22. Earthquake Magnitude Determination in relation to Regional Variations of P wave Amplitudes Part 1.

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Abstract

Body wave magnitude m_{pz} in EDR (Earthquake Data Report) of USCGS for earthquakes with shallow forcal depth ($H \leq 50$ km) determined at near and regional epicentral distances ($5° \leq \Delta < 30°$) deviates significantly from the magnitude of the same events determined at teleseismic distances ($\Delta \geq 30°$). Overestimation of magnitude by as much as 0.5 to 1.5 magnitude units in the epicentral distance ranging between 5° and 13° relative to the magnitude at teleseismic distances shows that the zone of low amplitude signals predicted by Gutenberg and Richter (1956) in that distance range does not exist as a worldwide phenomenon. Available distance range of the calibrating function $Q(\Delta)$ provided by Gutenberg and Richter as a worldwide standard should be limited to the distance range of more than 20°.

Regional correction factor as a function of epicentral distance subtractive from the calibrating function $Q(\Delta)$ are calculated for the five reference stations, College/Alaska, Tonto Forest/Arizona, Caracas/Venezuela, Port Moresby/New Guinea and Rabaul/New Britain Island.

1. Introduction

There are two independent estimations of the calibrating functions for body waves, i.e. the Q-functions of Gutenberg-Richter (1956) and the β-functions of Vaněk-Stelzner (1960). Comparison of the β function with the Q-function for PZ component shows fairly good agreement between the two in the epicentral distance range between 20° and 100° in spite of the fact that the Q-function was constructed as a worldwide standard and β-function as a European standard (Fig. 1).

Recently, Carpenter et al. (1967) computed an amplitude-distance curve by using a least-squares program for short-period P waves at
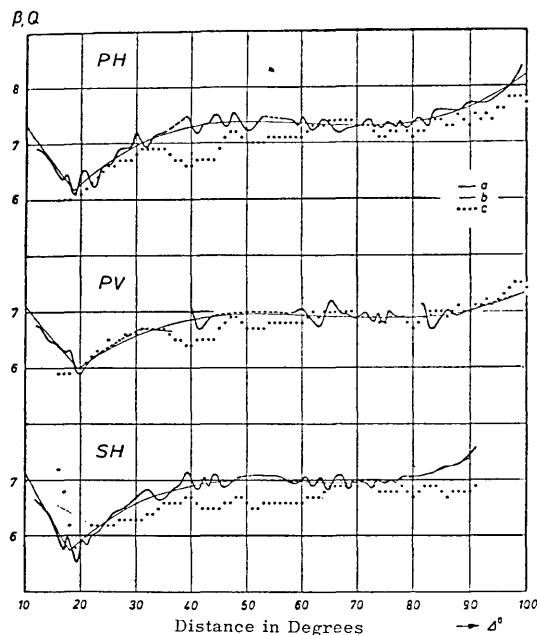
Fig. 1. Comparison of β-functions with Gutenberg-Richter's Q-functions for PH, PV and SH (a-3rd approximation of β-functions, b-1st approximation of β-functions, c-Q-functions) (After Vaněk, J. et al., 1960)

distances between 30° and 120° from nuclear explosion data (Fig. 2). Cleary (1967) analyzed P wave amplitudes at LRSM stations using the least-squares program devised by Carpenter from the same set of earthquake data used by Cleary and Hales (1966) in their study of P times. When the input amplitude data are expressed as logarithms of half the maximum peak to trough ground motion of P in microns, the source amplitude term gives a direct estimate of magnitudes of the events, based on Gutenberg and Richter's unified magnitude scale. This is not applicable to the case of Cleary's analysis, since Cleary measured the amplitude of the first peaks. Nevertheless, comparing the Cleary's curve with the Gutenberg-Richter's curve, it is worth noticing that the agreement between the two is very good for the broad distance range, though the values calculated by the least-squares program show much less fluctuation in amplitude between 30° and 80° (Fig. 3).

The circumstances mentioned above suggest that the Q-function for PZ component is available as a worldwide standard calibrating function for magnitude determination in the epicentral distance range between 30° and 100°, when we ignore the small partial departures from the amplitude-distance curves derived by the different authors with different source recordings and analytical procedures. Thus, in the following analysis, we select the five reference stations (Table 1) and re-evaluate the magnitudes of the earthquakes around them (Table 2) by use of the amplitude data at the stations between 30° and 90° based on the Gutenberg-Richter's magnitude determination system to see the regional deviation of magnitude values.

2. Material Used

Preliminary Determination of Epicenter (PDE) or Earthquake Data Report (EDR) of USCGS is used, which includes both magnitudes for the individual stations caluated from the maximum amplitude A of the initial P wave group and its period and the average of them usually noted as "USCGS magnitude" m_{CSG}. Shallow earthquakes ($H \leq 50$ km) with epicentral distances less than 30° from the following five reference stations in Table 1 are selected from EDR for the period of 1965–1967 and tabulated in Table 2 in order of their epicentral distances. In Table 2, the following items are included, i. e. (A) Year, (B) Month, (C) Day, (D) Origin time, (E) Depth in km (ND: probably shallow, ND*: Automatically restricted to 33 km), (F) Epicentral distance $\varDelta$ in degrees, (G) Azimuth measured from north clockwise from the epicenter to the station, (H) Jefferys-Bullen travel time residual in sec., observed minus computed, (I) USCGS magnitude: m_{CGS}, (J) Reference station magnitude: m_r, (K) Averaged magnitude of the stations at
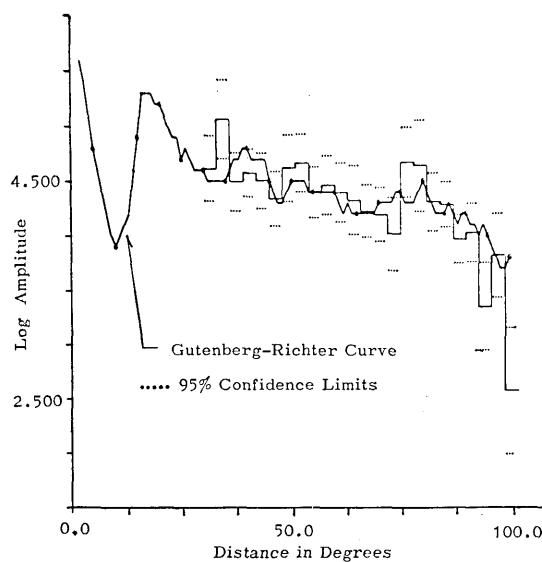
Fig. 2. Amplitude-distance curve with confidence limits from least-squares analysis compared with Gutenberg and Richter's curve for surface focus (after Carpenter et al., 1967)

Table 1. Location of the reference stations

| No.	Station Name	Abbreviation	Latitude	Longitude	Height
1	College, Alaska	COL	64° 54′ 00″. 0 N	147° 47′ 36″. 0 W	183 m
2	Tonto Forest, Arizona	TFO	34° 17′ 12″. 0 N	111° 16′ 03″. 0 W	1609 m
3	Caracas, Venezuela	CAR	10° 30′ 24″. 0 N	66° 55′ 39″. 5 W	1035 m
4	Port Moresby, New Guinea	PMG	9° 24′ 33″. 0 S	147° 09′ 14″. 0 E	70 m
5	Rabaul, New Britain	RAB	4° 11′ 33″. 0 S	152° 10′ 16″. 0 E	184 m
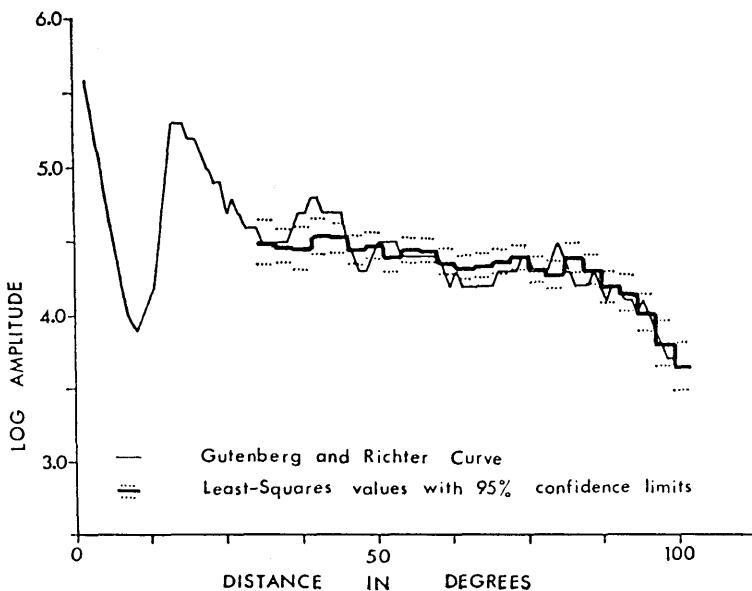
Fig. 3. Amplitude-distance curve with confidence limits from least-squares analysis compared with the Gutenberg and Richter's curve for surface focus (after Cleary, J., 1967)

the distance of $30° \leq \varDelta < 90°$: m_t, (L) $\delta m = m_r - m_t$ (M) EDR No. and Page and (N) Region name abbreviation.

3. Regional Magnitude Deviations

The amplitude-distance curves derived by different authors including the Gutenberg-Richter's Q-function for PZ component show fairly good agreement between them for epicentral distance ranging from 30° to 90° or up to 100° as described previously. This circumstance permits us to use the Q-function as a worldwide standard calibrating function for the magnitude determination at teleseismic distance from 30° to 90° in order to re-evaluate independently of the USCGS magnitude m_{CGS} in EDR taking the average value of the individual station magnitude m_t at the epicentral distance of $30° \leq \varDelta < 90°$. The effect of regional variations of amplitude on magnitude values caused by the regional difference of the vertical velocity structure in the crust and upper mantle will be largely removed by this procedure.

Regional magnitude deviation factor $\delta m(\varDelta)$ is introduced to see the

Table 2. List of earthquakes

1. Earthquakes around COL ($\Delta<30°$)

A	B	C	D h m s	E	F	G	H	I	J	K	L	M	N
66	D E C	23	164007.6	N D*	5.5	348.5	−0.8	4.5	5.1	4.3	0.8	91 P 16	G F A L
66	J A N	15	160802.3	33	5.7	346.9	0.0	4.4	4.9	4.0	0.9	04 P 12	G F A L
66	J U N	03	112206.8	14	5.7	2.1	0.5	3.7	5.0	3.7	1.3	46 P 02	K N P N
66	S E P	13	053001.4	N D*	6.8	24.2	−0.2	4.3	5.5	4.1	1.4	65 P 30	A L P N
66	M A R	23	071507.5	N D*	7.1	6.2	−0.7		5.1	3.9	1.2	17 P 35	G F A L
66	M A R	19	061047.0	02	7.6	16.9	−0.6	4.6	5.0	4.3	0.7	18 P 24	K O D I
66	J A N	01	084151.9	32	8.1	19.4	0.0	4.4	4.7	4.1	0.6	01 P 02	K O D I
66	A P R	11	182611.8	N D*	8.2	17.1	−1.4	4.9	5.3	4.9	0.4	20 P 42	K O D I
66	A P R	08	091909.6	N D*	8.3	12.4	−1.7	4.7	5.5	4.4	1.1	22 P 17	K O D I
66	A P R	22	101550.6	N D*	8.3	11.9	−1.0	4.9	5.5	4.6	0.9	24 P 29	K O D I
66	M A R	07	202133.0	N D*	8.3	10.5	−0.8	5.0	5.2	4.5	0.7	16 P 12	K O D I
66	A P R	13	003158.2	N D*	8.3	11.9	−2.2	4.8	5.0	4.2	0.8	23 P 17	K O D I
66	M A R	04	141930.5	N D	8.4	16.6	−2.4	4.8	5.2	4.6	0.6	15 P 12	K O D I
66	A P R	16	044044.9	N D*	8.4	17.3	−1.2	4.5	4.7	4.4	0.3	22 P 30	K O D I
66	A P R	16	012715.3	N D*	8.4	17.0	−2.3	5.7	6.2	5.6	0.6	22 P 28	K O D I
66	A P R	08	221059.3	N D*	8.4	12.1	−1.9	5.1	5.4	4.9	0.5	20 P 36	K O D I
66	A P R	09	200838.6	N D*	8.5	12.3	−1.2	5.5	5.7	5.2	0.5	22 P 22	K O D I
66	A P R	22	072347.6	09	8.5	12.3	−0.3	4.7	5.0	4.2	0.8	23 P 15	K O D I
66	A P R	11	230024.0	N D*	8.5	12.1	−2.4	5.4	5.9	5.2	0.7	21 P 30	K O D I
66	A P R	09	201744.5	N D	8.6	12.7	−1.1	5.1	5.3	4.8	0.7	22 P 22	K O D I
66	N O V	19	163903.2	N D*	8.6	17.9	−1.2	4.5	5.1	4.4	0.7	83 P 14	K O D I
66	A P R	09	084815.2	N D*	8.6	13.3	−0.6	4.4	4.8	4.1	0.7	22 P 21	K O D I
66	A P R	06	222838.7	N D*	8.9	18.6	−1.4	5.5	5.8	4.8	1.0	20 P 34	K O D I
66	J A N	08	203014.3	N D*	9.2	23.9	−1.1	4.4	4.6	4.2	0.4	02 P 10	A L P N
66	O C T	10	211734.5	N D*	9.4	328.2	−3.1	4.8	5.4	5.0	0.4	75 P 12	S A L S
66	J A N	22	142707.9	N D*	9.4	15.5	−3.4	5.8	6.3	5.5	0.8	08 P 11	S A L S
66	M A R	25	215926.4	22	10.3	329.1	−3.8	4.7	4.9	4.6	0.3	19 P 20	S A L S
66	A P R	29	014642.6	N D*	12.2	20.5	−7.5	5.2	5.4	5.2	0.2	25 P 21	S A L S
66	J A N	10	001726.8	N D*	12.6	27.8	−0.5	4.5	4.5	4.5	0.0	04 P 05	A L P N
66	M A Y	19	070626.8	28	13.5	30.7	−0.4	5.8	5.6	5.5	0.1	32 P 19	U N M I
66	M A Y	19	091834.7	35	13.5	30.0	−0.1	4.4	4.6	4.2	0.4	34 P 14	U N M I
66	S E P	16	171039.0	34	13.6	28.7	−0.2	4.9	5.0	4.7	0.3	65 P 32	U N M I
66	A U G	22	111012.8	35	13.7	29.6	−3.9	4.5	4.8	4.4	0.4	62 P 21	U N M I
66	A P R	13	111750.9	N D*	14.3	33.1	−0.3	3.9	3.8	3.9	−0.1	25 P 05	F O X I
66	M A R	29	225715.5	N D	14.3	32.0	−0.2	4.3	4.1	4.2	−0.1	20 P 15	F O X I
66	A P R	28	064116.7	N D*	14.4	32.2	−0.1	5.0	4.0	4.4	−0.4	29 P 11	F O X I

