}$	A	Nevada
1917, May 1[16]	18:26.6	31 S.	179 W.	8	C	Kermadec Islands
1917, June 26[17]	05:49.7	$15\frac{1}{2}$ S.	173 W.	$8\frac{1}{4}$	B	Tonga Islands
1918, Aug. 15[18]	17:30.2	$5\frac{1}{2}$ N.	126 E.	8	A	Philippine Islands
1918, Sept. 7	17:16.2	$45\frac{1}{2}$ N.	$151\frac{1}{2}$ E.	$7\frac{3}{4}$	B	Kurile Islands
1919, April 30	07:17.1	19 S.	$172\frac{1}{2}$ W.	8	B	Tonga Islands
1919, May 6	19:41.2	5 S.	154 E.	8	B	Bismarck Islands
1920, June 5	04:21.5	$23\frac{1}{2}$ N.	122 E.	$7\frac{3}{4}$	A	Formosa

[1] *See* Rosenthal (1906, 1907). A considerable group of earthquakes; the largest is that given in the table. Of the foreshocks, one, at 14^h was also of magnitude $7\frac{3}{4}$ to 8. Of the many aftershocks that on June 27 at 0^h was almost as large as the shocks of June 25. Some damage at Petropavlovsk.

[2] *See* Middlemiss (1910); Omori (1907a).

[3] *See* Sieberg (1932a, p. 789). Violent in the eastern Tannu-ola area.

[4] *See* Rudolph and Szirtes (1912).

[5] *See* Lawson, *et al.*, (1908).

[6] Two great earthquakes occurred about half an hour apart. For the earlier, in the Aleutian Islands, our only information is taken from seismograms; the latter was the destructive Valparaiso earthquake. *See* Rudolph and Tams (1907), with reproduction of principal seismograms.

[7] Many landslides and a seismic sea wave. *See* Sieberg (1910; summarized 1932a, p. 911).

[8] Violent on the islands Simeuloe and Nias, off the coast of Sumatra.

[9] *See* Boese, *et al.* (1908). Very destructive.

[10] *See* Galitzin (1911).

[11] Jeffreys (1923) is a discussion of the mechanical connection between this shock and a great landslide in the Pamir region which accompanied it. Later opinion, to which Jeffreys has also subscribed, accepts the landslide as an effect of the earthquake.

[12] Epicenter from readings at Apia, Berkeley, Göttingen, Osaka, and Jena. Strong at Yap (Sieberg, 1932a, p. 919).

[13] Based on reports from Osaka and European stations.

[14] Destructive on the north coast of the Sea of Marmora. *See* Sieberg (1920; 1932a, p. 758). Epicenter from macroseismic data, consistent with instrumental observations.

[15] Epicenter from macroseismic data. This shock was accompanied by formation of fault scarps about 14 feet in height in Pleasant Valley, south of Winnemucca, Nevada (Jones, 1915). For a later study including the scarps formed in 1915 *see* Page (1935).

[16] Possibly deeper than normal.

[17] Instrumental epicenter by Gutenberg (1925). Violent in the Tonga and Samoa Islands (Sieberg, 1932a p. 923).

[18] Violent in southern Mindanao (Masó, 1918).

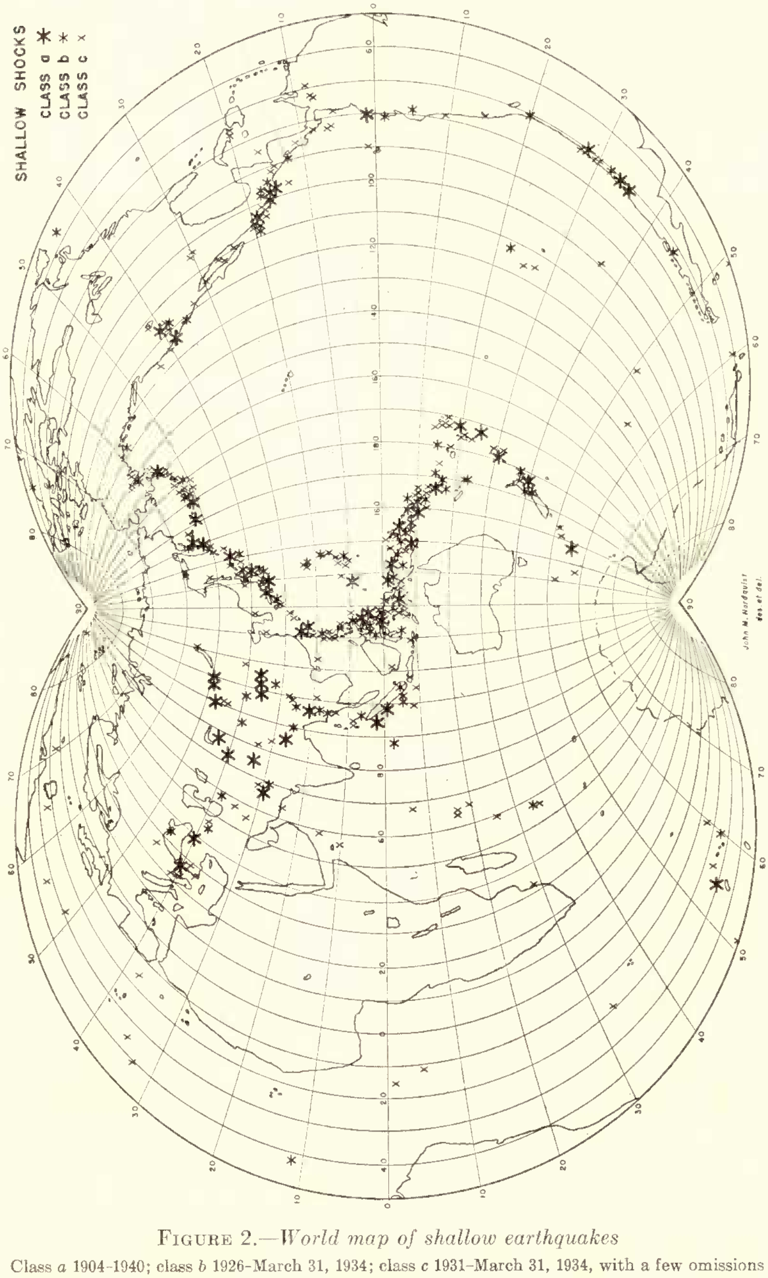

FIGURE 2.—*World map of shallow earthquakes*

Class *a* 1904-1940; class *b* 1926-March 31, 1934; class *c* 1931-March 31, 1934, with a few omissions in active regions earthquakes, shocks of class *d* were included only for the period January 1931 to March 1934.

