Temporal Variation of the Activity of Intermediate and Deep Focus Earthquakes

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The temporal variation of the activity of intermediate and deep focus earthquakes for the period from 1904 to 1974 is investigated on the basis of a uniform body-wave magnitude scale. The m_b scale has been traditionally used for intermediate and deep focus earthquakes. However, the period of seismic waves and the Q function used for the magnitude determination have changed as a function of time, so that uniform evaluation of the activity is difficult. In this study, we used a body-wave magnitude m_B determined from the maximum amplitude of body waves recorded by broad-band or long-period instruments to investigate the temporal variation. For the period from 1904 to 1952, m_B values were calculated from the unpublished material of Gutenberg and Richter. For 1953 to 1958, m_B values were calculated from the amplitude and the period data in Gutenberg's unpublished file. For the period from 1959 to 1974, seismological bulletins from various stations were used to determine m_B. Consistency between the values of m_B calculated from these different sources was carefully checked. The temporal variation of the number of intermediate-deep events with $m_B \geq 7$ is remarkably similar to that of shallow earthquakes with $M_s \geq 7$. The temporal variation of the energy release in intermediate-deep earthquakes shows a maximum around 1910. The sum of the energy release curve of intermediate-deep and shallow earthquakes shows a good correlation with the amplitude of the Chandler wobble. The energy release becomes maximum at the depth of 350 and 600 km.

1. INTRODUCTION

The activity of intermediate and deep focus earthquakes provides important clues to the mechanical property and the stress distribution within the downgoing lithosphere. *Gutenberg* [1956, 1957] discussed the variation of seismic energy release as a function of depth by using the magnitude of intermediate and deep focus earthquakes. *Honda et al.* [1967] found a systematic pattern of stress axes for Japanese deep focus earthquakes. *Isacks and Molnar* [1969] made an extensive study on the stress regime in the downgoing slab in various subduction zones. Estimates of stress release in deep focus earthquakes have been made by various investigators [e.g., *Mikumo*, 1969, 1971*a*, *b*; *Fukao*, 1970, 1972; *Wyss*, 1970; *Wyss and Molnar*, 1972]. Recently, *McGarr* [1977] related the activity of intermediate and deep focus earthquakes to the phase changes in the downgoing slab. The study of detailed physical mechanism provides important constraints on various models of plate subduction.

From this point of view, the size (or magnitude) of intermediate and deep focus earthquakes is one of the most important parameters. The magnitude of intermediate and deep focus earthquakes was first determined by *Gutenberg* [1945*b*] by using seismic body waves. Since then a large number of determinations have been made by various investigators, seismological stations and agencies and have been published in various catalogs [*Gutenberg and Richter*, 1954; *Richter*, 1958; *Duda*, 1965; *Rothé*, 1969; *Earthquake Data Reports* (EDR) of the U.S. Coast and Geodetic Survey and U.S. Geological Survey; *Bulletin of International Seismological Center* (ISC)].

Unfortunately, as will be discussed later, the magnitude scale used in these catalogs varies significantly from one catalog to another so that it is not possible to discuss the spatial and temporal pattern of seismicity of intermediate and deep focus earthquakes on a uniform basis.

The purpose of this paper is to provide a uniform magnitude catalog of large intermediate and deep focus earthquakes and to discuss the temporal and depth variations of these earthquakes. Following *Gutenberg and Richter* [1954], here 'intermediate' is used for the depth range from 70 to 300 km, and 'deep' for depths larger than 300 km.

Since the magnitude is determined entirely from observed records without due consideration to the source model of the earthquake, its physical significance in terms of the earthquake source size is somewhat vague. This is particularly so for very large shallow earthquakes in which the source dimension is much larger than the wavelength of seismic waves used for the magnitude determination, and consequently the scale saturates.

On the other hand, for intermediate and deep focus earthquakes, the source dimension is probably not very large, so that the magnitude determined at 5 to 20 sec period on either broad-band or long-period records would probably represent the overall size of the earthquake reasonably well.