(to be continued)

Table 2.

(continued)

A	B	C	D h m s	E	F	G	H	I	J	K	L	M	N
66	J U N	23	130625.5	16	15.1	33.6	0.1	4.2	4.0	4.1	−0.1	45 P 17	F O X I
66	M A Y	07	032646.3	45	15.1	33.5	0.0	4.9	4.3	4.9	−0.6	30 P 16	F O X I
66	M A Y	15	043410.9	N D	15.3	33.6	1.0	4.7	4.3	4.6	−0.3	32 P 15	F O X I
66	J U N	11	142543.7	N D	15.3	33.1	1.8	4.1	4.0	4.1	−0.1	44 P 07	F O X I
66	J U N	16	152951.7	N D	15.3	33.0	1.6	4.1	4.0	4.1	−0.1	45 P 10	F O X I
66	M A Y	16	231634.8	15	15.4	33.5	0.3	4.6	4.5	4.6	−0.1	35 P 05	F O X I
66	M A Y	05	073958.2	N D	15.4	33.7	−0.2	4.3	3.8	4.3	−0.5	30 P 10	F O X I
66	M A Y	05	075115.6	N D	15.4	34.0	0.2	4.1	3.5	4.1	−0.6	30 P 11	F O X I
66	M A Y	14	093358.7	N D	15.5	33.6	0.4	4.1	3.9	4.1	−0.2	32 P 13	F O X I
66	M A Y	04	202533.0	25	15.6	34.2	0.2	4.3	4.2	4.4	−0.2	30 P 09	F O X I
66	M A Y	16	133946.4	N D	15.6	33.6	−0.6	4.0	3.5	4.0	−0.5	33 P 15	F O X I
66	M A Y	05	002227.3	25	15.6	34.3	0.4	4.7	4.7	4.7	0.0	28 P 15	F O X I
66	M A Y	13	171653.9	N D	15.6	33.5	−0.2	4.0	3.7	3.8	−0.1	32 P 12	F O X I
66	M A Y	06	091042.6	25	15.9	33.6	0.5	4.1	3.6	4.0	−0.4	30 P 15	F O X I
66	A P R	23	180512.6	N D*	15.9	32.3	−0.7	4.8	4.5	4.5	0.0	24 P 31	F O X I
66	A P R	25	074811.4	N D	16.2	32.9	0.5	4.8	3.4	4.3	−0.9	27 P 11	F O X I
66	S E P	02	221450.9	N D	16.3	34.7	−1.6	4.9	4·4	4.9	−0.5	68 P 06	F O X I
66	N O V	16	231609.1	N D	16.6	35.5	1.9	4.9	4.2	4.9	−0.7	81 P 16	F O X I
66	O C T	04	043239.1	35	16.6	32.9	0.7	4.3	3.5	4.3	−0.8	73 P 11	F O X I
66	N O V	11	153104.2	38	16.7	32.6	−1.0	5.4	5.3	5.8	−0.5	79 P 30	F O X I
66	F E B	16	115814.2	47	16.8	33.3	−0.2	4.8	4.2	4.8	−0.6	09 P 44	F O X I
66	J A N	20	163219.9	19	16.8	33.2	−0.4	5.3	4.2	4.8	−0.6	05 P 16	F O X I
66	J A N	14	215549.6	N D*	17.4	31.0	−2.5	4.4	3.9	4.4	−0.5	05 P 10	F O X I
66	J A N	31	192018.6	N D*	17.9	32.8	−1.2	4.6	4.1	4.6	−0.5	09 P 14	F O X I
66	M A Y	04	070936.9	N D*	17.9	32.2	−0.5	3.9	3.7	4.0	−0.3	31 P 07	F O X I
66	M A Y	25	165856.5	N D	18.1	32.7	0.1	4.1	3.8	4.1	−0.3	39 P 05	F O X I
66	F E B	04	083520.0	N D	18.1	36.0	0.0	3.7	3.5	3.8	−0.3	12 P 09	A N D I
66	D E C	29	080706.1	N D	18.2	36.1	0.6	4.1	3.7	4.2	−0.5	96 P 09	A N D I
66	M A Y	25	215621.7	N D	19.2	36.2	−0.5	4.6	4.2	4.5	−0.3	39 P 05	A N D I
66	M A Y	03	120653.8	20	20.0	37.2	−1.3	4.9	4.3	4.7	−0.4	32 P 05	A N D I
66	N O V	17	214555.9	N D	20.0	36.1	−0.9	4.1	4.1	4.2	−0.1	84 P 15	A N D I
66	N O V	15	161907.4	48	20.2	36.5	−2.0	5.0	4.8	5.0	−0.2	80 P 29	A N D I
66	A P R	19	105956.8	N D	20.3	36.9	−0.4	4.3	4.2	4.2	0.0	25 P 10	A N D I
66	S E P	23	215022.8	39	20.4	37.1	0.4	4.6	4.1	4.5	−0.4	68 P 23	A N D I
66	M A Y	28	215012.2	N D	20.6	38.0	0.0	5.2	4.6	5.0	−0.4	35 P 24	A N D I
66	M A Y	15	144606.5	31	20.7	37.9	0.5	5.8	5.2	5.8	−0.6	31 P 18	A N D I

(to be continued)

Table 2.

A	B	C	D h m s	E	F	G	H	I	J	K	L	M	N
66	M A Y	03	025208.8	30	20.8	37.9	0.4	5.1	4.0	4.8	−0.8	32 P 05	A N D I
66	J A N	05	070157.5	N D*	20.8	37.3	0.4	5.0	4.7	4.6	0.1	04 P 03	A N D I
66	J U N	20	012412.9	34	20.8	38.0	0.8	5.1	4.7	5.1	−0.4	41 P 17	A N D I
66	N O V	08	035008.2	41	20.9	37.4	0.7	4.7	4.4	4.6	−0.2	80 P 18	A N D I
66	M A Y	17	091150.7	15	20.9	37.4	0.4	4.4	4.2	4.3	−0.1	33 P 17	A N D I
66	D E C	18	133315.5	38	20.9	37.9	0.5	4.5	4.0	4.5	−0.5	91 P 11	A N D I
66	M A R	25	125455.7	N D	21.2	38.5	0.0	4.9	4.4	4.8	−0.4	20 P 11	A N D I
66	N O V	21	022232.5	N D	21.3	39.2	0.6	4.6	4.8	4.6	0.2	89 P 04	R A T I
66	N O V	15	000807.1	43	21.4	38.5	−0.6	5.0	4.8	5.0	−0.2	80 P 28	A N D I
66	A P R	18	150733.5	N D	21.5	38.1	−0.7	4.5	3.8	4.4	−0.6	25 P 09	A N D I
66	J U L	03	152127.9	15	21.6	39.1	−0.4	4.5	4.5	4.4	0.1	46 P 14	R A T I
66	J U L	03	013258.1	N D	21.7	39.0	0.9	4.3	4.4	4.2	0.2	49 P 12	R A T I
66	A P R	11	234516.4	N D*	21.7	38.2	−0.6	4.3	3.9	4.3	−0.4	27 P 02	R A T I
66	J U L	01	045326.0	20	21.7	39.2	−0.5	4.5	4.5	4.5	0.0	49 P 10	R A T I
66	O C T	12	021229.1	42	21.8	39.1	2.0	4.4	4.2	4.5	−0.3	74 P 12	R A T I
66	J A N	21	180330.6	48	21.8	38.6	0.6	4.7	3.9	4.4	−0.5	13 P 02	R A T I
66	F E B	20	082757.8	48	21.8	38.4	0.0	4.0	3.9	4.0	−0.1	14 P 14	R A T I
66	A P R	20	075705.4	10	22.1	37.9	−0.1	4.7	3.8	4.3	−0.5	30 P 05	R A T I
66	J A N	27	193904.5	41	22.3	38.9	−0.5	5.4	5.0	5.3	−0.3	05 P 24	R A T I
66	S E P	02	005440.7	14	22.5	38.9	0.0	5.2	4.7	5.0	−0.3	62 P 37	R A T I
66	D E C	25	230322.8	47	22.6	40˙8	0.6	4˙8	4.8	4.8	0.0	91 P 21	R A T I
66	O C T	09	033228.9	47	22.6	40.5	−0.1	3.8	3.9	3.8	0.1	75 P 12	R A T I
66	J U N	01	023356.3	15	22.8	40.3	1.0	5.1	4.5	4.8	−0.3	35 P 26	R A T I
66	D E C	11	071459.5	N D*	22.9	40.8	0.3	4.2	4.2	4.2	0.0	89 P 12	R A T I
66	J U N	10	042514.3	N D	22.9	41.5	1.0	4.9	4.7	4.8	−0.1	42 P 14	N E A I
66	M A Y	02	232123.8	25	23.0	41.2	1.1	4.3	4.3	4.2	0.1	27 P 18	R A T I
66	A P R	07	220846.8	N D*	23.0	42.2	−0.5	4.2	4.2	4.2	0.0	22 P 16	N E A I
66	J U N	10	191117.1	45	23.1	42.6	2.3	4.9	4.9	4.6	0.3	44 P 06	N E A I
66	J U N	02	032753.3	41	23.2	39.7	−0.9	6.0	5.5	5.8	−0.3	35 P 27	R A T I
66	M A Y	13	075442.1	N D	23.2	39.5	0.6	4.8	4.3	4.5	−0.2	35 P 03	R A T I
66	A P R	08	234650.8	45	23.3	42.4	1.1	4.9	4.6	4.8	−0.2	21 P 27	N E A I
66	M A R	26	133647.9	44	23.4	39.4	−0.6	4.5	4.2	4.4	−0.2	21 P 09	R A T I
66	A P R	11	160541.6	29	23.4	42.8	0.9	5.2	4.9	4.8	0.1	21 P 29	N E A I
66	N O V	08	113557.0	41	23.4	42.7	1.0	4.9	5.1	4.9	0.2	80 P 18	N E A I
66	D E C	09	164357.7	21	23.4	41.0	1.5	5.2	4.8	5.2	−0.4	88 P 13	N E A I
66	D E C	09	171207.3	17	23.5	40.9	0.5	4.7	4.3	4.8	−0.5	88 P 14	N E A I

Table 2.