Certain areas are conspicuously inactive. These are the Pacific basin and the continental shields. They will be discussed following the active belts, and this discussion will cover some of the scattered groups of shocks already mentioned. The remainder of these scattered shocks fall into the areas, usually of complex structure, lying between the active belts and the stable shields.

THE CIRCUM-PACIFIC BELT

GENERAL SURVEY

The circum-Pacific belt, although practically continuous, includes segments and branches in which the activity is very dissimilar in character. Geographically remote segments often show striking analogies.

Between Alaska and central Mexico seismicity is relatively low, in spite of occasional large shocks, and consists exclusively of shallow earthquakes. The sector is unique in this respect, unless the same is true of the little-known and possibly very different sector between South America and New Zealand.

On the American side two loops extend eastward from the main line: the Caribbean or Antillean loop, and the South Antillean loop through the Falkland Islands and South Georgia. In both loops intermediate as well as shallow shocks occur.

The Pacific coast of South America is noteworthy for the comparative rarity of shocks at shallow depth, the considerable seismicity consisting very largely of intermediate earthquakes. Very deep shocks occur farther inland. Off the coast lies a moderately active belt, in which a few intermediate shocks accompany a majority of shallow shocks. This may possibly be a branch of the main belt.

On the opposite side of the Pacific there is a similar and unquestionable phenomenon of branching, as shown by the epicenters of shallow and intermediate shocks. The active belt extending from Alaska through the Aleutian Islands, Kamchatka and the Kurile Islands divides in central Japan. Its western branch leads through the Riu-Kiu Islands and Formosa to the Philippines, and its eastern branch leads southward to the Marianne Islands. In this eastern branch intermediate shocks are relatively more frequent than in the western branch. Parallel to the eastern branch runs a belt of deep foci—which, however, departs from it and continues across Japan and the Japan Sea into Manchuria, where it turns at right angles and extends northeastward parallel to the belt of shallow and intermediate activity.

The western branch appears to continue from the eastern Philippines through the Moluccas, round the Banda Sea, and by way of the Sunda

ALEUTIAN ARC

The Aleutian structural arc is probably seismically active throughout its length, although the instrumental data of recent years show great differences in its various parts. The western end abuts against the very active region of Kamchatka; but from here eastward through the Commander (Komandorski) Islands activity is comparatively slight. The central part of the arc, opposite the Aleutian trough, is one of the most active areas of the globe, with very frequent shocks, some of them of the largest magnitudes. As may be seen from Figure 2, this activity diminishes only slightly eastward toward the Alaskan peninsula. The arc ends in the region of the Kenai Peninsula, where there is again considerable activity; shocks in this area are frequently felt sometimes causing damage at Seward and other neighboring points. The belt of activity continues northward, following the trend of the Alaska Range. Perhaps the shocks in the region of Fairbanks should also be included here; the most recent large one occurred on July 22, 1937 (Bramhall, 1938).

Except for the eastern end in Alaska, epicenters on the Aleutian arc are exclusively from instrumental data. Although the larger shocks of the group are well recorded at all the principal stations of the Northern Hemisphere, location is usually only reasonably good. In some cases this is evidently due to complexity in the shock, leading to imperfect or confused seismograms. In other instances difficulty appears to result from a focal depth slightly deeper than usual for shallow earthquakes (say 50 km.). A few cases of intermediate focus are positively identified (Fig. 1), and many others are suspected.

Most of the better determined epicenters lie on the south side of the structure, between the islands and the Aleutian trough; a few of them lie farther north, even among the islands. The epicenters of the intermediate shocks fall among this northern group. This appears to be an instance of the phenomenon which is well developed along other Pacific coasts, that the shallow shocks fall farther out to sea than the intermediate ones.

The seismic history of the region is imperfectly known. Shocks have been reported felt at Unalaska and other points since the earliest explorations. For the Aleutian Islands, west of Unalaska, most of the data consist of occasional reports of shocks felt on shipboard. For the Alaskan region the state of macroseismic information is well indicated on a map by Sieberg (1932a, p. 938). For recent years macroseismic data for Alaska are summarized by the United States Coast and Geodetic Survey in publications under the serial head *United States Earthquakes.*

ALASKA TO MEXICO

This sector extends from central Alaska to central Mexico. In strong contrast with the constant activity and frequent large shocks characteristic is an area of considerable submarine relief, with five large islands and some small rocks; this area manifests moderate seismic activity. Still farther southwest is the epicenter of the shock of January 4, 1933, mapped on Figure 2 at 28°.5 N. 127° W. This is a very well located epicenter, but whether it should be considered as a Pacific shock or as a continental shock remains somewhat uncertain, as there is no assurance that the margin of the continental shelf is actually the boundary between Pacific and continental crustal structure. Along the entire coast between Alaska and central Mexico there are no oceanic deeps, such as mark the margin of the Pacific elsewhere.

In this discussion, earthquakes in Owens Valley and Nevada have been included with the Pacific belt. While these shocks occur in a district somewhat remote from the coast, the association is natural.

MEXICO AND CENTRAL AMERICA

The Pacific coastal lands of central Mexico rank with the Aleutian arc among the most active sources of shallow earthquakes (Fig. 3). The distribution of epicenters on our maps is affected by high activity in 1931 in Oaxaca and in 1932 in Jalisco. The intervening coast has been very active in other years, as exemplified by the large Guerrero earthquake of 1907.

The east-west belt of shocks at intermediate depth (mostly near 100 km.) across central Mexico follows a zone of active volcanism. Some of these shocks have been destructive—such as that of February 10, 1928 in Puebla, and that of July 26, 1937 in Vera Cruz. Destructive shocks in earlier years along this line may have had equal focal depth.

Note that the coastal belt of shallow shocks apparently turns southward off shore in western Panama; eastern Panama, including the Canal Zone, is comparatively inactive. The epicenters far off the coast near 100° W. are to be considered in connection with those of the Galapagos Islands and southward.

In the volcanic zones of Central America there are frequent shocks originating near the surface, often very destructive in limited areas. However, the principal inland activity is at intermediate depth (down to 200 km.). The shocks in the Gulf of Honduras, near the limit between shallow and intermediate depth, suggest a branching of the main Pacific active belt, and a connection with the West Indian activity.

CARIBBEAN LOOP

The Caribbean seismic loop (Fig. 3) diverges from the main circum-Pacific belt near the Isthmus of Tehuantepec. It strikes out through the Gulf of Honduras, along the margins of the Bartlett Deep to Cuba and Haiti, and thence round the Atlantic side of the Lesser Antilles to the South American coast. Here it gradually trends inland, and follows the northern Andean structures through Venezuela into Colombia, where it becomes identified with the main Pacific belt.