2. MAGNITUDE SCALES USED IN VARIOUS CATALOGS

We first review the scales used in various catalogs (see Table 1 for summary). For the period 1904 to 1952, the catalog of *Gutenberg and Richter* [1954] is the most complete. However, the magnitude M listed in this catalog (denoted by M_{GR} in this paper) is not clearly defined. We investigated the original notepads of Gutenberg and Richter and found that

$$M_{GR} = \log\left(\frac{A}{T}\right) + Q_{\text{old}} + s + c \quad (1)$$

where A and T are the amplitude and the period of seismic body waves such as P, PP, and S defined in *Gutenberg* [1945*a*, *b*]. The Q function used above, Q_{old}, is significantly different from that used later by *Gutenberg and Richter* [1956] and described in *Richter* [1958]. It is described in *Gutenberg* [1945*b*]. In the above expression, s is the station correction, and c is the correction applied to large earthquakes [*Gutenberg*, 1945*a*, *b*, 1956]. This correction changed as a function of time. The magnitudes listed in Tables XIV-3 and XIV-4 of

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TABLE 1. Magnitudes of Deep Earthquakes

Period	*Gutenberg and Richter* [1954]	*Richter* [1958]	*Duda* [1965]	This Study
1904–1952	M_{GR}	M_R for $m_B \geq 7.5$, none for others	M_R for $m_B \geq 7.5$, M_{GR} for others	m_B
1953–1958	none	ditto, none for 1958	M_{GR} for all until July 1954 and M_R for all	m_B
1959–1974	none	none	M_R? until 1964, none for 1965–1974	m_B

(1) m_B: $m_B = \log A/T + Q_{revised} + s$ (s = station corrections); (2) M_{GR}: $M_{GR} = \log A/T + Q_{old} + s + c$ (c = corrections for large shocks); (3) M_R: $M_R = (m_B - 2.5)/0.63$.
Examples: June 16, 1910, h = 100 km, m_B = 7.9, M_{GR} = 8.1, M_R = 8.6; December 18, 1921, h = 650 km, m_B = 7.5, M_{GR} = 7.6, M_R = 7.9; November 24, 1944, h = 170 km, m_B = 7.4, M_{GR} = 7.5.

Richter [1958] were calculated from the body wave magnitude m_B by

$$M_R = (m_B - 2.5)/0.63 \quad (2)$$

where m_B is determined by

$$m_B = \log\left(\frac{A}{T}\right) + Q_{revised} + s \quad (3)$$

Here the Q function is the revised one given in *Gutenberg and Richter* [1956] and reproduced in *Richter* [1958, pp. 688–689]. Equation (2) was applied to the earthquakes with $m_B \geq 7.5$. For these large events, M_R is significantly larger than m_B (e.g., for $m_B = 7.9$, $M_R = 8.5$).

Duda's [1965] catalog employs different scales for different periods and magnitude ranges as shown in Table 1. The magnitude for intermediate and deep focus earthquakes in *Rothé* [1969] is essentially the same as that in Duda for large earthquakes. (For details, see *Abe and Kanamori* [1979].) In the present study we used m_B defined by (3). The method of calculation is described in detail in *Abe and Kanamori* [1979] and is not repeated here.

In short, for the period from 1904 to 1952, the data for the individual stations listed in the unpublished notepads of *Gutenberg and Richter* [1954] were carefully examined and m_B values calculated. For 1953 to 1958, Gutenberg's unpublished data of amplitudes and periods were used. For the period from 1959 to 1974, we used the amplitude and the period data reported in the seismological bulletins of various stations. Approximately 20 stations were used. Since 1975, most stations discontinued reporting the amplitude data, from either long-period or broad-band records, in their station bulletins so that no reliable m_B determination could be made. Two examples of such m_B determinations are illustrated in Tables A-1 and A-2 in Appendix A[1] (on microfiche).

3. RESULT

The m_B scale adopted here is the same as that originally defined by Gutenberg (see (3)), and the revised Q function described in *Gutenberg and Richter* [1956] and *Richter* [1958] is used. For the station corrections, we used the values listed by *Gutenberg* [1945*b*] when available; if it is not listed, s is assumed to be zero. Since we used a large number of data (approximately 30) for each earthquake, the station correction is not very significant.