(continued)

A	B	C	D h m s	E	F	G	H	I	J	K	L	M	N
66	J A N	20	144606.2	29	23.5	43.8	0.8	5.4	5.4	5.2	0.2	05 P 15	N E A I
66	S E P	20	061348.0	21	23.6	42.3	0.6	4.8	4.5	4.5	0.0	66 P 23	N E A I
66	J A N	16	091150.0	25	23.6	43.6	0.5	5.7	5.5	5.4	0.1	05 P 10	N E A I
66	J U N	25	213211.6	N D	23.6	44.5	−0.5	4.6	4.5	4.5	0.0	49 P 05	N E A I
66	M A R	02	115120.7	40	23.7	42.8	0.8	5.3	5.1	5.0	0.1	11 P 30	N E A I
66	F E B	25	224955.8	N D	23.8	43.1	0.9	4.3	4.1	4.3	−0.2	11 P 21	N E A I
66	M A R	08	232640.3	18	23.9	44.7	0.6	4.7	4.9	4.5	0.4	14 P 31	N E A I
66	N O V	13	211004.2	N D*	24.1	45.3	0.5	4.7	4.7	4.7	0.0	85 P 08	K O M I
66	J U N	12	064908.9	N D	24.3	43.8	−0.8	4.5	4.9	4.2	0.7	42 P 18	N E A I
66	J U N	06	145932.9	N D	24.5	49.5	1.5	4.3	4.2	4.3	−0.1	40 P 11	K O M I
66	M A Y	20	114428.8	46	24.7	47.7	−0.2	5.3	5.2	5.1	0.1	33 P 20	K O M I
66	O C T	24	135344.5	N D	24.7	47.6	0.3	4.9	5.1	4.9	0.2	83 P 03	K O M I
66	D E C	23	234927.3	28	26.2	47.4	−0.2	4.9	4.7	4.9	−0.2	91 P 18	N E K M
66	D E C	23	235609.0	N D*	26.5	47.0	−1.0	4.6	4.4	4.7	−0.3	91 P 18	N E K M
66	F E B	05	012532.1	17	27.6	44.9	−0.4	4.5	4.4	4.5	−0.1	11 P 06	O E K M
66	F E B	20	055809.6	44	28.6	45.0	−1.1	4.9	4.4	4.9	−0.5	12 P 23	N E K M
66	F E B	05	142445.0	44	29.2	44.6	0.1	5.2	4.6	5.1	−0.5	07 P 34	N E K M

2. Earthquakes around TFO ($\Delta < 30°$)

A	B	C	D h m s	E	F	G	H	I	J	K	L	M	N
66	M A Y	10	011555.7	N D	5.8	4.5	−2.0	4.4	4.0	4.3	−0.3	31 P 12	G L C L
67	M A Y	10	175933.4	N D	7.5	3.6	−0.3	4.3	4.6	4.8	−0.2	31 P 38	G L C L
67	A P R	10	190025.6	05	7.6	224.7	−1.1	4.8	4.5	4.9	−0.4	27 P 20	C L R D
66	M A R	17	114748.7	38	7.8	179.0	−0.4	4.5	4.1	4.4	−0.3	16 P 20	U T A H
66	J U N	29	195324.1	05	7.8	98.9	−2.1	4.9	4.8	5.0	−0.2	45 P 29	C R C L
66	J U N	28	040854.7	05	7.8	98.8	−2.2	5.0	5.1	5.0	0.1	45 P 27	C R C L
66	J U N	28	042612.4	04	7.8	99.3	−2.9	5.3	5.2	5.2	0.0	45 P 28	C R C L
66	S E P	12	164101.7	08	8.7	122.9	1.7	5.4	5.6	5.3	0.3	67 P 16	N C A L
67	A P R	14	100417.3	N D	8.8	350.7	−1.0	4.1	4.5	4.2	0.3	27 P 32	G L C L
66	A P R	13	130735.6	N D	8.9	349.5	−3.5	4.3	4.2	4.3	−0.1	23 P 17	G L C L
66	M A Y	18	032077.3	N D	9.4	348.7	−2.0	5.3	5.0	5.3	−0.3	33 P 18	G L C L
66	M A Y	24	034952.8	2	10.1	119.3	−0.4	4.5	4.5	4.3	0.2	37 P 07	N C A L

(to be continued)

A	B	C	D h m s	E	F	G	H	I	J	K	L	M	N
67	A P R	24	044517.5	N D	10.3	345.2	0.9	4.3	4.8	4.7	0.1	29 P 31	G L C L
66	M A Y	24	054906.3	01	12.5	109.9	3.1	5.2	5.2	4.7	0.5	43 P 03	O C N C
66	N O V	26	043057.9	N D	12.8	113.6	4.3	4.6	5.6	4.7	0.9	83 P 20	O C N C
66	D E C	17	151630.5	N D*	12.9	113.3	3.8	4.6	5.1	4.2	0.9	90 P 18	O C N C
67	J A N	26	060433.9	N D	13.0	351.3	1.1	5.3	5.9	5.2	0.7	08 P 26	R G D I
66	F E B	06	202112.3	N D	13.3	112.5	4.3	4.6	5.0	4.0	1.0	12 P 11	O C N C
66	M A Y	22	092922.7	48	13.3	350.8	0.4	5.2	5.7	5.0	0.7	33 P 23	R G D I
66	M A Y	22	060630.3	28	13.4	351.5	−0.2	4.7	5.1	4.3	0.8	35 P 10	R G D I
66	F E B	06	101617.6	N D*	14.1	109.9	3.2	4.8	5.1	4.4	0.7	14 P 05	O C N C
66	A U G	11	144704.4	N D	14.5	352.5	0.4	4.5	4.5	4.9	−0.4	59 P 20	R G D I
67	J A N	23	212413.0	N D	14˙5	353.6	1.1	4.4	5.0	5.0	0.0	07 P 25	R G D I
66	A U G	11	132537.3	N D	14.6	352.1	0.7	4.6	4.9	4.6	0.3	59 P 20	R G D I
67	J A N	30	024421.1	N D	14.7	352.1	0.7	4.4	4.6	4.7	−0.1	09 P 37	R G D I
67	J A N	18	053434.8	N D	14.7	351.5	0.3	4.3	4.3	4.9	−0.6	07 P 14	R G D I
66	J A N	24	052304.7	N D	14.8	113.8	−4.8	4.6	3.7	4.4	−0.7	08 P 16	O C N C
66	J A N	14	055940.7	N D	14.9	114.8	−0.8	4.6	4.1	4.4	−0.3	07 P 14	O C N C
66	N O V	09	031827.7	N D	14.9	352.7	0.9	4.2	4.4	4.7	−0.3	80 P 19	R G D I
67	F E B	11	122944.0	N D	15.1	349.7	0.9	4.3	4.4	5.1	−0.7	12 P 20	R G D I
66	J U L	24	085239.3	N D	15.1	350.7	0.3	4.8	4.4	5.3	−0.9	54 P 15	R G D I
67	M A Y	03	003145.8	N D	15.1	350.3	1.3	4.3	4.4	4.8	−0.4	31 P 25	R G D I
66	J U N	11	023738.7	45	15.2	350.1	0.4	5.3	4.5	5.3	−0.8	41 P 09	R G D I
66	A U G	08	080245.8	N D	15.2	350.0	1.8	5.4	5.2	5.4	−0.2	56 P 18	R G D I
66	F E B	07	074022.4	N D	15.4	350.8	0.6	4.9	4.5	5.0	−0.5	09 P 28	R G D I
66	J A N	28	101506.6	N D*	15.5	121.8	1.8	5.2	4.0	4.6	−0.6	06 P 22	O C O R
66	A P R	28	223005.1	18	16.0	121.6	1.0	5.0	4.4	5.1	−0.7	24 P 33	O C O R
66	D E C	20	075538.6	N D	16.0	345.0	0.3	4.6	4.4	5.0	−0.6	90 P 21	O C J M
66	A P R	05	060813.2	N D	16.0	350.9	−1.6	4.0	3.4	4.6	−1.2	20 P 30	R G D I
66	D E C	20	014501.5	N D	16.0	344.8	0.1	4.2	3.7	4.8	−1.1	90 P 20	O C J M
66	D E C	20	022703.4	N D	16.1	345.7	0.2	4.4	4.3	5.3	−1.0	90 P 21	O C J M
66	J A N	04	023048.0	N D*	16.1	351.9	−2.0	4.4	3.5	4.8	−1.3	02 P 04	R G D I
67	A P R	04	181801.9	N D	16.7	341.0	−0.6	4.5	4.4	4.9	−0.5	27 P 13	N C J M
67	J A N	17	005007.9	N D*	16.7	120.5	1.6	4.0	3.4	4.1	−0.7	06 P 09	O C O R
66	S E P	04	012822.8	N D	16.8	121.4	−0.5	3.9	3.5	4.4	−0.9	68 P 07	O C O R
66	M A R	19	012336.8	N D	17.0	119.6	4.1	4.6	3.4	4.0	−0.6	16 P 21	O C O R
66	O C T	24	110534.0	N D*	17.0	120.7	1.6	4.2	3.8	4.1	−0.3	77 P 17	O C O R
67	J A N	25	234947.5	N D	17.4	120.0	3.3	3.8	3.6	4.3	−0.7	09 P 21	O C O R
67	J A N	26	082628.9	N D	18.4	117.7	3.4	4.1	4.0	4.2	−0.2	10 P 14	O C O R

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A	B	C	D h m s	E	F	G	H	I	J	K	L	M	N
66	J U N	16	085937.7	N D	19.0	341.7	1.3	3.9	3.8	4.3	−0.5	48 P 02	O C M M
66	O C T	13	023755.1	N D	19.9	346.7	0.8	4.2	3.8	4.3	−0.5	79 P 06	O C M X
66	A P R	06	130245.2	15	20.1	331.1	1.3	4.1	3.9	4.3	−0.4	23 P 09	G R M X
66	F E B	20	185957.1	N D	20.1	331.6	0.1	4.4	4.1	4.7	−0.6	15 P 05	N C G M
67	F E B	17	202319.1	47	20.6	329.0	−0.4	4.6	4.5	4.8	−0.3	17 P 06	G R M X
66	O C T	12	190404.6	N D	20.8	311.1	1.4	4.0	4.0	4.0	0.0	80 P 03	N C G M
66	O C T	12	185527.9	25	20.8	329.7	0.0	4.6	4.6	4.5	0.1	77 P 06	N C G M
66	J U N	17	130538.5	N D*	21.2	331.1	0.0	3.8	3.6	3.7	−0.1	44 P 14	N C G M
67	F E B	11	044805.3	34	21.2	329.7	0.4	4.6	4.5	4.5	0.0	12 P 17	N C G M
67	F E B	11	042546.8	38	21.2	329.8	0.6	4.7	4.6	4.9	−0.3	09 P 47	N C G M
67	F E B	19	114639.8	25	21.4	329.7	0.1	4.8	4.8	4.9	−0.1	13 P 22	N C G M
66	N O V	01	145531.2	N D	22.0	327.8	1.1	4.6	4.7	4.5	0.2	78 P 27	O X M X
66	J U N	25	231706.1	40	22.5	326.6	−0.1	4.8	4.5	4.9	−0.4	43 P 38	O X M X
66	J U N	15	021947.8	43	22.5	322.2	2.1	4.3	4.1	4.3	−0.2	47 P 04	C H P M
66	J A N	26	044508.4	36	22.9	324.5	1.2	3.7	3.3	3.7	−0.4	09 P 11	O X M X
66	J A N	23	005721.8	32	23.2	323.6	0.7	4.6	4.8	4.6	0.2	05 P 21	O X M X
67	F E B	08	193914.2	46	23.3	327.3	1.4	4.7	4.4	4.8	−0.4	09 P 47	O X M X
66	A U G	03	102438.9	N D*	23.8	318.2	1.3	3.9	4.1	3.7	0.4	58 P 08	C H P M
66	F E B	19	020043.9	43	24.3	323.8	0.6	4.8	5.0	4.7	0.3	09 P 45	N C O X
66	S E P	30	070322.4	46	24.4	323.5	1.5	4.7	4.6	4.4	0.2	71 P 16	N C O X
66	N O V	26	105559.9	44	24.6	324.1	1.1	4.2	4.3	4.2	0.1	83 P 21	N C O X
67	A P R	12	143239˙1	N D	24.6	323.8	1.2	4.7	4.6	4.9	−0.3	24 P 33	N C O X
67	A P R	30	132103.3	N D	24.9	345.3	0.0	4.4	4.3	4.5	−0.2	30 P 17	O C M X
66	S E P	03	162420.7	47	24.9	346.6	−0.6	5.3	4.7	5.1	−0.4	63 P 27	O C M X
67	A P R	02	115829.7	45	25.3	322.6	1.4	4.5	4.4	4.7	−0.3	27 P 08	N C C M
66	N O V	04	063636.4	35	25.7	323.9	1.1	4.8	4.7	4.8	−0.1	79 P 21	N C C M
67	J A N	18	074813.0	N D*	25.8	321.9	0.7	3.9	4.2	4.4	−0.2	07 P 15	N C C M
67	J A N	28	134300.9	N D	25.8	322.9	1.0	4.3	4.2	4.4	−0.2	09 P 27	N C C M
67	F E B	10	223230.3	50	26.1	322.6	0.5	4.0	3.9	4.1	−0.2	12 P 17	N C C M
66	D E C	14	065234.1	26	26.2	322.7	−1.0	4.4	4.1	4.4	−0.3	90 P 14	N C C M
66	D E C	10	141020.1	N D*	26.3	322.4	0.9	4.2	3.9	4.3	−0.4	91 P 06	N C C M
67	F E B	(7	090234.5	N D*	26.3	322.6	1.7	4.2	3.8	4.3	−0.5	09 P 45	N C C M
67	A P R	14	042504.3	N D*	26.5	322.5	1.0	4.1	3.8	4.3	−0.5	28 P 23	N C C M
66	D E C	10	145627.9	N D	26.6	322.4	−1.4	3.9	3.6	4.0	−0.4	91 P 06	N C C M
67	M A R	05	213632.5	N D	26.6	346.0	−0.1	4.3	3.9	4.4	−0.5	16 P 19	O C M X
66	J U N	23	133337.6	40	26.6	319.7	−0.1	4.2	4.0	4.2	−0.2	46 P 14	G T M L
66	D E C	11	065926.4	09	26.7	322.8	0.3	4.5	4.3	4.5	−0.2	89 P 12	O C C M