On the west, the loop is closed off by the Central American structural and seismic belt; on the east, there is not the slightest evidence of an

TABLE 6.—*Additional earthquake epicenters in the Caribbean region*

Day	Time	Epicenter		Quality	Class
		Latitude, degrees	Longitude, degrees		
1929, Jan. 17	11:45:39	10½ N.	64½ W.	B	c
1922, May 11	06:45:35	12 N.	59½ W.	B	c
1928, Sept. 27	00:44:05	12 N.	60 W.	A	c
1925, July 7	17:43:43	17½ N.	60½ W.	B	c
1925, Sept. 29	17:33:50	18½ N.	62 W.	B	c
1927, Aug. 2	00:51:46	19 N.	64½ W.	A	c
1918, Oct. 11	14:14:30	18½ N.	67½ W.	A	b
1922, Dec. 18	12:35:03	19 N.	67 W.	B	c
1920, Feb. 10	22:07:15	18 N.	67½ W.	B	c
1926, March 24	05:41:21	19½ N.	69½ W.	C	d
1923, Nov. 3	08:37:46	19½ N.	73½ W.	B	c
1923, March 15	06:03:12	20 N.	68 W.	C	d
1930, June 25	12:06:20	19 N.	64 W.	B	c
1924, Jan. 30	20:54:48	20 N.	77½ W.	C	d
1934, July 10	01:02:10	20 N.	80 W.	B	d
1939, June 12	04:05:09	20½ N.	66 W.	A	c
1938, Nov. 10	15:23:30	20¾ N.	74 W.	B	d
1938, April 13	13:53:13	12 N.	60½ W.	C	d
1939, Nov. 7	15:44.0	18 N.	72½ W.	B	d
1939, March 7	11:20:49	18 N.	67 W.	B	d
1940, Nov. 10	20:40:27	17 N.	84 W.	C	d
1941, April 7	23:29:17	17¾ N.	78½ W.	A	b

active belt extending from the Lesser Antilles across the Atlantic, as indicated on most old seismic maps of the world.

Activity here is low compared to that of most of the circum-Pacific belt, though it is higher than that of many other regions. It apparently resembles that in California. During four centuries of recorded history, many earthquakes, some extremely destructive, are known to have occurred thus giving the West Indies a reputation for high seismicity which is not altogether deserved.

Instrumentally determined epicenters can be supplemented from the history of destructive shocks, but careful discrimination is required. (*See*, Sieberg, 1932a, p. 961–974; Scherer, 1912; and Taber, 1920; 1922.)

In general, macroseismic and historical data support the assumption of one continuous active belt, though this may be subdivisible laterally, as Taber indicates. A conspicuous exception was the destructive earth-

The fairly high seismicity of the Andean zone is due primarily to earthquakes at intermediate depth. Even the shocks designated as shallow in the present study frequently show evidence of focal depth greater than that found elsewhere. For the earlier years especially there is great difficulty in discriminating shallow shocks from intermediate earthquakes at depths of 70 to 100 km. This difficulty is diminished beginning about 1931 when a short-period vertical-component Benioff instrument was installed at Pasadena. The records of the station at Huancayo, Peru, which began operating in August, 1932, are also filed at Pasadena, and are of very great assistance in studying the depth of South American earthquakes. Further, beginning about 1931 there was general recognition of the occurrence of deep shocks, which were then more frequently reported as such, with details of the characteristic seismographic phases, by many stations. The period 1931–1933, for which all the shocks listed in the International Summary have been examined with care, is much more acceptable for statistical purposes. For these years 15 shallow shocks (not including small aftershocks) and 32 intermediate shocks have been located in the Andean zone. Because of their special interest, more effort was made to locate the intermediate shocks, and moreover they are often more clearly recorded than shallow shocks of the same energy. On the other hand, some of the shocks mapped as shallow in Figure 4 may prove to be intermediate.

Ample evidence now exists for the occurrence of shocks at intermediate depth, large enough to be very destructive at the surface. The great Chillán earthquake of January 25, 1939 at a depth of 70 km., has already been mentioned; its epicenter is marked by an arrow in Figure 4. Another striking case is the destructive Colombian earthquake of February 5, 1938, originating at a depth of 160 km. The vast extent of the perceptibly shaken areas in many South American shocks has long been a matter of remark; this is to be expected if the focus is deeper than ordinary. A related observation concerns the difficulty in drawing isoseismals for these earthquakes. Especially in Chile, where the centers of population are scattered, it has often been said that the apparent intensity bears a more evident relation to the character of the ground than to distance from the epicenter. (*See* Willis, 1929.) Such effects are very marked in cases of deep focus, both in South America and elsewhere. Finally, it is noteworthy that there is no credibly established instance in South America when surface faulting accompanied a great earthquake, although such instances are known from many other seismic regions. In some cases considerable changes of level, particularly at the coast, accompanied great shocks; such effects may have been the surface distortion occasioned by a deep-seated fracture.

Deep shocks in the restricted sense are comparatively rare; to date only 18 have been identified. Only one of these occurred during the period shallow focus, probably located farther west, off the coast opposite San Antonio where the shock was felt by a few persons.