Table 2 lists the results for larger events with $m_B \geq 7.3$ for the period from 1904 to 1974. In Appendix B[1] (on microfiche), all the events with $m_B \geq 7.0$ for the period from 1904 to 1974 are listed. Tables A-3 and A-6 list, respectively, the intermediate and deep events listed in *Gutenberg and Richter* [1954]. Tables A-5 and A-8 are for the events from 1953 to 1974. The events which are not listed in *Gutenberg and Richter* [1954] but are included in the original worksheets of Gutenberg and Richter are listed in Tables A-4 and A-7 for intermediate and deep focus earthquakes respectively. In these tables, the period T used in (3) is included. The values of T reported in the bulletins were usually determined from the pulse width of the phase being measured. Although the meaning of these periods is somewhat ambiguous, they approximately represent the period of the waves for which m_B is determined. The values of M listed in these tables are taken from *Gutenberg and Richter* [1954]. Figure 1 shows the relation between M and m_B. The solid line shows the commonly used relation between M_s and m_B [*Gutenberg and Richter,* 1956; see also *Abe and Kanamori,* 1979], and the dotted line is $M = m_B$. It is evident that M, the magnitude listed in *Gutenberg and Richter* [1954] corresponds to neither M_s nor m_B. This situation is different from that for shallow earthquakes for which M is essentially the same as M_s [*Geller and Kanamori,* 1977].

Since 1963, the *Earthquake Data Reports* (EDR) and the *Bulletin of International Seismological Center* (ISC) have published the body-wave magnitudes m_1 determined from short-period, usually about 1 sec, body waves. These values are different from the m_B values determined in this paper as shown by Figure 2, where the m_1 values are taken from *Bulletin of the International Seismological Center* for the period from 1964 to 1974 and the data for $m_B < 7.0$ are added from our unpublished files. In all cases, m_B is significantly (approximately 0.8 unit) larger than m_1. Thus m_1 determined for recent large events (e.g., Colombian earthquakes of July 31, 1970, m_1 = 6.5, m_B = 7.5) cannot be compared directly with m_B used for older events. In the present study m_B was determined for all the events with $m_B \geq 7.0$ to enable direct comparison.

It is well known that very large shallow earthquakes are often complex multiple events. This is also true for intermediate and deep focus earthquakes. Examples are the Brazil earthquake of November 9, 1963 [*Fukao,* 1972], and Spanish earthquake of March 19, 1954 [*Chung and Kanamori,* 1976]. For these events, m_B may not adequately represent the entire source process. Nevertheless, since m_B is determined at 10 to

[1] The appendix is available with entire article on microfiche. Order from American Geophysical Union, 1909 K Street, N.W., Washington, D. C. 20006. Document J79-003; $1.00. Payment must accompany order.