(to be continued)

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A	B	C	D h m s	E	F	G	H	I	J	K	L	M	N
67	J A N	03	062527.8	N D	26.8	346.3	−0.6	4.1	3.9	4.2	−0.3	02 P 13	O C M X
66	O C T	25	010840.2	N D	26.8	344.9	−0.8	4.5	4.1	4.6	−0.5	78 P 14	O C M X
66	O C T	21	103323.7	31	27.0	321.3	0.5	4.6	4.5	4.7	−0.2	76 P 22	G T M L
66	O C T	21	103616.7	46	27.1	320.5	0.3	4.7	4.6	4.7	−0.1	76 P 22	G T M L
66	J U L	14	232813.7	48	27.3	321.7	0.3	4.1	3.9	4.0	−0.1	48 P 24	N C G M
66	J U L	17	204427.1	N D*	27.6	322.3	1.1	4.1	4.0	4.2	−0.2	57 P 04	N C G M
66	A U G	29	173524.8	N D	27.8	321.5	1.5	3.9	3.9	3.8	0.1	62 P 32	N C G M
66	N O V	26	053837.2	N D	27.9	344.9	−0.8	4.2	4.0	4.4	−0.4	85 P 20	O C M X

3. Earthquakes around CAR ($\Delta < 30°$)

A	B	C	D h m s	E	F	G	H	I	J	K	L	M	N
66	M A R	06	210418.8	46	5.7	53.8	2.4	5.0	5.8	4.2	1.6	13 P 26	V N Z L
65	S E P	11	221514.8	14	5.9	53.9	2.1	6.0	6.1	4.2	1.9	72 P 31	V N Z L
66	F E B	24	173446.2	47	7.1	58.3	−0.1	4.5	5.5	4.0	1.5	13 P 14	N C L B
67	M A Y	08	080627.1	29	7.4	59.6	2.0	4.4	6.3	4.4	1.9	31 P 33	N C L B
65	S E P	06	045941.0	N D	8.2	176.4	−0.4	5.7	5.6	4.0	1.6	71 P 35	M N P S
67	F E B	21	041621.1	44	8.7	173.7	0.4	4.8	5.8	4.8	1.0	13 P 26	M N P S
67	F E B	18	125122.8	22	8.7	173.9	−1.4	4.2	5.5	4.2	1.3	14 P 13	M N P S
66	S E P	27	063433.2	24	8.7	225.2	−1.4	4.6	5.8	4.6	1.2	67 P 35	L W D I
66	J A N	13	103051.1	41	8.8	194.5	0.4	5.0	5.7	4.9	0.8	03 P 14	V R G I
66	S E P	10	215846.8	28	8.8	173.5	−0.5	4.7	5.8	4.6	1.2	65 P 27	M N P S
67	F E B	21	062939.8	34	8.8	173.5	−0.1	4.2	5.5	4.3	1.2	13 P 27	M N P S
66	J A N	15	063558.5	N D*	8.9	190.0	0.9	4.1	5.2	4.2	1.0	08 P 04	P T R C
67	M A Y	06	140041.4	39	9.2	161.0	4.0	5.3	6.2	5.3	0.9	31 P 30	D M R B
65	D E C	12	093652.1	N D	9.7	54.6	0.1	4.2	5.4	4.2	1.2	97 P 07	C L M B
67	M A Y	22	062329.5	33	9.8	185.7	−0.6	4.4	5.5	4.4	1.1	37 P 27	N A T O
67	F E B	13	135321.0	45	10.8	37.0	−2.1	4.7	5.5	4.6	0.9	13 P 14	C L M B
67	A U G	03	082844.9	40	10.9	45.0	0.2	4.1	5.4	4.0	1.4	50 P 32	C L M B
66	F E B	26	003043.9	35	11.2	67.6	−0.1	4.5	5.6	4.3	1.3	14 P 17	N W C L
65	A U G	02	191747.7	35	11.4	77.9	0.1	4.1	5.8	4.1	1.7	64 P 53	P N M A
66	J U L	26	161705.3	N D*	11.4	66.7	1.1	4.1	5.3	4.0	1.3	55 P 11	N W C C
65	A U G	16	121649.9	15	11.7	62.7	−1.7	5.1	6.3	5.0	1.3	66 P 35	N W C C
65	A U G	02	204330.6	N D	11.7	74.5	−1.9	4.7	5.9	4.6	1.3	64 P 53	P N M A

(to be continued)

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A	B	C	D h m s	E	F	G	H	I	J	K	L	M	N
65	A U G	02	184422.8	N D*	11.7	75.4	−1.4	5.0	5.6	4.5	1.1	64 P 51	P N M A
65	A U G	03	195613.2	N D	11.7	76.0	−1.2	4.5	5.9	4.4	1.5	66 P 13	P N M A
65	A U G	02	130456.3	N D*	11.8	74.6	−1.8	4.8	5.9	4.8	1.1	67 P 08	P N M A
65	A U G	02	164330.9	02	12.0	74.2	−4.5	5.4	6.3	5.2	1.1	64 P 50	P N M A
67	J U L	14	073807.3	46	12.4	72.1	0.5	4.3	5.5	4.2	1.3	45 P 46	S P N M
67	M A R	25	142913.6	35	13.0	75.3	−0.7	4.7	5.6	4.6	1.0	21 P 33	S P N M
66	F E B	04	161556.2	N D	15.6	74.5	−0.1	4.4	4.6	4.3	0.3	08 P 23	S P N M
65	O C T	04	062304.5	38	15.7	82.9	−1.3	4.6	4.8	4.4	0.4	77 P 34	P C B R
67	A P R	22	144321.4	40	15.8	80.8	0.5	5.0	4.9	5.0	−0.1	28 P 27	P N C T
66	A P R	02	083427.6	N D	16.2	71.3	0.9	4.6	4.7	4.3	0.4	20 P 23	S P N M
66	A P R	15	064259.7	N D	16.3	69.4	−0.3	4.8	4.6	4.8	−0.2	22 P 28	S P N M
66	S E P	16	122824.6	N D*	16.3	70.1	0.7	4.5	4.4	4.4	0.0	72 P 06	S P N M
66	A P R	01	151951.8	39	16.4	69.7	0.6	4.8	4.7	4.6	0.1	20 P 21	S P N M
65	O C T	16	142255.5	50	16.4	83.3	−0.5	5.0	5.0	4.9	0.1	79 P 36	C S R C
67	J U N	22	134948.7	N D	16.6	39.5	2.8	4.8	4.8	4.9	−0.1	45 P 08	P B B R
66	A U G	09	111239.4	35	16.7	84.6	1.0	5.0	4.8	4.3	0.5	56 P 19	C S R C
66	A P R	09	023423.0	40	17.0	85.0	−1.0	5.3	5.0	5.2	−0.2	20 P 37	C S R C
65	D E C	28	220452.0	14	17.0	36.0	−0.7	5.5	5.1	5.5	−0.4	96 P 18	P E B R
65	D E C	29	040824.1	24	17.1	37.0	−0.2	4.7	4.3	4.6	−0.3	96 P 18	P E B R
65	S E P	06	211330.5	21	17.7	76.2	−0.1	5.1	5.3	5.0	0.3	70 P 58	O C C A
67	A P R	19	062657.9	47	18.0	50.0	−0.1	4.5	4.4	4.4	0.0	29 P 20	N C E C
66	M A R	23	051132.5	D N*	19.5	106.2	−1.3	5.3	4.8	5.2	−0.4	17 P 34	C R B S
67	A U G	09	071408.1	46	20.1	20.1	0.5	5.0	5.1	4.9	0.2	49 P 54	P B B R
65	A U G	13	005442.7	34	20.3	43.5	−1.6	5.1	5.2	4.8	0.4	65 P 35	P E B R
65	O C T	18	161740.6	N D	20.3	63.1	−0.2	4.7	4.9	4.5	0.4	81 P 23	O C E C
67	J U N	10	180439.6	N D	20.6	256.0	−2.5	4.9	5.2	4.8	0.4	41 P 19	N A T R
67	J U N	12	000506.5	N D	20.6	225.5	1.9	5.1	5.1	5.1	0.0	40 P 35	N A T R
66	J U L	22	194740.8	48	21.6	40.1	−1.5	4.9	4.9	4.9	0.0	56 P 03	N C N P
65	D E C	10	025915.9	30	21.8	39.5	0.0	4.6	4.7	4.5	0.2	91 P 23	N C N P
66	M A R	03	101223.2	34	22.7	248.1	2.8	4.7	4.7	4.6	0.1	13 P 22	N A T R
66	O C T	20	222248.9	46	22.9	12.2	0.4	4.5	4.7	4.5	0.2	77 P 12	P E R U
66	O C T	21	103616.7	46	23.6	96.6	0.4	4.7	4.9	4.7	0.2	76 P 22	G T M L
66	O C T	17	230422.1	39	23.9	29.4	0.5	5.2	4.8	5.2	−0.4	76 P 13	N C P R
66	O C T	17	233237.7	N D	24.1	29.8	−0.1	5.0	4.9	4.9	0.0	73 P 23	N C P R
66	O C T	17	214156.3	38	24.1	29.4	1.6	6.3	6.6	6.4	0.2	73 P 21	N C P R
66	O C T	20	235053.0	27	24.2	30.3	2.3	4.7	4.8	4.5	0.3	77 P 12	O C P R
66	A P R	03	091726.7	22	24.2	31.8	1.2	4.7	4.7	4.6	0.1	20 P 25	O C P R

(to be continued)

(continued)

A	B	C	D h m s	E	F	G	H	I	J	K	L	M	N
66	O C T	18	010342.8	N D	24.3	29.8	0.9	4.5	4.4	4.3	0.1	75 P 20	N C P R
66	O C T	23	153254.2	44	24.3	29.8	0.3	5.0	4.7	5.0	−0.3	76 P 29	N C P R
66	O C T	18	082607.7	30	24.4	31.3	0.2	4.9	4.8	5.0	−0.2	77 P 10	O C P R
66	O C T	18	110203.8	N D	24.4	30.2	0.4	4.6	4.8	4.5	0.3	76 P 14	O C P R
66	O C T	18	125214.6	N D*	24.5	30.2	0.1	4.7	4.8	4.6	0.2	76 P 15	O C R P
65	J U L	16	124713.2	N D	25.2	67.5	1.0	5.1	5.0	4.9	0.1	64 P 13	G L D I
66	J U N	10	081325.8	22	26.7	20.3	1.9	5.0	5.1	5.0	0.1	42 P 15	W C P R
66	J U N	19	154047.6	29	26.7	20.0	−1.6	5.1	4.9	5.0	−0.1	41 P 17	W C P R
66	J U N	07	005946.4	48	26.8	19.8	−0.5	4.8	5.1	5.5	−0.4	36 P 37	N C P R
66	J U L	06	000551.0	07	27.0	18.8	0.5	5.1	4.9	5.0	−0.1	46 P 30	N C P R
66	J U N	07	032417.2	42	27.0	19.7	−1.1	4.9	4.8	4.8	0.0	36 P 38	N C P R
66	S E P	04	053749.7	08	29.0	14.4	−0.5	5.1	5.2	5.1	0.1	64 P 22	O C P R