Of the smaller shallow shocks that of May 22, 1936 is in the province of

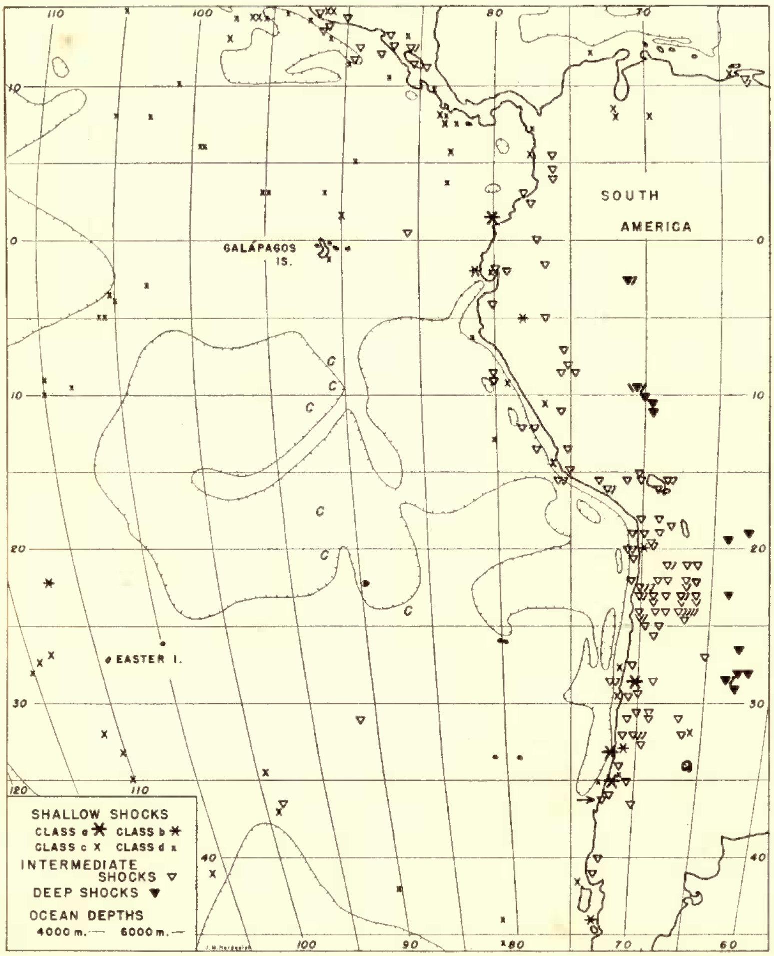

FIGURE 4.—*Map of epicenters, South America and adjacent Pacific*
Arrow indicates shock of 1939, January 25. Letter "C" indicates continental structure

San Luis, Argentina, considerably east of Mendoza. It is the only well-established epicenter which confirms the conclusion, strongly suggested by the history of the region, that shallow shocks occur here in a limited area east of the Andes. Since instances of intermediate focus are known here the mere historical fact of frequent reports of shocks in Mendoza and surrounding provinces is no proof of shallow activity. However, such destructive shocks as the Mendoza earthquake of 1861 cannot have origi-

The analogy with the West Indies is structural as well as geographical; there is an oceanic deep on the outside of the arc, and active volcanism in the South Sandwich group. The general correspondence extends, with some qualification, to the seismic activity.

Epicenters were occasionally located in this region during the earliest period of instrumental seismology; but the matter escaped general notice until it was discussed by Tams (1927a; 1930a). These shocks are very distant from all but a few seismological stations; consequently the epicenters are less accurate than for most other important seismic areas, and it is not possible to work with any but large shocks. The seismicity as a whole is high, decidedly greater than that of the West Indies. All located epicenters, including those of some intermediate shocks, are plotted on the south polar chart (Fig. 5).

Historical and macroseismic data are very scanty and of little significance. The distribution of known epicenters suggests a closed ring rather than a loop, as the activity does not extend into the Antarctic, and is not clearly connected with that of western South America.

Shocks are most frequent near the South Sandwich Islands and the deep east of them; some of these are large, and one (that of June 27, 1929) is on the list of great shocks (Table 5). Most of the intermediate shocks are in this part of the arc.

The epicenters farther east, and near Bouvet Island possibly indicate a connection with the seismic belt of the Indian Ocean, to be discussed in later sections.

SOUTHEASTERN OCEANIC BRANCH

Seismograms, chiefly at the stations in the Americas, show that a belt of moderate seismic activity runs near the center of the Easter Island Ridge (Fig. 4). A search was made for authentic epicenters in the southeastern Pacific Ocean, in which every adequately recorded shock west of the South American coast was investigated. The large majority of these epicenters were found to lie along a comparatively narrow belt.

The activity is relatively mild, and large shocks are infrequent, so that our knowledge of the seismicity is necessarily imperfect. That the principal belt is an outlying branch of the circum-Pacific zone is a natural hypothesis substantiated in a certain measure by the occasional occurrence of shocks at intermediate depth, thus distinguishing it from the otherwise similar active belts in the Atlantic and Indian Oceans. However, the manner of this supposed branching is difficult to derive from the comparatively few mapped epicenters. Those plotted on the southwestern part of Figure 3 should also be noted here. The most plausible suggestion is that the branching takes place in Mexico, and that an active zone extends southward from Oaxaca past the Galapagos Islands. The few available is still so fragmentary that any attempt to correlate seismicity with bottom contours is somewhat hazardous. Contours shown in Figures 4 and 5 are taken partly from Vaughan, *et al.* (1940) and partly from several charts supplied by the U. S. Hydrographic Office, particularly their Nos. 5411 and 5412. The Hydrographic Office has given the authors prompt and helpful response to inquiries.

Seismograms written at Huancayo for many shocks of this group show a large reflected longitudinal wave (PP); the distances from these epicenters to the station are such that these large amplitudes are evidence of a crustal structure of continental type at the points of reflection. Three instances were noted, and one seismogram was reproduced, in the paper in which this criterion was first discussed (Gutenberg and Richter, 1935). The present investigation adds three more shocks large enough for the purpose; it can now be stated that all of the six larger shocks on and near the Easter Island Ridge south of the equator, as recorded at Huancayo, show clear evidence of continental structure at the points of reflection of PP. These points, which are midway from the station to the corresponding epicenters, are indicated by the letter C on Figure 4. Their dates are: November 2, 1932; February 30 and April 9, 1934; September 15, 1935; March 5 and August 26, 1936. On the other hand, the same type of evidence establishes Pacific structure (1) north of the Galapagos Islands, from seismograms of Chilean earthquakes at Pasadena; and (2) just west of the Easter Island Ridge, near 43° S., 120° W., from a Chilean earthquake as recorded at Wellington (New Zealand). The Easter Island Ridge appears to be the southeastern boundary of the major Pacific basin; but large isolated areas of Pacific structure may exist outside this boundary.

PACIFIC ANTARCTIC

Additional data on submarine contours for the following discussion and for Figure 5 have been taken from the results of the second Byrd expedition, as reported by Roos (1937). The course of the 4000-meter isobath is largely hypothetical. It appears probable that the Easter Island Ridge continues southwestward as indicated, although its summit may descend below the 4000-meter level. On this continuation eight epicenters are mapped:

1937, Nov. 23	13:52:8	44° S.	115° W.
1930, June 15	21:08:2	46° S.	116° W.
1933, April 19	01:45:33	51° S.	116½° W.
1932, March 10	05:17:52	54° S.	135° W.
1940, Jan. 20	09:58:0	55° S.	133° W.
1937, Aug. 13	11:47:38	57° S.	131° W.
1930, Aug. 2	16:09:05	57° S.	135° W.
1938, Sept. 5	14:42:32	55° S.	152° W.

All these shocks are of magnitude class *c*. This is the most difficult of all active areas for the location of epicenters, and any of those mapped may

Twenty-seven were identified as originating in distant parts of the world; 73 others were located between the station and New Zealand, by using records at Wellington, Christchurch, and Perth. Locations for the remainder are not mentioned; but considering the characteristics of the instruments then in use, it is not likely that trustworthy conclusions could be drawn from these seismograms. It is quite possible that no truly Antarctic shocks were recorded, and that the most southerly of those noted belonged to the group now to be discussed.