TABLE 2. Large Intermediate and Deep Earthquakes (m_B = 7.3 or Over), 1904–1974

Date	Time, GMT	Depth, km	Location	M	m_B	T, sec
June 7, 1904	08:17	350	40N134E	7½	7.4	5
Jan. 22, 1905	02:43	90	1N123E	7¾	7.8	5
June 2, 1905	05:39	100	34N132E	7¾	7.5	6
Sept. 1, 1905	02:45	230	45N143E	7½	7.3	7
Jan. 21, 1906	13:49	340	34N138E	8.0	7.7	6
Sept. 28, 1906	15:24	150	2S79W	7½	7.5	8
May 25, 1907	14:02	600	51½N147E	7.4	7.4	5
June 25, 1907	17:54	200	1N127E	7½	7.5	6
March 26, 1908	23:03	80	18N99W	7.8	7.7	13
Feb. 22, 1909	09:21	550	18S179W	7.5	7.6	6
March 13, 1909	14:29	80	31½N142½E	7.7	7.6	7
July 7, 1909	21:37	230	36½N70½E	7¾	7.6	8
Nov. 10, 1909	06:13	190	32N131E	7.6	7.5	9
April 12, 1910	00:22	200	25½N122½E	7¾	7.6	6
June 1, 1910	05:55	80	20S169E	7½	7.3	8
June 16, 1910	06:30	100	19S169½E	8.1	7.9	10
Aug. 21, 1910	05:38	600	17S179W	7¼	7.4	8
Nov. 9, 1910	06:02	70	16S166E	7¾	7.5	6
May 4, 1911	23:36	240	51N157E	7.6	7.4	10
June 15, 1911	14:26	160	29N129E	8.2	8.1	9
July 4, 1911	13:33	190	36N70½E	7.6	7.4	7
Nov. 22, 1911	23:05	200	15S169E	7¼	7.3	7
Aug. 6, 1912	21:11	260	14S167E	7.2	7.3	7
Nov. 7, 1912	07:40	90	57½N155W	7½	7.3	6
Dec. 7, 1912	22:46	620	29S62½W	7½	7.3	6
Aug. 13, 1913	04:25	75	5½S105E	7.2	7.3	5
Oct. 14, 1913	08:08	230	19½S169E	7¾	7.6	6
Oct. 3, 1914	17:22	100	16N61W	7.4	7.4	5
Nov. 24, 1914	11:53	110	22N143E	8.1	7.9	7
Jan. 5, 1915	14:33	200	15S168E	7¼	7.3	5
Jan. 5, 1915	23:26	160	25N123E	7¼	7.3	7
June 6, 1915	21:29	160	18½S68½W	7.6	7.3	10
Sept. 7, 1915	01:20	80	14N89W	7¾	7.4	9
April 18, 1916	04:01	170	53¼N170W	7.5	7.4	6
June 21, 1916	21:32	600	28½S63W	7.5	7.4	6
July 31, 1917	03:23	460	42½N131E	7.5	7.4	5
Aug. 30, 1917	04:07	100	7½S128E	7¾	7.3	5
Jan. 30, 1918	21:18	330	45½N135E	7.7	7.4	8
May 20, 1918	17:55	80	28½S71½W	7.5	7.6	6
Nov. 18, 1918	18:41	190	7S129E	7.8	7.5	8
Jan. 1, 1919	02:59	180	19½S176½W	7¾–8	7.7	10
Aug. 31, 1919	17:20	180	16S169E	7¼	7.3	7
Feb. 4, 1921	08:22	120	15N91W	7.5	7.4	15
July 4, 1921	14:18	200	25½N141½E	7.2	7.4	7
Nov. 15, 1921	20:36	215	36.5N70.5E	7¾	7.6	6
Dec. 18, 1921	15:29	650	2½S71W	7.6	7.5	7
Jan. 17, 1922	03:50	650	2½S71W	7.6	7.4	8
Oct. 24, 1922	21:21	80	47N151½E	7.4	7.3	8
Dec. 6, 1922	13:55	230	36½N70½E	7.5	7.3	4
June 26, 1926	19:46	100	36½N27½E	7.9	7.7	7
June 29, 1926	14:27	130	27N127E	7.5	7.4	7
Jan. 13, 1929	00:03	140	49¾N154¾E	7.7	7.4	11
Oct. 19, 1929	10:12	100	23S69W	7.5	7.4	8
Feb. 20, 1931	05:33	350	44.3N135.5E	7.4	7.4	5
May 26, 1932	16:09	600	25½S179¼E	7¾	7.5	6
March 1, 1934	21:45	120	40S72½W	7.1	7.3	8
April 16, 1937	03:01	400	21½S177W	7¾	7.5	6
Oct. 20, 1938	02:19	90	9S123E	7.3	7.3	5
April 18, 1939	06:22	100	27S70½W	7.4	7.3	5
Oct. 17, 1939	06:22	120	14S167¾E	7.4	7.3	6
Dec. 21, 1939	21:00	150	0N123E	8.0	7.8	9
Jan. 17, 1940	01:15	80	17N148E	7.3	7.3	8
July 10, 1940	05:49	580	44N131E	7.3	7.3	4
July 14, 1940	05:52	80	51¾N177½E	7¾	7.4	7
Nov. 10, 1940	01:39	150	45¾N26½E	7.4	7.3	8
Dec. 28, 1940	16:37	80	18N147½E	7.3	7.3	7
May 28, 1942	01:01	120	0N124E	7.5	7.4	8
Nov. 26, 1942	14:27	110	45½N150E	7.4	7.4	6
July 23, 1943	14:53	90	9½S110E	7¾	7.6	11
Dec. 1. 1943	06:04	120	4¾S144E	7.2	7.3	7
Oct. 5, 1944	17:28	120	22½S172E	7½	7.3	6
Nov. 24, 1944	04:49	170	19S169E	7.5	7.4	7
Sept. 26, 1947	16:01	110	24¾N123E	7.4	7.4	5
May 11, 1948	08:55	70	17½S70¼W	7.3	7.4	5

TABLE 2. (Continued)