4. Earthquakes around PMG ($\Delta < 30°$)

A	B	C	D h m s	E	F	G	H	I	J	K	L	M	N
67	F E B	18	023919.4	41	6.9	239.3	−0.6	5.4	6.7	5.3	1.4	11 P 32	N I R L
66	N O V	02	200011.3	34	7.1	243.1	−1.3	4.6	6.1	5.0	1.1	79 P 19	N W B R
67	A P R	10	231307.7	N D*	7.2	146.7	−1.2	5.5	6.2	5.0	1.2	26 P 29	N N C N
66	J A N	18	080005.7	49	7.4	236.3	−0.6	***	6.3	5.1	1.2	06 P 08	N I R L
66	N O V	28	081710.1	13	7.8	254.5	−0.9	5.0	6.6	5.4	1.2	85 P 25	S O L I
66	J U L	06	034445.6	27	7.9	141.6	−1.0	4.8	5.6	4.8	0.8	50 P 11	N N C N
66	D E C	25	202153.9	48	8.1	201.1	3.6	4.7	6.2	5.2	1.0	95 P 14	N I R L
66	O C T	23	091548.2	34	8.5	249.4	0.3	5.0	6.4	5.4	1.0	77 P 15	S O L I
67	A P R	12	145149.4	21	8.7	256.4	0.7	5.3	6.3	5.4	0.9	24 P 33	S O L I
67	A P R	12	134605.0	49	8.7	256.6	−0.5	5.1	5.6	5.1	0.5	25 P 29	S O L I
66	O C T	06	111604.9	34	9.0	127.5	−0.9	5.2	5.4	5.1	0.3	76 P 06	W N W G
66	M A R	21	160021.7	16	9.6	134.8	−0.4	5.5	5.8	5.4	0.4	19 P 15	N N C W
66	N O V	12	090001.4	28	10.6	129.7	−1.0	5.4	5.8	4.9	0.9	90 P 04	W N W G
66	S E P	04	094123.8	39	10.8	129.8	0.7	6.0	6.3	5.4	0.9	63 P 28	W N W G
66	O C T	05	203233.5	17	11.0	130.0	−0.7	4.7	5.8	4.7	1.1	81 P 02	W N W G
66	F E B	28	210345.1	N D*	11.9	132.8	−1.0	4.7	5.6	4.7	0.9	81 P 02	W N W G
66	J U N	16	094658.1	27	13.6	272.7	9.7	5.0	5.1	5.0	0.1	44 P 12	S O L I
66	J U N	17	114738.7	N D	13.6	273.5	3.8	5.1	5.2	5.0	0.2	42 P 26	S O L I
66	J U N	17	222604.1	N D	13.7	271.9	2.3	5.6	5.9	5.6	0.3	45 P 11	S O L I

(continued)

A	B	C	D h m s	E	F	G	H	I	J	K	L	M	M
67	J AN	13	134811.7	32	14.0	273.7	1.4	5.7	6.0	5.9	0.1	02 P 29	S O L I
66	J UN	15	195900.6	N D	14.1	273.3	−0.4	5.4	5.2	5.6	−0.4	43 P 25	S O L I
66	D E C	18	094822.9	50	14.1	273.1	1.7	5.3	5.5	5.1	0.4	91 P 10	S O L I
66	M A R	30	012634.8	40	14.2	272.2	1.1	5.2	5.2	5.4	−0.2	21 P 13	S O L I
66	S E P	16	075039.7	21	14.9	120.9	5.1	5.4	5.3	5.5	−0.2	67 P 24	W N W G
66	O C T	12	075659.4	41	15.0	274.8	0.3	5.0	5.1	5.3	−0.2	37 P 10	S O L I
66	D E C	21	112505.4	32	15.4	272.5	2.7	4.5	4.2	4.7	−0.5	96 P 06	S O L I
66	J U L	26	114047.4	43	16.4	121.4	−0.1	4.8	4.4	5.1	−0.7	53 P 14	W N W G
66	A U G	08	072413.8	16	17.0	272.0	−0.2	5.3	5.2	5.4	−0.2	56 P 17	S C R I
67	J A N	03	104325.1	N D	18.0	273.2	1.6	4.8	4.4	5.0	−0.6	02 P 13	S C R I
67	J A N	02	202051.8	N D	18.1	274.3	0.0	4.5	4.2	4.7	−0.5	08 P 06	S C R I
67	M A R	21	190630.3	39	18.2	274.7	0.8	4.9	4.5	5.2	−0.7	20 P 29	S C R I
67	J A N	16	160222.7	38	18.2	274.3	0.3	5.1	4.8	5.4	−0.6	05 P 11	S C R I
67	J A N	16	142622.9	06	18.3	273.9	1.1	5.3	5.2	5.5	−0.3	09 P 08	S C R I
67	J A N	16	144849.3	N D	18.4	274.3	−0.6	5.1	4.8	5.3	−0.5	08 P 14	S C R I
67	J A N	01	125329.9	N D	18.6	275.1	0.6	4.7	4.7	5.0	−0.3	07 P 02	S C R I
67	J A N	07	164103.0	N D	18.7	275.7	0.3	5.1	5.2	5.3	−0.1	02 P 23	S C R I
67	J A N	03	212321.8	N D	19.1	277.0	−0.2	5.0	5.3	5.5	−0.2	02 P 17	S C R I
66	N O V	16	080814.0	50	19.3	278.9	1.3	5.1	5.2	5.4	−0.2	83 P 11	N W H I
66	J U N	01	101443.2	48	19.6	280.8	0.9	5.5	4.8	5.5	−0.7	37 P 12	N W H I
66	J U N	29	214654.5	35	19.6	280.6	0.9	6.2	5.2	5.6	−0.4	50 P 08	N W H I
66	A P R	09	144922.8	47	19.7	281.4	1.2	5.4	5.3	5.6	−0.3	23 P 23	N W H I
66	J U N	06	014545.5	37	20.9	282.7	−0.5	5.5	5.0	5.5	−0.5	41 P 05	N W H I
66	D E C	07	165929.2	N D	21.7	167.9	−1.7	5.1	5.5	5.3	0.2	85 P 32	S M R N
66	S E P	14	200042.8	N D*	21.8	112.1	6.1	5.0	4.6	5.0	−0.4	69 P 13	M L C S
66	N O V	16	005432.1	18	22.2	290.6	1.0	5.0	5.0	5.1	−0.1	86 P 13	N W H I
67	J A N	31	095747.0	N D	22.6	109.8	2.4	5.0	4.7	5.0	−0.3	11 P 17	M L C S
66	O C T	12	031626.8	N D*	23.3	178.6	4.2	4.8	4.7	4.8	−0.1	74 P 13	M R A N
66	O C T	18	174316.2	N D*	24.4	181.9	0.3	4.7	4.9	5.0	−0.1	74 P 23	D R A N
67	J A N	30	141923.8	N D	25.1	123.3	0.6	5.2	5.3	5.2	0.1	11 P 15	T L D I
66	M A Y	06	070027.9	N D	25.6	105.7	−1.2	5.2	5.1	5.0	0.1	31 P 08	C L B S
66	S E P	13	005042.8	28	26.2	297.3	3.5	5.0	5.0	5.1	−0.1	69 P 11	L Y T I
66	M A R	13	161434.7	N D*	27.4	93.3	1.1	5.2	4.8	5.1	−0.3	17 P 15	F L R I
66	J U N	30	122741.9	44	27.8	132.2	−0.9	5.4	5.1	5.2	−0.1	45 P 31	M N D N
66	J U N	06	230730.4	45	27.9	132.4	2.8	5.3	5.0	5.2	−0.2	44 P 04	M D P H
66	J U N	06	231633.3	45	27.9	131.8	1.9	5.2	5.0	4.9	0.1	44 P 04	M D P H
67	J A N	16	143909.0	42	28.0	122.5	−1.0	5.2	5.5	5.3	0.2	05 P 10	M D P H
66	A P R	20	140126.2	28	28.1	179.5	2.8	5.2	5.1	4.9	0.2	24 P 23	M R A N
66	A P R	20	060039.4	N D*	28.2	179.2	0.8	5.1	5.0	5.0	0.0	24 P 22	M R A N

5. Earthquakes around RAB ($\varDelta < 30°$)

A	B	C	D h m s	E	F	G	H	I	J	K	L	M	N
65	D E C	17	063536.9	N D*	5.1	101.1	−0·1	4.8	5.6	4.8	0.8	10 P 63	B S M S
67	M A Y	04	133242.3	39	5.7	72.5	0.2	5.1	5.5	4.9	0.6	33 P 13	E N W G
67	M A Y	04	162200.9	49	5.8	72.0	−1.1	5.2	5.4	5.2	0.2	33 P 14	E N W G
66	J A N	01	122430.1	N D*	6.1	335.0	−2.9	5.6	5.9	5.4	0.5	03 P 02	D N T I
66	N O V	25	205756.7	14	6.1	46.9	0.2	***	5.6	5.2	0.4	87 P 09	E N W G
67	M A R	26	223901.5	14	6.2	35.5	−0.9	5.3	6.1	5.7	0.4	33 P 22	E N W G
66	S E P	23	045148.3	39	6.8	311.2	0.0	4.9	5.3	5.2	0.1	77 P 02	S O L I
66	J U N	21	133248.8	42	7.7	82.8	1.0	5.5	5.6	5.3	0.3	46 P 13	N W G N
66	O C T	28	014119.1	32	9.3	305.2	6.4	5.5	5.6	5.6	0.0	77 P 20	S O L I
66	A U G	07	030716.2	48	10.9	305.4	6.1	5.5	6.0	5.3	0.7	57 P 20	S O L I
66	J U N	16	000348.5	34	11.1	305.4	1.3	4.9	6.1	5.1	1.0	43 P 26	S O L I
66	D E C	18	094822.9	50	11.1	303.5	4.1	5.3	5.8	5.1	0.7	91 P 10	S O L I
66	J U N	16	120022.0	N D*	11.2	305.0	2.7	5.4	5.7	4.8	0.9	47 P 09	S O L I
66	N O V	12	090001.4	28	13.3	97.1	0.4	5.4	5.4	4.9	0.5	90 P 04	W N W G
67	M A R	04	224114.5	20	13.3	153.4	0.1	5.1	6.0	5.3	0.7	19 P 06	C R L I
66	S E P	04	094123.8	39	13.5	97.6	0.2	6.0	5.9	5.4	0.5	63 P 28	W N W G
66	A U G	08	072413.8	16	13.6	296.4	−1.4	5.3	5.5	5.4	0.1	56 P 17	S C R I
66	D E C	26	171636.6	37	13.7	298.9	0.4	5.2	5.3	5.3	0.0	91 P 22	S C R I
66	A P R	04	233222.3	37	13.7	297.8	0.4	5.3	5.7	5.2	0.5	21 P 19	S C R I
66	D E C	31	221514.0	N D	14.4	298.3	−0.1	5.2	5.2	5.3	−0.1	97 P 16	S C R I
66	J U N	21	004313.5	25	14.6	296.1	1.4	5.3	5.4	5.1	0.3	44 P 18	S C R I
67	J A N	03	104325.1	N D	14.7	296.1	1.0	4.8	5.1	5.0	0.1	02 P 13	S C R I
67	J A N	03	123209.2	N D	14.7	296.8	2.7	5.2	5.0	5.4	−0.4	06 P 04	S C R I
67	J A N	03	113134.4	N D	14.8	296.9	0.6	5.1	4.8	5.3	−0.5	02 P 15	S C R I
67	J A N	01	215857.8	N D	14.9	296.6	2.6	5.4	4.9	5.5	−0.6	02 P 05	S C R I
67	J A N	03	110515.4	N D	14.9	296.8	1.5	5.3	4.9	5.4	−0.5	02 P 14	S C R I
67	M A R	21	190630.3	39	15.1	297.5	0.2	4.9	4.6	5.2	−0.6	20 P 29	S C R I
67	J A N	16	142622.9	06	15.1	296.5	0.0	5.3	4.9	5.5	−0.6	09 P 08	S C R I
67	J A N	16	160222.7	38	15.1	297.0	0.9	5.1	4.8	5.4	−0.6	05 P 11	S C R I
67	J A N	16	044427.3	N D	15.1	296.8	2.1	5.3	5.1	5.4	−0.3	03 P 17	S C R I
67	J A N	16	144849.3	N D	15.2	296.9	1.4	5.1	4.8	5.3	−0.5	08 P 14	S C R I
67	J A N	01	141851.4	N D	15.7	300.0	1.8	5.0	4.7	5.1	−0.4	03 P 02	S C R I
67	J A N	07	164103.0	N D	15.7	297.9	0.2	5.1	4.7	5.3	−0.6	02 P 23	S C R I
67	F E B	20	224144.6	22	15.9	297.4	−3.8	4.7	4.7	5.1	−0.4	12 P 40	S C R I
67	J A N	01	002106.6	N D	16.0	298.2	1.2	4.9	4.8	5.1	−0.3	04 P 02	S C R I
66	O C T	17	134854.3	N D*	16.1	294.6	0.8	4.8	4.6	4.9	−0.3	77 P 09	S C R I
67	J A N	03	212321.8	N D	16.2	298.9	0.5	5.0	4.6	5.5	−0.9	02 P 17	S C R I

(continued)