MACQUARIE ISLAND LOOP

Seismograms, and occasional reports of shocks felt on shipboard, long ago established the occurrence of earthquakes southwest of New Zealand, between 50° and 60° S. Earlier writers took for granted that this indicated an active belt extending, without much change in direction, from New Zealand into the Antarctic. The better recorded shocks of this group were investigated carefully before plotting on a large-scale map, when the unexpected result appeared that the alignment has the character of an active loop open to the east (Fig. 5). This adds a third member to the group of loops connected with the circum-Pacific belt, quite comparable to the Caribbean and South Antillean loops, and indicates the presence of a hitherto unknown structure of geological importance.

The seismic loop is rather narrow; this suggests that the epicenters are on the interior of the supposed structural loop. Deep soundings have been obtained at a few points in the interior. The apex of the loop is near 50° S. 140° E., not far from the point where some charts show Royal Company Islands.[3]

The degree of seismicity is closely comparable with that of the South Antilles, the greater number of located epicenters being due to the proximity of the stations in Australia and New Zealand, which makes it possible to work with smaller shocks than in the South Atlantic. On the north limb of the loop, not far from Macquarie Island, is the great shock of June 26, 1924 (Table 5).

Intermediate shocks, which might be expected on analogy with the other Pacific loops, have not been found here. However, it would be difficult to distinguish a shock at a depth of 100 km. from a shallow shock in this area; and intermediate shocks have been identified a little farther north, between the loop and New Zealand. Doubtless the Macquarie Island loop is associated with a structure of Pacific type; whether it forms part of the boundary of the Pacific basin cannot be determined at present.

[3] According to information kindly furnished by Prof. W. H. Hobbs and by Colonel L. A. Martin of the Library of Congress, these islands were reported seen before 1814 and were reported not found in 1820 and on several occasions since. The possibility of temporary volcanic islands should not be overlooked.

The north side of the salient is much less active than the east side, and only the few epicenters mapped in this part of Figure 6 can be verified. This is a result of a careful search of the International Summary and recent station bulletins. Particular attention was given to shocks indicated as outside the Tonga salient, as these would fall into the otherwise inactive Pacific basin; but only a few shocks near Samoa could be verified, the remainder being small, doubtful, or clearly in error. The interior of the salient had already been thoroughly canvassed in a search for deep-focus earthquakes.

Figures 5 and 6 show only selected shallow shocks, while every intermediate or deep shock located in the region is mapped. The comparative numbers of the two types of shocks shown are consequently without much statistical significance, apart from the evident fact that it has been possible to locate an exceptionally large number of deep shocks here.

Closely associated with the belt of shallow earthquakes are a number of shocks at depths near 100 km. Most of these are along a northeast-southwest belt nearly parallel to the belt of shallow shocks, but farther from the Pacific. A few occur between Samoa and the most northeasterly shallow shocks, and are consequently the only shocks found immediately external to the Tonga salient.

In this area distinction between intermediate and shallow shocks is difficult only for small shocks or for those of early date. In New Zealand shallow shocks predominate. Not only the data of the local stations, but also macroseismic observations, bear on this point. Faulting at the surface was observed in 1855, 1888, 1929, and probably on other occasions, so that at least these large shocks must have had a shallow origin. The few New Zealand shocks indicated as intermediate are distinguished by a wider spacing of the isoseismals, combined with lower epicentral intensity, than is the case for shallow shocks of about the same magnitude. From the Kermadec Islands to Samoa the instrumental statistics indicate that shallow shocks are relatively, perhaps absolutely, less frequent.

West of the main belt of shallow and intermediate shocks, but trending more nearly north and south, is a somewhat irregular zone which is the most active source of very deep shocks in the world. At least 25 shocks at depths of 500 km. or more have been located here; and there are not a few others for which the depth and general region are known, but which have not been recorded sufficiently well for a close determination of the epicenter. The depths are greatest near 21° S., 180°, where the hypocenters range down to nearly 700 km. below the surface. Some of these are earthquakes of very large magnitude; that of May 26, 1932 (No. 52) wrote enormous amplitudes comparable with those of the great shallow shocks of Table 5, for all but the surface waves. (*See* Brunner, 1938.) No shock of this group is found south of 33°.

with the relation found in other regions. The New Zealand seismologists recognize other active lines, all with the same general longitudinal trend.

The southern half of the South Island is comparatively quiet; this is supported by the meager historical data, except for the fiord region at the

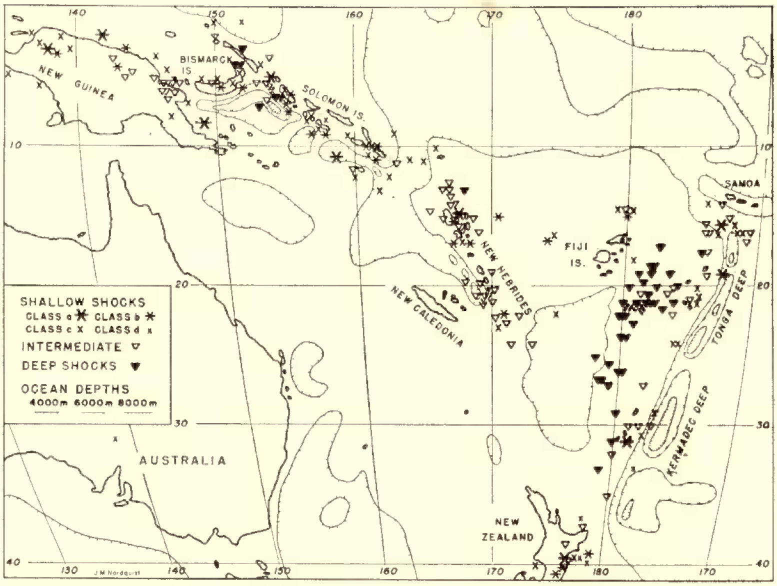

FIGURE 6.—*Map of epicenters, New Zealand to New Guinea*

southwest, which is near the epicenter of the large intermediate shock (depth 70 km.) of December 16, 1938.

The Kermadec, Tonga and Samoan Islands have a history of strong shocks.

NEW HEBRIDES TO NEW GUINEA

The extremely active seismic belt of the Melanesian islands (Fig. 6) follows a structure which in its western course parallels the margin of the Australasian continental area, as indicated by the andesite line. Farther east it trends southeastward, departing from the andesite line as usually drawn, so that it apparently passes from a marginal to an interior structure.