Date	Time, GMT	Depth, km	Location	M	m_B	T, sec
March 4, 1949	10:19	230	36N70½E	7.5	7.4	7
April 30, 1949	01:23	130	6½N125E	7.4	7.3	7
Feb. 28, 1950	10:20	340	46N144E	7.8	7.5	5
Nov. 2, 1950	15:28	220	7S129½E	7.5	7.4	8
Dec. 4, 1950	16:28	110	5S153½E	7.2	7.3	7
Dec. 9, 1950	21:38	100	23½S67½W	8.0	7.7	7
Dec. 14, 1950	01:52	200	19¼S175¾W	7.7	7.5	8
July 2, 1953	06:56	250	19.5S169.5E		7.4	7
March 21, 1954	23:42	180	24.2N95.1E		7.4	5
Oct. 11, 1956	02:24	110	45.9N150.7E		7.3	5
Nov. 29, 1957	22:19	170	20.9S67.0W		7.4	10
April 26, 1959	20:40	113	24.9N122.8E		7.5	9
June 14, 1959	00:11	100	20.4S69.0W		7.5	8
Sept. 14, 1959	14:09	73	28.7S177.7W		7.3	8
Jan. 13, 1960	15:40	200	15.8S72.8W		7.5	11
March 28, 1961	09:35	83	0.2N123.6E		7.3	5
Aug. 31, 1961	01:57	629	10.5S70.7W		7.3	6
Sept. 8, 1961	11:26	125	56.3S27.1W		7.6	7
Feb. 26, 1963	20:14	182	7.6S146.2E		7.3	6
Aug. 15, 1963	17:25	593	13.8S69.3W		7.3	5
Nov. 4, 1963	01:17	108	6.9S129.5E		7.8	12
May 26, 1964	10:59	114	56.5S27.7W		7.5	11
July 9, 1964	16:39	127	15.6S167.6E		7.4	11
March 14, 1965	15:53	205	36.4N70.7E		7.5	13
Jan. 19, 1969	07:02	238	44.9N143.2E		7.3	5
July 31, 1970	17:08	653	1.5S72.6W		7.5	6
July 27, 1971	02:02	88	2.8S77.4W		7.3	5
Nov. 24, 1971	19:35	99	52.9N159.2E		7.4	5
Feb. 14, 1972	23:29	101	11.4S166.4E		7.3	10
June 11, 1972	16:41	336	3.9N124.3E		7.4	6
Aug. 28, 1973	09:50	75	18.3N96.6W		7.3	6
Sept. 29, 1973	00:44	567	41.9N131.0E		7.4	4

20 sec for these large earthquakes, it can be considered more adequate than m_1 in representing the overall size of these large events.

4. DISCUSSION

Temporal Variation

Figure 3 shows the temporal variation of the annual number of intermediate and deep focus earthquakes with $m_B \geq 7.0$. The dotted curve shows an unlagged 5-year running average. Three peaks are notable, around 1910, 1940, and 1950. The sudden decrease in N prior to 1910 may be partly due to the poor detection and location capability. The data prior to 1922 may be somewhat incomplete [*Gutenberg*, 1956], but the existence of the 1910 peak is probably real. The number of events for the recent years is considerably smaller than the average, 4.7/year. It is interesting to compare this curve with that for shallow earthquakes. Figure 4 shows the comparison. The curve for shallow earthquakes shows the annual number of events with $M_s \geq 7$ taken from *Kanamori* [1977*a*]. The correla-

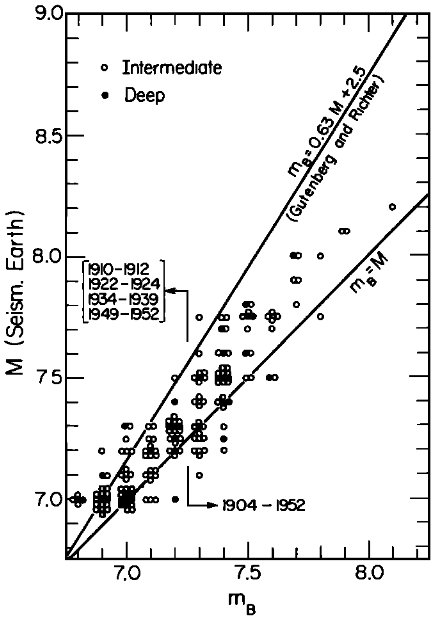

Fig. 1. The relation between the magnitude M in *Gutenberg and Richter* [1954] and m_B. For $m_B \leq 7\frac{1}{4}$, only the data for arbitrarily chosen periods (1910–1912, 1922–1924, 1934–1939, 1949–1952) are shown to avoid cluttering the figure. Note that M differs from $(m_B - 2.5)/0.63$ ($\equiv M_s$) or m_B.