A	B	C	D h m s	E	F	G	H	I	J	K	L	M	M
66	N O V	16	080814.0	50	16.7	300.8	3.2	5.1	4.5	5.4	−0.9	83 P 11	N W H I
66	A P R	09	144922.8	47	17.3	303.0	2.9	5.4	5.0	5.6	−0.6	23 P 13	N W H I
66	N O V	23	021913.8	48	18.0	304.9	1.2	5.6	4.8	5.7	−0.9	88 P 06	N W H I
66	M A Y	03	184332.9	30	18.2	144.9	1.7	5.6	4.6	5.0	−0.4	33 P 04	W C R I
66	D E C	29	145442.2	41	18.7	159.6	−2.5	4.6	4.6	4.7	−0.1	91 P 26	M R A N
66	O C T	04	072254.6	47	18.9	147.4	1.4	5.2	4.9	5.2	−0.3	71 P 19	S M R N
66	J U L	26	114047.4	43	19.4	100.0	−0.8	4.8	4.6	5.1	−0.5	53 P 14	W N W G
66	A U G	09	222542.3	N D*	19.9	309.0	−0.5	5.2	4.8	5.4	−0.6	63 P 28	N H B I
66	N O V	19	140934.2	N D	20.1	155.9	1.4	4.7	5.1	5.4	−0.3	85 P 12	M R A N
66	A P R	12	231529.6	30	20.6	309.5	−0.1	5.3	5.2	5.3	−0.1	25 P 04	N H B I
66	S E P	14	200048.5	N D*	25.6	96.8	−0.9	5.0	5.1	5.0	0.1	69 P 13	M L C S
66	S E P	13	005042.8	28	25.9	313.7	0.9	5.0	5.1	5.1	0.0	69 P 11	L Y T I
67	M A R	01	142426.5	49	26.3	102.6	0.4	5.3	5.4	5.3	0.1	17 P 14	M L C S
67	J A N	31	095747.0	N D	26.6	95.4	−1.5	5.0	5.1	5.0	0.1	11 P 17	M L C S
66	O C T	27	142104.8	29	26.9	166.0	−0.8	6.0	5.8	6.0	−0.2	76 P 32	N P C O

regional variation of magnitude at the epicentral distance range of $5° \leq \Delta < 30°$ as a function of Δ. The definition of $\delta m(\Delta)$ is given by the following equation.

$$\delta m(\Delta) = m_r(\Delta) - m_t \quad (5° \leq \Delta < 30°)$$

where $m_r(\Delta)$ is the magniude at a reference station located at the epicentral distance between $5°$ and $30°$ and m_t is the averaged magnitude of the stations for $30° \leq \Delta < 90°$. Regional magnitude deviation factor $\delta m(\Delta)$ are calculated for the five reference stations listed in Table 1. The average of $\delta m(\Delta)$ for the each intervals of the epicentral distance of $1°$ reperesented as $\delta \overline{m}(\Delta)$ are tabulated in Table 3.

4. Results and Interpretations

Epicenters of earthquakes given in Table 2 are illustrated in Figs. 4 to 8. Regional magnitude deviation factor $\delta \overline{m}(\Delta)$ introduced in the previous section is characterized by its patterns as revealed in the next three different epicentral distance ranges around the stations: (1) near $(5° \leq \Delta < 13°)$, (2) near-regional $(13° \leq \Delta < 20°)$ and (3) regional $(20° \leq \Delta < 30°)$ (Fig. 9).

Table 3. Regional magnitude deviation factor $\delta\overline{m}(\varDelta)$ with standard deviations (in magnitude units)
Interpolated values are parenthesized and the values associated with only one source data are shown without standard deviation.

St. \ $\varDelta$	COL	TFO	CAR	PMG	RAB
5°	—	−0.30±	—	—	0.80±
6	1.00±0.22	(−0.25)	1.75±0.15	—	0.42±0.14
7	1.30±0.10	(−0.21)	1.70±0.20	1.23±0.11	0.10±
8	0.65±0.22	−0.17±0.18	1.60±	1.00±0.20	0.30±
9	0.67±0.18	0.05±0.26	1.08±0.16	0.68±0.22	0.00±
10	0.30±	0.15±0.05	1.15±0.05	0.40±	(0.42)
11	(0.25)	(0.36)	1.32±0.26	0.97±0.10	0.83±0.13
12	0.20±	(0.57)	1.24±0.14	0.90±	(0.72)
13	0.00±	0.79±0.32	1.00±	(0.49)	0.60±0.10
14	0.09±0.28	0.70±	(0.71)	0.07±0.27	0.20±0.26
15	−0.30±0.22	−0.40±0.32	(0.42)	−0.30±0.15	−0.38±0.29
16	−0.31±0.28	−0.93±0.21	0.13±0.21	−0.70±	−0.48±0.21
17	−0.62±0.11	−0.61±0.19	−0.10±0.32	−0.20±	−0.75±0.15
18	−0.38±0.10	−0.20±	0.15±0.15	−0.57±0.15	−0.65±0.25
19	−0.30±	−0.50±	(0.15)	−0.20±0.08	−0.30±0.16
20	−0.22±0.17	−0.50±0.09	0.15±0.33	−0.47±0.17	−0.45±0.15
21	−0.30±0.28	−0.10±0.15	0.20±0.20	−0.50±	−0.10±
22	−0.24±0.24	0.20±	0.10±0.10	−0.10±0.25	(−0.07)
23	−0.08±0.20	−0.24±0.24	0.15±0.05	−0.20±0.10	(−0.03)
24	0.08±0.31	0.30±0.09	0.03±0.24	−0.10±	(0.00)
25	0.07±0.31	−0.22±0.18	0.15±0.05	0.10±	(0.04)
26	−0.20±	−0.27±0.13	−0.10±0.17	0.00±0.10	0.07±0.05
27	−0.30±	−0.30±0.16	(−0.03)	−0.30±	−0.05±0.15
28	−0.10±	−0.17±0.21	(0.03)	0.03±0.15	—
29	−0.50±	—	0.10±	—	—

In the near epicentral distance ($5° \leq \varDelta < 13°$), $\delta\overline{m}(\varDelta)$ decreases with increase of $\varDelta$ for the cases of COL and CAR, while it increases with increase of $\varDelta$ for the case of TFO. $\delta\overline{m}(\varDelta)$ for PMG and RAB show more complicated patterns with a small minimum in that epicentral distance range. According to the Jefferys' earth model (1962), the ray paths of P waves observed at 5° and 13° have their deepest points at depths of about 48 km and 155 km respectively in case of a surface focus event. Therefore, the remarkable differences in the patterns of $\delta\overline{m}(\varDelta)$ around
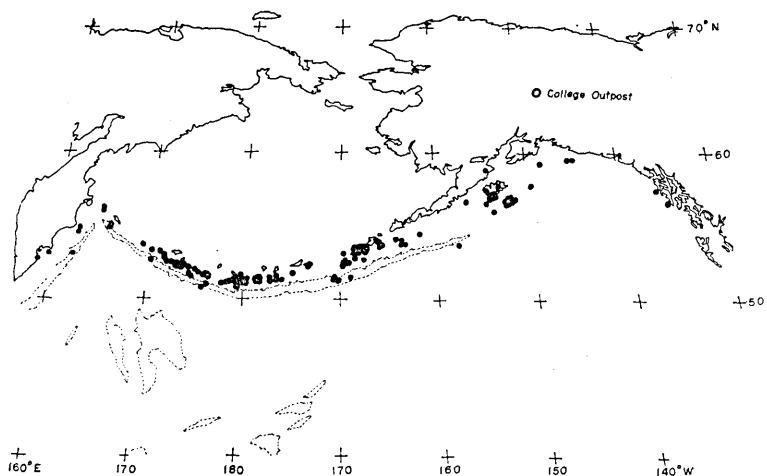
Fig. 4.   Epicentral distribution of the earthquakes used within 30° from College, Alaska.
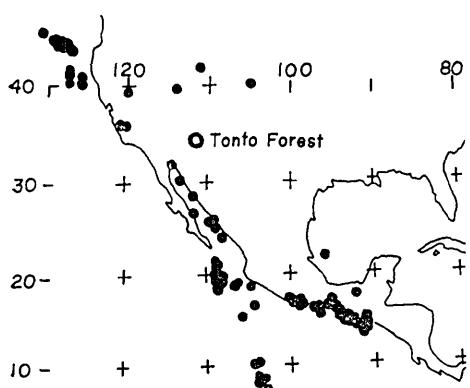
Fig. 5.   Epicentral distribution of the earthquakes used within 30° from Tonto Forest, Arizona.
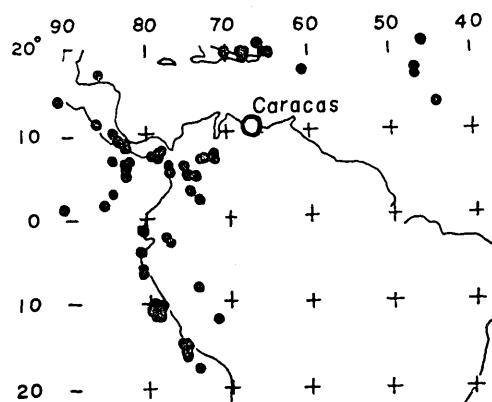
Fig. 6.   Epicentral distribution of the earthquakes used within 30° from Caracas, Venezuela.

the stations considered are presumably caused by the differences of vertical velocity structure in the crust and upper mantle down to 150 km or so.   A distance range giving minimum value of $\delta\overline{m}(\varDelta)$ commonly found for the five stations in case of the near regional distance ($13°\leq \varDelta<20°$) is followed by the regional distance range ($20°\leq\varDelta<30°$) characterized by the small fluctuation of $\delta\overline{m}(\varDelta)$.   Such patterns of $\delta\overline{m}(\varDelta)$ as described above lead us to conclude that the available distance range of the Q-function as a worldwide standard calibrating function should be limited to the range of $\varDelta\geq20°$.   Magnitude deviation factor $\delta\overline{m}(\varDelta)$ consists of the following two terms as given by
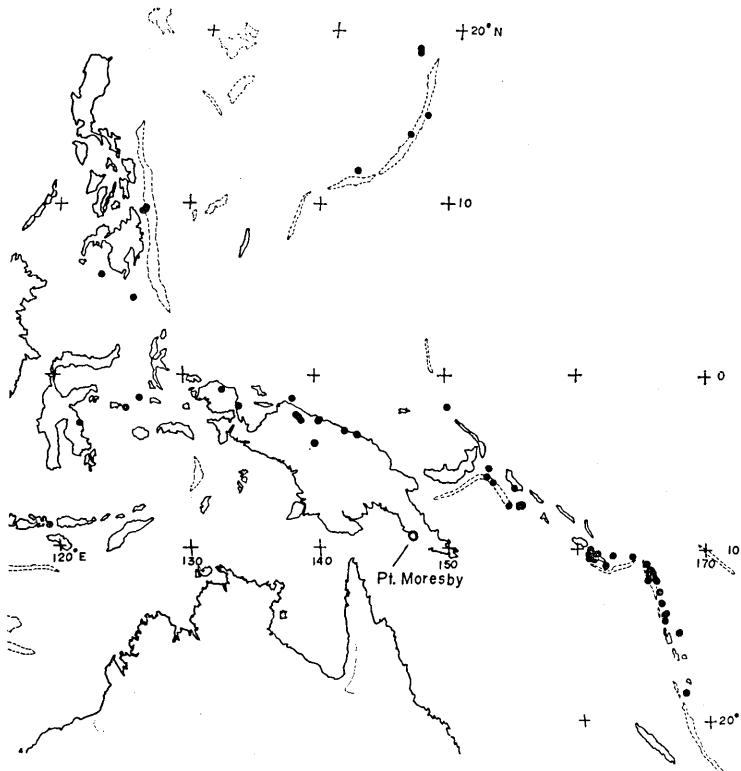
Fig. 7. Epicentral distribution of the earthquakes used within 30° from Port Moresby, New Guinea.

$$\delta \overline{m}(\varDelta) = C(\varDelta) + C_s \qquad (5° \leq \varDelta < 30°)$$

where the first term $C(\varDelta)$ is the correction term depending on $\varDelta$ and the second term C_s is the constant term in regard to a specified station. To the station correction usually used in magnitude compulations is given by $-C_s$. We calculate C_s for the five reference stations assuming that C_s is given by the average deviation of $\delta \overline{m}(\varDelta)$ from zero level in the regional distance $(20° \leq \varDelta < 30°)$. The results are given in Table 4.