The majority of the shocks are shallow or in the shallower part of the intermediate range. It has not been necessary to list or map additional shocks, as investigation revealed no verifiable epicenters in areas not already well represented, except for: 1938, April 20, 06:27:05, 22° S. 175° E., A c.

are discussed in detail in a previous paper (Gutenberg and Richter, 1934), where they are tentatively attributed to the displacement of large crustal blocks.

Oceanic troughs, and most of the active epicenters, lie to the south of the Solomon Islands and New Hebrides, or on the side away from the Pacific basin. This is contrary to what is found on the east face of the Tonga salient, on the coast of Japan, and elsewhere on the Pacific boundary where the relation of focal depth to epicentral position also appears to be opposite to that in the present region. Intermediate shocks in the Solomon Islands are usually at depths near 100 km. West of the northwestern island of the group (Bougainville Island) are three shocks at depths near 400 km. It is natural to associate these with shocks at nearly the same depth in the Bismarck Islands northwest of them.

The Bismarck Islands clearly indicate a change in the seismic belts as well as in the geographical and geological relations. The northeastern island, New Ireland (Neu-Mecklenburg) is on the general line of the Solomon Islands, and the activity pattern is fairly similar, including the deep shocks just mentioned. It has been suggested that the shocks near New Ireland, including an additional shock at 1° S. 152° E. (1938, Feb. 7, 1:19:04, B d) are on an extension of the seismic belt following the Marianne Islands. However no shocks, deep or shallow, have been found in the intervening gap across the Caroline Islands. Our data are still manifestly incomplete, especially for deep shocks.

The few shocks associated with the larger island of New Britain (Neu-Pommern), appear on the map as if associated with the trough on the convex side of the curved island structure. These, with the shocks along the north coast of New Guinea follow a volcanic belt (Fisher, 1940).

CAROLINE ISLANDS

The passage of a branch of the circum-Pacific belt from New Guinea to the western Caroline Islands is a little uncertain, and it is not yet possible finally to reject the older view which prolonged the extremely active belt of the Melanesian islands directly into the equally active region of the East Indies. The reasons for this rejection are largely based on the structure of the complicated region between Halmaheira, Ceram and New Guinea, across which such a connection must be drawn. That almost inactive and extremely active segments follow one another in the same branch is no difficulty; several instances of the sort have been given in following round the Pacific.

Undoubtedly the boundary of the Pacific basin runs northward in this region, and the Philippine basin northwest of the Caroline Islands covers a region predominantly of continental type, perhaps comparable with that in the southeast Pacific between South America and the Easter Island

Guam. The western Caroline Islands, including Yap, are andesitic; the eastern Carolines are islands of Pacific type, so that the andesite line and the Pacific boundary must run between the two groups. Whether the andesite line is continued southwesterly to a point north of western New Guinea, as drawn by Born (1933, p. 766), or more nearly south, as drawn by Chubb (1934), seems to be rather arbitrary, as there appear to be no data bearing on the point. The seismological evidence, as will now appear, slightly favors Born's interpretation.

Shocks in this region are relatively infrequent. Figure 7 shows the result of investigating every shock indicated in the International Summary or recent station bulletins as occurring in or south of the Caroline Islands. All verified epicenters in this area are shown,—except that near Guam, where the activity increases (Repetti, 1939) minor shocks are omitted.

The critically important area shows only shallow earthquakes, although deeper shocks occur both in the Melanesian belt and in the Marianne Islands from Guam north. The activity is very slight on the whole, increasing in the western Carolines between Yap and Guam. One great shock (that of 1911, Table 5) is shown near Yap. A shock off the west point of New Guinea (August 10, 1927) is from Table 4.

Fortunately, two epicenters have been verified in the otherwise complete interruption of the active line between New Guinea and Yap. One of these (November 15, 1928) is directly in the suggested line, at 2° N. 133° E. It is fairly well recorded; the data, in good agreement, are supported by those of another shock from the same source 5 hours later. The shock of October 3, 1930, at 2° N. 135½° E., is not so good a case; but the data place it definitely east of the 1928 shock. At 7° N. 140° E. is an epicenter clearly southeast of Yap, in a position similar to that of the 1930 shock. This one (September 1, 1935) is well recorded, and the location is good. All three epicenters together support the hypothesis that a fairly wide active belt lies just southeast of the line from Western New Guinea to Yap.

MARIANNE ISLANDS TO JAPAN AND KAMCHATKA

The earthquakes of Japan, included partly here and partly under the next head, are difficult to summarize in a general discussion. The unusual wealth of material naturally results in making the treatment of this region somewhat more detailed than that of other areas of equal importance.

In certain local areas seismicity reaches a peak hardly exceeded elsewhere. Many of the shocks are large, and could be located even without the help of the numerous seismological stations of Japan. On the world map (Fig. 2) shocks of 1931–1933 which should have been mapped were so numerous that it was not possible to indicate them separately. In spite of their larger scale, the same difficulty arose at some points on Figures 7 and 8.

this area since 1933 have been investigated only when large or well recorded, or when the epicenter appeared to be unusual.

Table 11 contains additional shocks in the Kurile Islands, resulting from examination and revision of epicenters located in the International Summary in the Pacific basin area. As in other regions, unusual epicenters

TABLE 11.—*Additional earthquake epicenters east of Japan and the Kurile Islands*

Day	Time	Epicenter		Quality	Class
		Latitude, degrees	Longitude, degrees		
1929, March 14	14:14:55	40 N.	146 E.	C	d
1930, August 21	15:05:20	44 N.	148 E.	C	d
1929, July 25	15:07:54	47 N.	153 E.	C	c
1925, Jan. 31	17:00:40	45 N	149 E.	C	d
1921, Jan. 2	07:06:40	43½ N.	150 E.	C	c
1922, May 5	00:18:45	47 N.	151 E.	C	c
1930, April 24	00:23:45	47 N.	150 E.	C	c

have all been revised; a number of misinterpreted deep-focus shocks have been found in this way.

Historical data for Japan are more significant than for most seismic areas, since the records kept for centuries include many shocks of great magnitude, which are important and useful in studying the relation of present activity to that in the past. For the larger facts of this kind *see* Imamura (1937, especially p. 144–150).

Extending north from Guam are two seismic belts, geographically related in a way which apparently is not duplicated anywhere else. There is an eastern belt of shallow and intermediate earthquakes, and a western belt of deep shocks, which diverge as they go northward, take entirely different courses, and approach once more near Kamchatka. They will now be discussed separately.