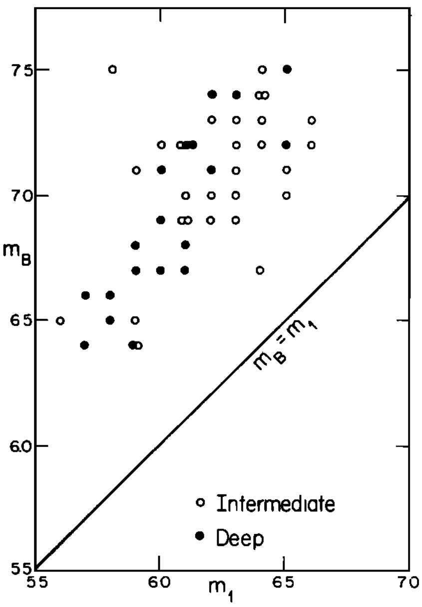

Fig. 2. Comparison between m_B and m_1.

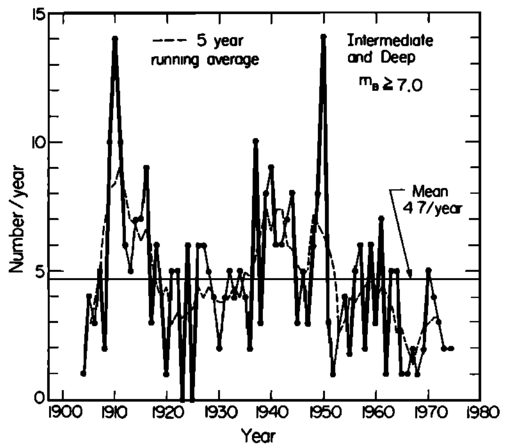

Fig. 3. The number of intermediate and deep focus earthquakes with $m_B \geq 7.0$ as a function of year. The dotted curve is unlagged 5-year running average taken at the center of the interval.

tion is quite remarkable; the correlation coefficient is 0.7 for the period from 1910 to 1972.

Another comparison can be made in terms of the amount of energy released in earthquakes. According to *Gutenberg and Richter* [1955, 1956] the seismic wave energy released in earthquakes can be written as

$$\log E = 5.8 + 2.4\, m_B \qquad (4)$$

(E in ergs). Figure 5 shows E as a function of time together with an unlagged 5-year average (solid curve). Although the major feature of this curve is similar to that of the annual number N (Figure 3), the peak around 1910 is more pronounced. This peak is mainly represented by three large intermediate earthquakes, June 16, 1910 (New Hebrides, $m_B = 7.9$), June 15, 1911 (Ryukyu Island, $m_B = 8.1$), and November 24, 1914 (Mariana Islands, $m_B = 7.9$). This energy release curve is

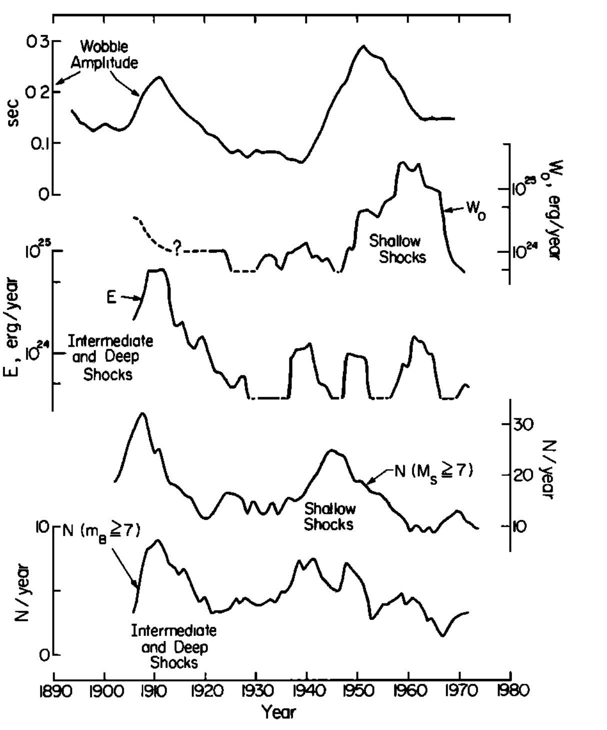

Fig. 4. Comparison of the amplitude of the Chandler wobble, energy release in shallow earthquakes, energy release in intermediate and deep focus earthquakes, the number of shallow earthquakes and the number of intermediate and deep focus earthquakes.