Amplitude/Period (A/T) versus Distance $(\varDelta)$ curve can be calculated from the equations as given by

$$\delta \overline{m}(\varDelta) = m_r(\varDelta) - \overline{m}_t$$
$$= \log_{10} \frac{A}{T}(\varDelta) + Q(\varDelta) - \overline{m}_t + C_s$$

and then, $\log_{10} \dfrac{A}{T}(\varDelta) = \delta \overline{m}(\varDelta) - Q(\varDelta) + \overline{m}_t - C_s$.
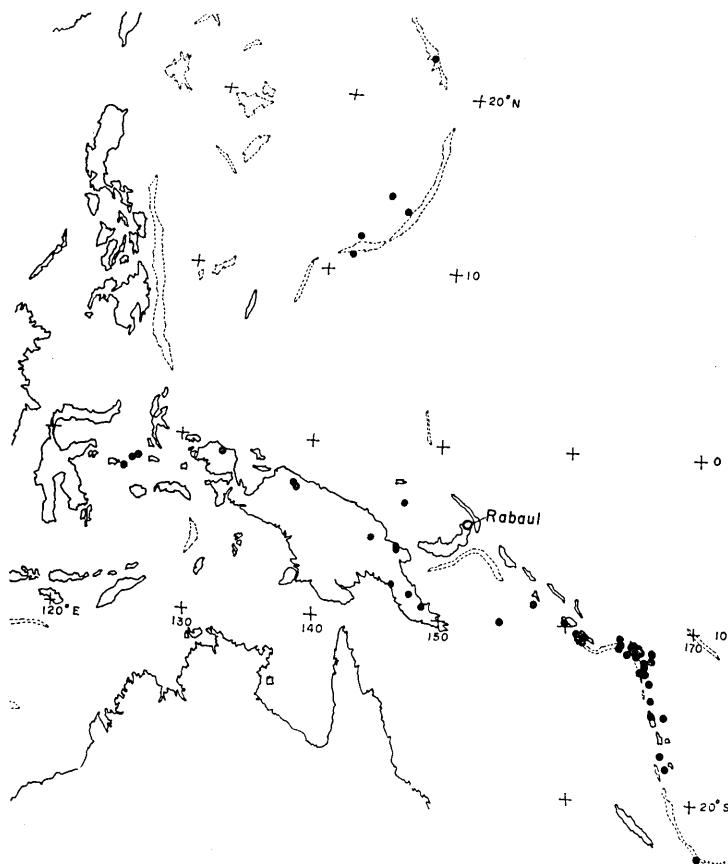
Fig. 8. Epicentral distribution of the earthquakes used within 30° from Rabaul, New Britain Island.

Table 4. Station correction factor C_s (in magniude units) with standard deviations

Station correction ordinarily used in magnitude computation is given by $-C_s$

St.	COL	TFO	CAR	PMG	RAB
C_s	-0.19 ± 0.16	-0.13 ± 0.24	0.08 ± 0.10	-0.17 ± 0.21	-0.07 ± 0.16
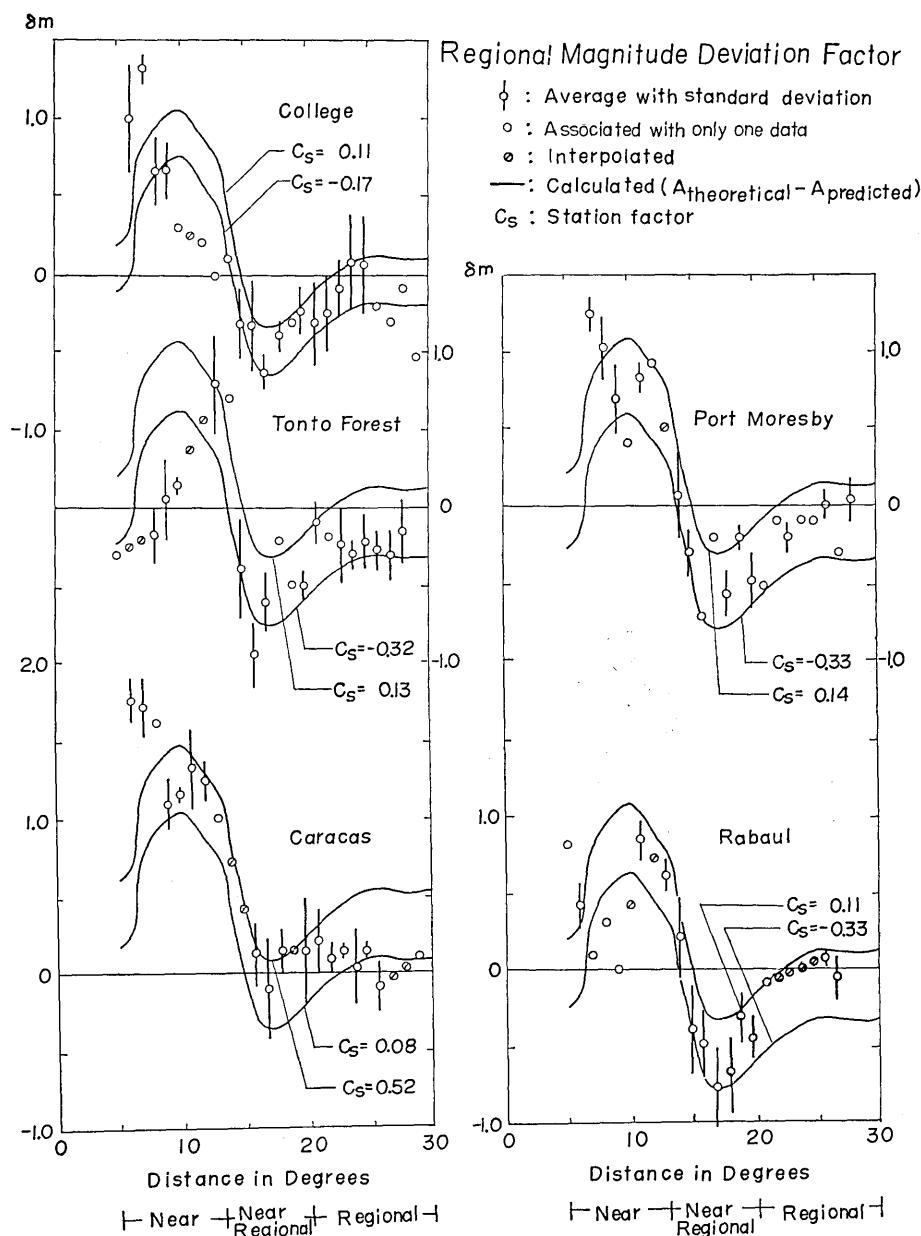
Fig. 9. Regional magnitude deviation factor $\delta m(\varDelta)$ for COL, TFO, CAR, PMG and RAB with illustration of magnitude deviation calculated from the theoretical amplitude basing on the Jefferys' earth model and the Q function.
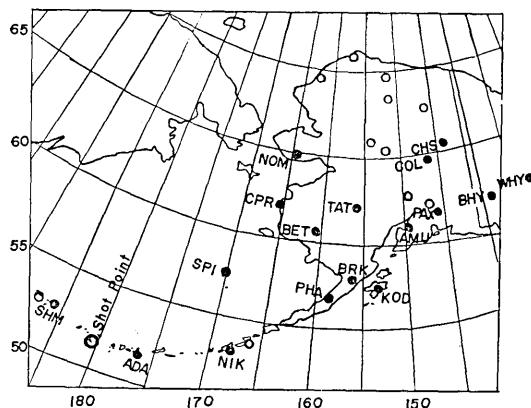
Fig. 10. Shot point (Amchitka Island 51° 26′ 17.0″ N, 179° 10′ 57.0″ E, Depth 700 m) and the station distributions (open circle: arrival time readings only, solid circle: both arrival time and amplitude readings) of the LONGSHOT experiment
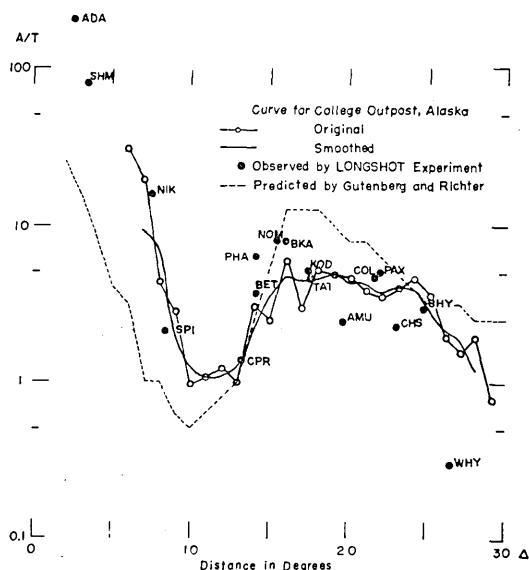
Fig. 11. Comparison of Amplitude/Period (A/T) versus distance Δ curve obtained from the magnitude analysis for COL (solid line) with LONGSHOT data (solid circle) and the predicted curve of the Q-function (dotted line)

The curve of A/T for COL calculated by the method represented above is compared with the result of the LONGSHOT experiment (Carder et al. 1967). The shot point at Amchitka Island and observation stations are shown in Fig. 10. Plots of A/T values show fairly good agreement with the curve obtained by using our method, excluding an extraordinarily small value of A/T at White Horse (WHY, Δ=26.6°), as illustrated in Fig. 11. Fig. 11 indicates that our curve for COL can be used as the calibrating function for the region of Alaska and Aleutian Islands. Large deviations of the Q-function from the actual A/T curve of the LONGSHOT suggest that the Q-function is not easily available for Δ<13° for this region. Ccmparison of A/T versus Δ curves obtained by use of the above method with Gutenberg-Richter's curve are illustrated in Fig. 12.

Theoretical amplitude of the ground motions of the free surface of the earth based on geometrical ray theory can be expressed as follows:
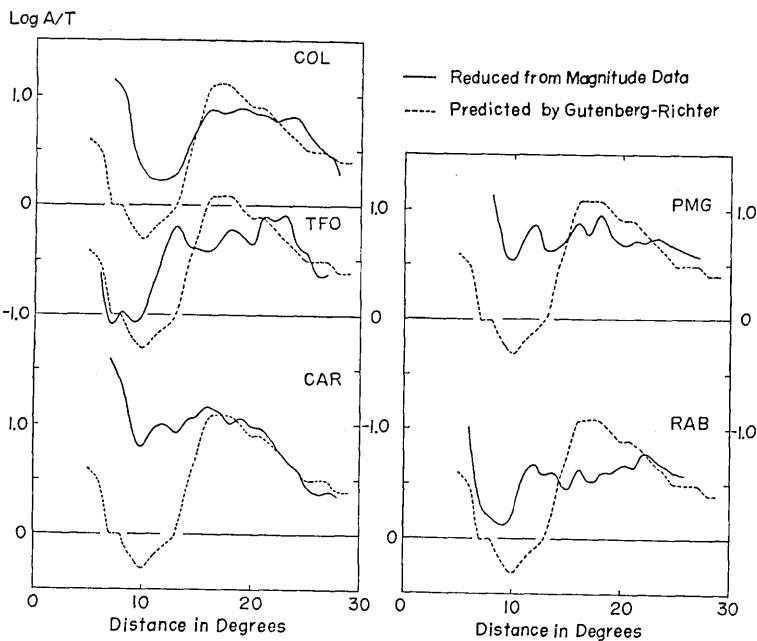
Fig. 12. Comparison of Amplitude/Period (A/T) versus distance curve reduced from the magnitude data with the curve predicted by Gutenberg and Richter.