From Guam the belt of shallow and intermediate earthquakes follows a series of island groups, where the nomenclature is very unsettled. Guam is the most southerly of the Marianne Islands, which for some reason are more commonly referred to as the Marianas, and occasionally by the older name of the Ladrones. North of these are minor islands and groups, among which are those formerly generally referred to as the Bonin Islands, but now more commonly called the Ogasawara-jima. Approaching the mainland of Japan the belt passes still other islands, including Hatidyo-zima (with many variant spellings[4]) and lastly the group of the Idzu

[4] Such as Fatsijo-shima. The practice of the Japanese themselves, not to mention that of foreigners, in transliterating local names into the Occidental alphabet, is extremely variable; many of the older and more familiar spellings are now little in use. Fujiyama is hardly recognizable as Mount Huzi, and the reader in seismology must learn that Tu and Tsu are the same. The syllables spelled "shima," "sima," "zima," "jima" form the Japanese word for "island."

A few shocks at depths of 200 km. and more occur inland or in the Japan Sea, far from the main belt of intermediate shocks. These apparently are not associated with the belt of deep shocks discussed below, but suggest an inner belt of intermediate shocks parallel to the main outer belt, somewhat similar to the belt of shocks at about the same depth under the eastern Andes.

The abundant historical data demonstrate the existence of three chief zones of destructive earthquakes, most of which must be at shallow depth. One of these zones is that lying off the Pacific coast of eastern Honshu. Here the larger shocks are destructive on land, and are frequently followed by still more destructive seismic sea waves (tsunamis). An important, but less active, second zone follows the northern and western coast of Honshu, along the Japan Sea. This is represented on Figure 8 by the following shocks:

1933, July 13	07:57:40	$42\frac{1}{2}$° N.	$138\frac{3}{4}$° E.	A	c
1933, Sept. 21	03:14:32	37° N.	137° E.	A	c
1933, Oct. 3	18:38:58	$37\frac{1}{4}$° N.	$138\frac{3}{4}$° E.	A	c
1939, May 1	05:58:33	40° N.	$139\frac{3}{4}$° E.	A	c
1940, Aug. 1	15:08:21	$44\frac{1}{2}$° N.	139° E.	A	b
1940, Aug. 13	15:36:40	36° N.	132° E.	B	c

and by the Tango earthquake of 1927 (Table 5), which is probably the largest of these shocks during the historical period. This zone is more naturally associated with the western main branch of the Pacific belt. It appears to have secondary branches of its own, which strike southward into eastern Honshu north of Tokyo, and may possibly account for the shocks of the Tokyo region. All shocks of the Japan Sea coast appear to be shallow; for the Tango earthquake there is no doubt of this, since fault displacements occurred at the surface. The same applies to the Mino-Owari earthquake of 1891, which is the outstanding shock of the third chief belt of shallow earthquakes. This belt crosses Honshu near its narrowest point, about Long. 137° E.; Figure 8 shows no shocks associated with it.

The remarkable structure known as the Fossa Magna is a zone of fissuring and volcanic activity extending from the Idzu peninsula through Fujiyama directly across Honshu. Geographically, it is an apparent continuation of the volcanic belt extending from the Marianne Islands to the Idzu group. Earthquake activity near the Fossa Magna is shallow, some of it being clearly superficial and volcanic in origin. Figure 8 shows shocks in the zone only near the coast west of Tokyo, about the Idzu peninsula. There is a marked difference in geology and possibly in the crustal layering on the two sides of the Fossa Magna. The Mino-Owari seismic belt and the transverse belt of deep shocks are far to the west of it.

In the Marianne Islands, deep earthquakes in the restricted sense are mine accurately. The belt extends past the Asiatic coast into Manchuria, where it ends, or makes a right angle turn, or intersects another similar belt, according to one's preference in interpreting the data. In this Manchurian area shocks at greater depths, down to nearly 600 km., are more frequent. From here the Sôya deep-focus zone of Wadati (1940), trends northeastward. The shocks appear to be actually fewer in number than those of the transverse zone crossing Honshu, although the smaller number of epicenters here is partly due to the greater distance from the stations of central Japan. Some evidence of separation into a northern and a southern line exists. The former at first remains inland, reaching the Asiatic coast at about 140° E.; it should cross Sakhalin near its center, where no epicenters are known at present, and appears to be continued across the Sea of Okhotsk into western Kamchatka, where the map shows the most northerly known deep shock, with a not very well-determined depth near 340 km. (No. 227). The southern line leaves the mainland more directly, and passes near the straits of Sôya between Sakhalin and Hokkaido. Here shocks near 400 km. are fairly frequent; beyond, the line enters the Sea of Okhotsk, where the focal depths of some shocks are below 600 km.; these are the deepest earthquakes in the entire Japanese area.

JAPAN, FORMOSA, AND LUZON

On reaching Kamchatka the circuit about the Pacific is complete; but we have yet to discuss the great western branch of the circum-Pacific belt, diverging from the eastern branch in central Japan, passing by way of the Philippines into the East Indies, and possibly connecting through the Sunda Islands and Burma with the trans-Asiatic zone.

This branch clearly accounts for the shocks along the Japan Sea coast of western Honshu, including the large Hamada earthquake of 1872. Probably it includes the locally strong shocks which are not rare in and near the Inland Sea north of Shikoku, especially near 34° N. 133° E.; one of the largest of these occurred on June 2, 1905.

Most maps of the seismicity of Japan show a submarine active belt including the shocks off the east coast of Honshu, but continuing along the entire Pacific coast of the islands past Shikoku to Kiushiu. Figure 8 does not support this. The absence of epicenters of large shocks between Kiushiu and central Honshu was verified by careful investigation of epicenters in the International Summary between the limits 30° and 35° N., 132° and 136° E. All of these were found to be imperfectly recorded and doubtfully located shocks, or else small shocks near the recording stations. Such local shocks are of no use in studying the seismic belts of Japan, as they occur in the vicinity of every recording station, and many of them are clearly volcanic in origin.

The map shows one intermediate shock in the questioned part of the

In addition to shallow and intermediate tectonic earthquakes, Kiushiu is visited by strong volcanic shocks. An important question is raised by the large Kagoshima earthquake of January 12, 1914, which accompanied an eruption of the near-by volcano Sakurajima. This shock had a large area of perceptibility, and sufficient energy to be well registered at European stations. It might be regarded as a purely tectonic shock, and its occurrence during an eruption as fortuitous; but similar instances are known, such as that of 1868 in Hawaii.

Intermediate shock No. 138 p (June 15, 1911), mapped at 29° N. 129° E., was originally in our list of great shallow shocks. It was destructive on the small island of Kikai, over 1 degree from the instrumentally determined epicenter.