compared with that for shallow earthquakes which is taken from *Kanamori* [1977*a*, Figure 4]. The energy release for the period prior to 1920 is uncertain in *Kanamori*'s [1977*a*] paper, but recent studies by *Kanamori and Abe* [1978] and *Abe* [1979] indicate that there is probably no peak of energy release in shallow earthquakes around the turn of the century. Thus the energy release curve for shallow earthquakes seems to be uncorrelated with that for intermediate and deep focus earthquakes. It is interesting to note that the peak of shallow earthquake activity is dominated by great earthquakes in Chile, Alaska, the Aleutians and Kamchatka [see *Kanamori*, 1977*a*] where major thrust earthquakes occur very frequently, whereas the three intermediate earthquakes that contribute to the peak of the intermediate-deep earthquake activity occurred in subduction zones where no great (large M_w, see *Kanamori* [1977*a*]) earthquakes occur (see Figure 4 of *Kanamori* [1978]). It thus appears that the major energy release in shallow and intermediate-deep earthquakes occurs in a complimentary manner. If this is the case, the lack of correlation between them may not be surprising. In this context, it is interesting to compare these energy release curves with the amplitude of the Chandler wobble (Figure 4).

The Chandler wobble amplitude shows two maxima, one around 1910 and the other around 1950. *Kanamori* [1977*a*] showed that the peak around 1950 seems to be correlated with the peak of the energy release curve for shallow earthquakes. However, the peak around 1910 remained unexplained. It is noteworthy that the 1910 peak correlates very well with the peak of the intermediate-deep focus earthquakes. Since the sum of the energy release for shallow and intermediate-deep earthquakes represents the total global energy release, it is reasonable that a global process such as the Chandler wobble correlates better with the sum rather than the individual energy release curve. However, it has been demonstrated [e.g., *Kanamori*, 1977*a*] that the amount of energy release in earthquakes expressed by W_0 or E in Figure 4 is much too small to affect the Chandler wobble significantly. Thus even if the above correlation is significant, the physical mechanism relating these two processes is unknown. One possibility is that earthquakes involve large aseismic deformation [*Kanamori*, 1977*b*] so that the energy release curve represents only a part of the total energy budget. This interpretation is tentative and further studies are obviously necessary.

Depth Variation

Figure 6 shows the variation of the number of events N and the energy release E as a function of depth. Except for the depth of 35 km (shallow earthquakes), each data point represents the total for the depth interval of 50 km centered at the depth given by the solid circle and for the time interval of 71 years from 1904 to 1974. These are calculated from all the

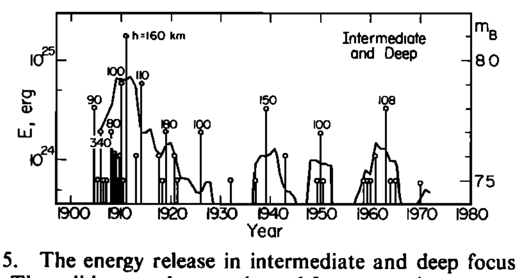

Fig. 5. The energy release in intermediate and deep focus earthquakes. The solid curve shows unlagged 5-year running average taken at the center of the interval. The number attached to each event indicate the focal depth.

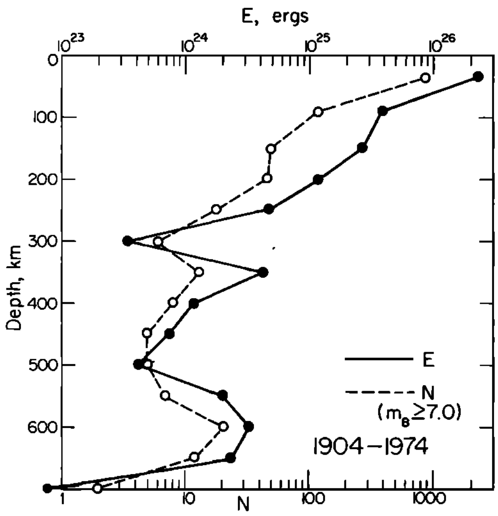

Fig. 6. The variation of intermediate and deep focus earthquakes as a function of depth. The solid curve shows the energy and the dotted curve, the number of events with $m_B \geq 7$. The scale at the top refers to the energy E, and that at the bottom refers to the number N. Each data point represents the value for a depth range of 50 km centered at the depth of each data point and for the time period of 75 years from 1904 to 1974.