$$A_v{}^2(\varDelta) = \frac{I \tan^2 e \sec^2 e (1+3\tan^2 e)^2}{\eta_1 \sin \varDelta (\eta^2 \tan^2 e - \eta_0^2 \sin^2 e)^{1/2} \{4 \tan e \tan f + (1+3\tan^2 e)^2\}^2} \left| \frac{d^2 T}{d\varDelta^2} \right|$$

where

$$\eta_1 \cos e_1 = \eta_0 \cos e = dT/d\varDelta,$$
$$\cos^2 e = 3 \cos^2 f,$$

and $A_v(\varDelta)$ is the amplitude of the vertical component of the P waves, I denotes the energy in this type emitted per unit solid angle from focus and e_1 is the angle which any ray leaving the focus makes with the surface of the earth through the focus (see Bullen, 1963). Knowing the ray parameter $dT/d\varDelta$ as a function of the angle of emergence e with use of the above equations, it would be theoretically possible to estimate A_v as a function of $\varDelta$ for a given earth model. We calculate A_v in case of surface focus for Jeffreys' earth model (1962) which has no asthenosphere low velocity layer. Discontinuous and very erratic behavior of the calculated amplitude curve is caused by some very slight irregularities produced by approximating the earth model with shells in
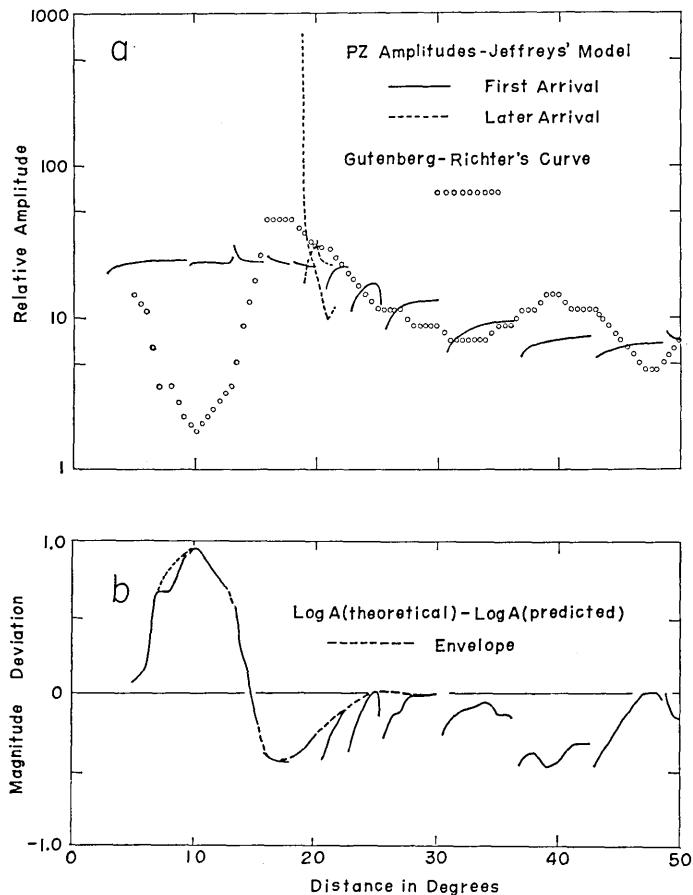
Fig. 13.   (a) Vertical component of P wave amplitude theoretically reduced
basing on the Jefferys' earth model in comparison to the Q-function.
(b) Magnitude deviation calculated from the theoretical and predicted (the Q-function) amplitudes.

which the velocity is given by linear functions of depth.   The theoretical
curve is smoothed taking its envelop as illustrated in Fig. 13.

Magnitude deviations produced when we assume the theoretical
amplitude patterns are actual ones can be given as $\delta m(\varDelta) = A_v(\varDelta) + Q(\varDelta)$,
which show large positive values between 5° and 13° corresponding to
the low amplitude at the same distance range of Q-function.   This pattern
of magnitude deviation derived by subtracting the predicted values (Q-function) from the calculated values basing on the Jeffreys' model

explains observed magnitude deviation factor $\delta\overline{m}(\Delta)$ for CAR at the distance of more than 9°, for PMG and RAB more than 11° and for COL and TFO more than 13° (Fig. 9). This indicates that in the region around CAR the amplitude versus distance curve can be well approximated by the Jefferys' earth model having no asthenosphere low velocity layer. As a conclusion, the information of the vertical velocity structure in the crust and upper mantle is quite important to construct the calibrating function in the near and regional distances.

5. Critical Remarks on USCGS Magnitude Determination

The USCGS magnitude is an average of the individual station magnitudes. Prior to October 31, 1966 the magnitude was the logarithm of the average of the $A/T \times 10^Q$ values where Q is the distance-depth factor as defined by Gutenberg and Richter, A is the P wave amplitude in microns, and T is the period in seconds. Values which deviate from the avrage by the equivalent of 0.7 unit of magnitude at any point in the computation, or which are associated with P readings having time residuals greater than 10 seconds, are not used in the average and are marked with an asterisk.

The magnitude computation system adopted by USCGS seems to provide reasonable magnitude values without any notable discrepancies in the data processing so long as it is applied to the data report of stations located at the epicentral distance of more than 20°. However, we frequently encounter such cases as the individual station magnitudes determined at $\Delta < 20°$ deviate from those for $\Delta \geq 20°$ by as much as 0.7 magnitude units or more as mentioned in the previous section. The typical examples of such cases showing notable discrepancy in magnitude computation by USCGS are found for earthquakes located at $\Delta < 20°$ from CAR. Overestimation of magnitudes by USCGS as exemplified in Table 3 and Fig. 14 is due to (1) the application of the Gutenberg-Richter Q-function for the distance of $\Delta < 20°$ in the calculation of individual station magnitudes and (2) improper setting of criterion for the data selection in taking an average of the individual station magnitudes. Thus, the USCGS magnitude will be improved by (1) taking an average of individual station magnitudes after correcting the regional deviation of the individual station magnitudes for $\Delta < 20°$ or (2) taking an average of individual station magnitudes for distance of $\Delta \geq 20°$. The latter

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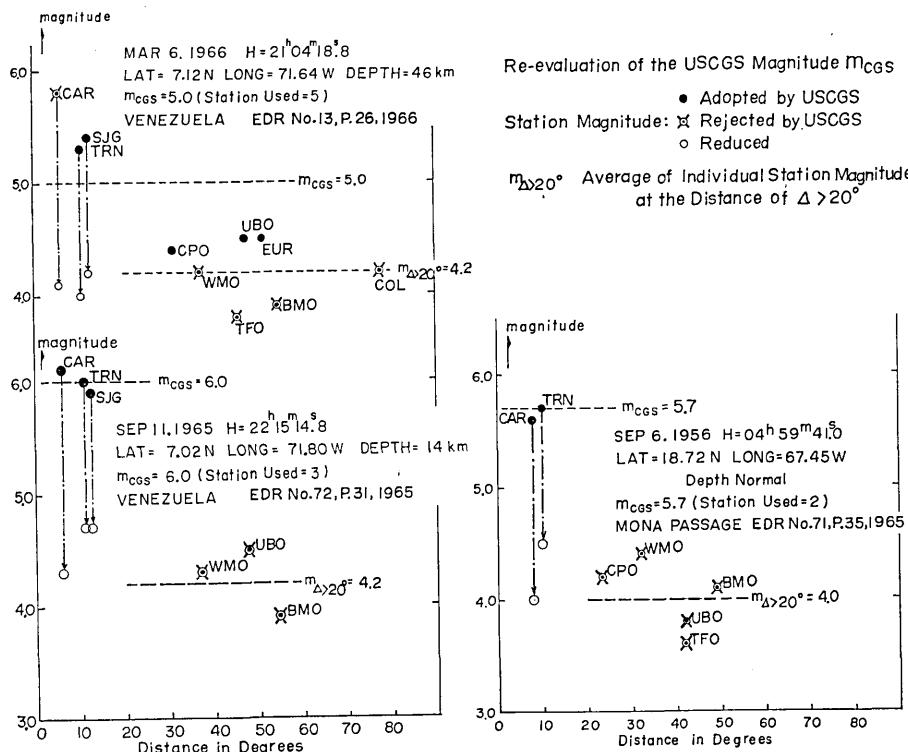
Fig. 14. Examples of re-evaluation of the USCGS magnitude Reduced values (open circle) for CAR, TRN and SJG are calculated by use of the magnitude deviation factor $\delta \overline{m}(\varDelta)$ for CAR Station Name Abbreviations CAR: Caracas, Venezuela/TRN: Trinidad, West Indies/SJG: San Juan, Puerto Rico/CPO: Cumberland Plateau, Tennessee/WMO: Wichita Mountains, Oklahoma/UBO: Uinta Basin, Utah/TFO: Tonto Forest, Arizona/EUR: Eureka, Nevada/BMO: Blue Mountains, Oregon/COL: College Outpost, Alaska.

method can be proposed as a practical data parocessing in the magnitude determination.

Conclusion

(1)   Available distance range of the calibrating function $Q(\varDelta)$ provided by Gutenberg and Richter as a worldwide standard should be limited to the distance range of more than 20°.

(2)   Overestimation of magnitude by as much as 0.5 to 1.5 magnitude units in the epicentral distance between 5° and 13° relative to the magnitude at teleseismic distances of more than 20° shows that the

zone of low amplitude signals predicted by Gutenberg and Richter in the distance range around 10° does not exists as a worldwide phenomenon.

(3) Jefferys' earth's model provides a fairly good approximation of the amplitude patterns at the distance of more than 13° for all stations considered.

(4) The information of vertical velocity structure in the crust and upper mantle is quite important to construct calibrating function for the magnitude determinations at near and regional epicentral distances ($\varDelta < 30°$).

(5) Re-evaluation of the USCGS magnitudes by rejecting the individual station magnitudes at the distance of $\varDelta < 20°$ will provide more reliable sets of magnitude data for the study of regional and worldwide seismicity.

Acknowledgements

References

BULLEN, K. E., An Introduction to the Theory of Seismology. 3rd ed., Cambridge University Press, 1963.

CARDER, D. S., Don TOCHER, Charles BUFE, S. W. Stewart, Joseph EISLER and Eduard BERG, Seismic wave arrivals from Longshot, 0° to 27°, *Bull. Seismol. Soc. Am.*, **57**, 573-590, 1967

CARPENTER, E. W., P. D. MARSHALL, and A. DOUGLAS, The amplitude-distance curve for short period teleseismic *P* waves, *Geophys. J.*, *12*, *in press*, 1967.

CLEARY, J., Analysis of the amplitudes of short-period *P* waves recorded by long range seismic measurements stations range 30° to 102°, *J. Geophys. Res.* **72**, 4705-4712, 1967.

GUTENBERG, B. and C. F. RICHTER, Magnitude and energy of earthquakes, *Ann. di Geofis.*, **9**, 1-15, 1956.

JEFFREYS, H., The Earth, 4th Edition, Cambridge University Press, 1962.

VANĚK, J. and J. STELZNER, The problem of magnitude calibrating functions for body waves. *Ann. di Geofis.* **13**, 393-407, 1960.

22. P波の振巾の地域性とマグニチュードの決定について (I)

地震研究所 溝 上 恵

Gutenberg-Richter (1956) によってあたえられた *Q*-function が震央距離 $\mathit{\Delta} \geq 30°$ での P 波の振巾と $\mathit{\Delta}$ との関係をあたえるよい近似関数であることは観測および理論からたしかめられている. しかしあさい震源 ($H \leq 50$ km) をもつ地震のマグニチュード m_{pz} が $\mathit{\Delta} \geq 30°$ できめられたものと $\mathit{\Delta} < 30°$ できめられたものとでは顕著な相違を示す場合がある. これは *Q*-function が $\mathit{\Delta} < 30°$ ではかならずしも P 波の振巾と $\mathit{\Delta}$ との関係をあたえるよい近似関数ではないことをしめしている. 特に地域によって $5° \leq \mathit{\Delta} < 13°$ できめられた m_{pz} が $\mathit{\Delta} \geq 30°$ できめられた m_{pz} と比較して, 0.5 ないし 1.5 程度おゝきくみつもられる傾向があるという事実は, *Q*-function によってあたえられる $\mathit{\Delta} = 10°$ 近傍の P 波の振巾が極度にちいさくみつもられすぎていることに対応する.

COL, TFO, CAR, PMG, RAB の各観測点の周辺 ($\mathit{\Delta} = 30°$) におきた地震 ($H \leq 50$ km) について, USCGS の EDR に報告されている初動 P 波の垂直成分の最大振巾, その周期 (1 sec 前後) およびこれらからもとめられたマグニチュード m_{pz} をつかって, これらの観測点の周辺の地域での P 波の振巾の $\mathit{\Delta}$ による変化およびそれがマグニチュードの数値におよぼす影響について考察した. その結果つぎのような結論をえた.

(1) Gutenberg-Richter の *Q*-function がマグニチュード決定のための世界全体に対する標準関数として使える震央距離の範囲は $\mathit{\Delta} \geq 20°$ である.

(2) $5° \leq \mathit{\Delta} < 13°$ できめられたマグニチュード m_{pz} が $\mathit{\Delta} \geq 20°$ できめられたマグニチュード m_{pz} に対して, 地域によって 0.5 ないし 1.5 程度おゝきくなる. これは *Q*-function によってあたえられているような $\mathit{\Delta} = 10°$ 近傍で P 波の振巾が極度にちいさくなるような現象が世界各地域で共通にみとめられるようなものではないことをしめしている.

(3) マントル上部におけるいわゆる "低速度層" をもたない Jefferys (1962) の地球モデルにもとずいて計算された P 波の振巾はマグニチュード決定のためのかなりよい標準函数をあたえるものであり, すくなくとも $\mathit{\Delta} \geq 13°$ に対しては世界全体に対する標準函数として使用することができるとおもわれる.

(4) マグニチュード m_{pz} を地域によるひずみがないように決定するためには地殻および上部マントルでの P 波の速度分布の地域性によって生ずる振巾の地域性を考慮にいれる必要がある.

(5) 以上のことから世界全体のサイスミシティを比較するためには, 各地震について USCGS によってきめられている観測点別の m_{pz} から $\mathit{\Delta} \geq 20°$ の観測点での m_{pz} だけをえらび, それらを平均してその地震のマグニチュードとすることがもっとも実際的な方法であるとおもわれる.