Formosa, or Taiwan, is a region of higher activity than the adjacent parts of the seismic belt, exceeding most regions of Japan in frequency and magnitude of the recorded shocks. The two great shocks of 1920 and 1922 are taken from Table 5. Two others, not large enough to be included in that list, are of interest for their effects. That of March 16, 1906 was accompanied by visible faulting along an east-west zone in west central Formosa (Omori, 1907b). That of April 20, 1935, was accompanied by block faulting in the northwest part of the island; it is the subject of two special publications. One, completely in the Japanese language, was published at Taihoku in 1937; the other contains a few abstracts and tables in English, and was published in 1936 as supplementary volume No. 3 of the Bulletin of the Earthquake Research Institute (Tokyo). In these two cases shallow focus is consequently thoroughly established, which is important in a region where intermediate shocks are known to occur. Formosa occupies a sharp bend in the seismic belt, presumably associated with an intersection of the east-west structures, just alluded to, and the more conspicuous structures longitudinal to the island.

Useful historical data are available for Formosa only in comparatively recent years. In the Philippines, on the other hand, records for more than three centuries are available (Masó, 1927a; 1927b); the region is very active; the seismicity being comparable with that of Formosa and most parts of Japan. Recent earthquakes and instrumental epicenters have been discussed in a series of papers by Repetti (1931a; 1931b; 1931c; 1932; 1935; 1940).

The active belt plainly continues along the west coast of Luzon, where the intermediate shocks in general occur farther from the Pacific than the shallow ones, with the result that their epicenters fall off shore in the China Sea, while the shallow shocks are close to the coast.

PHILIPPINES AND MOLUCCAS

The distribution of seismic activity, some of which is very intense, has an important bearing on the complicated structural problems of the large region of intersection of two seismically active structural belts, not unlike the region of intersection in Formosa.

Shallow and intermediate shocks continue down the west coast to Mindoro; but there is no evidence for seismicity in the structural belt which

TABLE 12.—*Additional earthquake epicenters in the Philippines and the East Indies*

Day	Time	Epicenter		Quality	Class
		Latitude, degrees	Longitude, degrees		
1925, April 22	23:10:42	½ S.	129 E.	C	c
1927, June 11	02:32:09	1½ S.	130 E.	B	c
1924, Feb. 13	22:50:13	2½ S.	122 E.	B	c
1924, July 29	05:18:45	2½ S.	120 E.	B	c
1925, Dec. 29	16:04:11	1½ S.	120½ E.	B	c
1936, July 6	18:21:01	½ S.	126½ E.	B	d
1938, May 19	17:08:21	1 S.	120 E.	B	b
1924, April 13	13:48:00	½ N.	117½ E.	A	c
1913, March 14	08:45:00	4½ N.	126½ E.	B	b
1930, July 21	14:06:02	7 N.	114 E.	B	c
1919, April 27	00:22:05	11 N.	123 E.	C	c
1937, Aug. 20	11:59:16	14¼ N.	121½ E.	A	b
1936, Oct. 19	12:04:17	2 S.	127 E.	B	c
1938, June 9	19:15:08	3 S.	127 E.	A	b
1935, Dec. 29	23:37:20	3½ S.	128½ E.	B	c
1936, Nov. 30	23:45:48	2 S.	126 E.	B	c
1935, March 16	07:50:12	4 S.	129 E.	B	d
1938, Aug. 30	17:08:42	4 S.	128½ E.	B	d
1930, Nov. 9	19:08:38	½ S.	132 E.	A	c
1934, July 19	01:27:35	½ S.	133 E.	B	b
1936, Feb. 15	12:46:57	4½ S.	133 E.	B	b
1937, Nov. 5	09:28:30	4 S.	134 E.	C	c
1926, Dec. 14	17:10:32	12 S.	121 E.	C	c
1923, April 19	03:09:08	2½ N.	117½ E.	B	b

here branches off to the southwest, passing through Palawan to Borneo. Borneo itself is part of an old stable land mass, discussed in a later section.

The principal active belt in the eastern Philippines is associated, directly or secondarily, with a great fracture system referred to by Willis (1937; 1940) following Becker, as the Philippine Fault. Repetti (1935) calls it the Master Fault, and draws it northwest across central Luzon, thus emphasizing the structural intersection in the west. This line includes the earthquake of August 20, 1937 (Table 12), which caused damage at Manila and was destructive farther east. In its southern course, passing Mindanao, this seismic belt has all the characteristics associated with the most active regions on the boundary of the Pacific. To the east is the great shock of May 14, 1932 (Table 5). The belt of negative gravity anomalies runs southward to the east of these epicenters, accompanied by an oceanic trough less well marked than the great deeps to the north of it, and then swings southwestward toward Celebes.

The occasional large shocks on all sides of Celebes are difficult to assign to definite seismic belts. That of December 14, 1932, mapped at 2.4° N. 121° E., is large and accurately located. Just south of Celebes is the large shallow shock of March 3, 1927 (Table 4). With these should probably be included such historical shocks as that of 1820, destructive at Makassar and followed by a tsunami. (*See*, Sieberg, 1932a, p. 843). The deep shocks in the same area will be discussed with the Sunda arc.

A belt of intermediate shocks follows the northern peninsula of Celebes and extends eastward to Halmaheira, following a well-known volcanic line which cuts across the structures associated with shallow earthquakes; from Halmaheira this belt turns north toward the Philippines, here running on the east side of the belt of shallow shocks. Near the parallel of 2° N. north of Celebes are three shocks at depths of not quite 300 km. Still farther north are two shocks at depths of 600 and 670 km., these may be associated with the north-south belt of deep shocks in the Philippines.

The current suggestion is that the structural belt followed by shallow earthquakes swings east from central Celebes, and runs round the Banda Sea to connect with the Sunda arc. This is very speculative; certainly the epicenters, as mapped, would leave plenty of room for connections of different character.

SUNDA ARC

The seismic area of the Netherlands East Indies is bounded on the south by epicenters in the structural belt which runs from Ceram round the Banda Sea, thence west by way of the Lesser Sunda Islands and the coasts of Java and Sumatra to the Nicobar and Andaman Islands.

Shocks are more frequent about the Banda Sea than Figure 9 suggests. Locations are not easy here, even when the depth of focus is well determined. Uncertainty as to the focal depth is common, and seriously affects the accuracy of the resulting epicenters. One great shallow shock is well located (Feb. 1, 1938; Table 5). This and other shallow shocks are near the Weber Deep. The belt of negative gravity anomalies follows the same course round the inside of the structural arc. Shocks at intermediate depth are here most frequent on the south side of the Banda Sea, where they seem to align with the east-west trend of the main Sunda arc. The deep shocks mapped in the Banda Sea east of 125° originated at depths from 370 km. to 500 km.

The seismicity of the Sunda islands from the Banda Sea to central Java is only lightly indicated on Figure 9. Most of the shocks are either shallow