tables in Appendix B. For shallow earthquakes, the data are taken from *Kanamori* [1977*a*, Figures 2 and 4] for the 57-year period from 1920 to 1976. It is assumed that shallow earthquakes represent the activity for the depth range from 0 to 70 km. The number of events and W_0 are reduced to those for a depth interval of 50 km and the time period of 71 years and plotted in Figure 6. The trends for N and E are very similar. Two peaks, one at 350 km and the other at 600 km, are found. This feature is essentially the same as that demonstrated by *Gutenberg* [1957] who used the data set compiled by *Gutenburg and Richter* [1954].

It is interesting to note that the depths of these two peaks coincide with those where rapid changes in seismic-wave velocity occur. These velocity changes have been interpreted in terms of phase changes of minerals in the mantle [*Anderson*, 1967].

Figure 6 shows that the energy release in shallow earthquakes per unit depth is nearly two orders of magnitude larger than that for deep focus earthquakes below 300 km. However, the total energy release in intermediate and deep focus earthquakes is about 1.0×10^{26} ergs/71 years and is comparable to that for shallow earthquakes, 3.2×10^{26} ergs/71 years.

Table 3 lists the largest (in m_B) earthquake in various depth ranges. For shallow earthquakes, the four largest earthquakes in M_w are also listed: m_B values are taken from *Geller and Kanamori* [1977] and *Abe and Kanamori* [1979].

TABLE 3. Largest Earthquakes for Given Depths, 1904–1974

h, km	Date	Depth, km	m_B	Region
	May 22, 1960	Normal	7.9	Chile (M_w = 9.5)
	March 28, 1964	N	7.9	Alaska (M_w = 9.2)
	March 9, 1957	N	7.7	Aleutians (M_w = 9.1)
	Nov. 4, 1952	N	7.9	Kamchatka (M_w = 9.0)
50	Nov. 6, 1958	60	8.2	Kurile Is.
100	June 16, 1910	100	7.9	New Hebrides
	Nov. 24, 1914	110	7.9	Mariana Is.
150	June 15, 1911	160	8.1	Ryukyu Is.
200	Jan. 1, 1919	180	7.7	Tonga Is.
250	Nov. 15, 1921	215	7.6	Hindu Kush
	July 7, 1909	230	7.6	Hindu Kush
	Oct. 14, 1913	230	7.6	New Hebrides
300	Aug. 21, 1911	300	7.2	Tonga Is.
350	Jan. 21, 1906	340	7.7	Japan
400	April 16, 1937	400	7.5	Tonga Is.
450	July 31, 1917	460	7.4	Japan Sea
500	March 29, 1907	500	7.2	Celebes
550	Feb. 22, 1909	550	7.6	Tonga Is.
600	May 26, 1932	600	7.5	Tonga Is.
650	Dec. 18, 1921	650	7.5	Peru
	July 31, 1970	653	7.5	Colombia
700	Sept. 22, 1940	680	7.0	Philippine Is.
	June 29, 1934	720	7.0	Celebes

5. CONCLUSION

In order to obtain a uniform magnitude catalog for intermediate and deep focus earthquakes, we adhered to *Gutenberg*'s [1945*b*] original definition of body-wave magnitude, m_B, determined from body waves recorded on a broad-band or long-period seismogram. The Q function defined by *Gutenberg and Richter* [1956] was used. The average period of the waves used is 5 to 20 sec for large earthquakes. These periods are long enough to make m_B represent the overall size of intermediate and deep focus earthquakes. The determination of m_B was made for all the events larger than $m_B \geq 7$ for the period from 1904 to 1974. Various inhomogeneities in the existing catalogs have been thus removed in the catalog obtained in this study (Table 2, Appendix B).

The temporal variation of the number of intermediate and deep earthquakes with $m_B \geq 7$ is remarkably similar to that of shallow earthquakes with $M_s \geq 7$. The temporal variation of the energy release in intermediate and deep earthquakes shows a maximum around 1910. The sum of the energy release curve of intermediate-deep and shallow earthquakes shows a good correlation with the amplitude of the Chandler wobble. The energy release becomes a maximum at depths of 350 and 600 km.

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