Topic	Magnitude calibration functions and complementary data
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1 Local magnitude Ml

Table 1 Calibration function $\sigma_L(\Delta)$ = - log A_o for local magnitudes Ml according to Richter (1958). A_o are the trace amplitudes in mm recorded by a Wood-Anderson Standard Torsion Seismometer from an earthquake of Ml = 0. Δ - epicentral distance in km.

Δ (km)	$\sigma_L(\Delta)$	Δ (km)	$\sigma_L(\Delta)$	Δ (km)	$\sigma_L(\Delta)$	Δ (km)	$\sigma_L(\Delta)$
0	1.4	90	3.0	260	3.8	440	4.6
10	1.5	100	3.0	280	3.9	460	4.6
20	1.7	120	3.1	300	4.0	480	4.7
30	2.1	140	3.2	320	4.1	500	4.7
40	2.4	160	3.3	340	4.2	520	4.8
50	2.6	180	3.4	360	4.3	540	4.8
60	2.8	200	3.5	380	4.4	560	4.9
70	2.8	220	3.65	400	4.5	580	4.9
80	2.9	240	3.7	420	4.5	600	4.9

Table 2 Regional calibration functions $\sigma_L(\Delta)$ = - log A_o for Ml determinations. Δ - epicentral distance and R - hypocentral ("slant") distance with $R = \sqrt{(\Delta^2 + h^2)}$, both in km ; h – hypocentral depth in km, T - period in s; Com. - recording component.

Region	$\sigma_L(\Delta)$ = - log A_o	Com.	Range (km)	Reference
Southern California	1.110 log (R/100) + 0.00189(R - 100) + 3.0	horiz.	10 ≤ R ≤ 700	Hutton&Boore (1987)
Central California	1.000 log (R/100) + 0.00301(R - 100) + 3.0	horiz.	0 ≤ Δ ≤ 400	Bakun&Joyner (1984)
Great Basin, Western USA	1.00.log (R/100) + 0.0069(R - 100) + 3.0 0.83 log (R/100) + 0.0026(R - 100) + 3.0	horiz. horiz.	0 ≤ Δ ≤ 90 90 ≤ Δ ≤ 600	Chávez&Priestley (1985)
Eastern N-America	1.55 log Δ - 0.22 1.45 log Δ + 0.11	horiz. vertic.	100 ≤ Δ ≤800 100≤ Δ ≤800	Kim (1998)
Greece	1.58 log (R/100) + 3.0; for ML ≤ 3.7 2.00 log (R/100) + 3.0; for ML > 3.7	horiz.	100≤ Δ ≤800	Kiratzi&Papazachos (1984)
Albania	1.6627 log Δ + 0.0008 Δ - 0.433	horiz	10 ≤Δ ≤ 600	Muco&Minga (1991)
Central Europe	0.83 log R + (0.0017/T) (R - 100) + 1.41	vertic.	100 ≤Δ ≤ 650	Wahlström&Strauch (1984)
CentralEurope	1.11 lg R + 0.95 R/1000 + 0.69	vertic.	10< R < 1000	Stange (2001)
Norway/Fennoskan.	0.91 log R + 0.00087 R + 1.010	vertic.	0 < R ≤ 1500	Alsaker et al. (1991)
Tanzania	0.776 log(R/17) + 0.000902 (R - 17) + 2.0	horiz.	0 < R ≤ 1000	Langston et al. (1998)
South Australia	1.10 log Δ + 0.0013 Δ + 0.7	vertic.	40 < Δ < 700	Greenhalgh&Singh (1986)

2 Teleseismic surface wave magnitude Ms

Table 3 Tabulated magnitude calibration values $\sigma_S(\Delta)$ as published in Richter (1958) for M_S determinations according to equation Ms = log $A_{Hmax}(\Delta) + \sigma_S(\Delta)$. A_{Hmax} is the (vectorially combined) maximum horizontal surface-waves displacement amplitude in μm for periods around 20 ± 2 s. Between 20° and 120° the values correspond (rounded to the nearest tenth magnitude unit), to the values calculated according to the Gutenberg (1945a) relation for the surface-wave magnitude: **Ms = log A + 1.656 log Δ + 1.818**. However, for larger distances this formula yields between 0.05 to 0.55 m.u. larger magnitudes than the tabulated values.

Δ (degrees)	$\sigma_S(\Delta)$	Δ (degrees)	$\sigma_S(\Delta)$	Δ (degrees)	$\sigma_S(\Delta)$
20	4.0	60	4.8	120	5.3
25	4.1	70	4.9	140	5.3
30	4.3	80	5.0	160	5.35
40	4.5	90	5.05	170	5.3
45	4.6	100	5.1	180	5.0
50	4.6	110	5.2		

Table 4 Ms magnitude calibration values $\sigma_S(\Delta)$ for vectorially combined maximum horizontal surface-waves displacement amplitude (in μm) from shallow earthquakes (h ≤ 60 km) as derived by the Prague-Moscow group (Vaněk et al. (1962)). The IASPEI recommended **standard magnitude formula Ms = log $(A_H/T)_{max}$ + 1.66 log Δ + 3.3** fits these tabulated values between 1° and 140° with deviations < 0.05 magnitude units. For larger distances the formula overestimates the magnitude between 0.05 and 0.55 (at 180°) m.u.. **Note:** For periods T = 20s the IASPEI standard formula for Ms yields magnitude values that are 0.18 m.u. larger than those derived from the Gutenberg formula for Ms (see Tab. 3). Since - in average – maximum horizontal and vertical component surface-wave amplitudes agree well, Tab. 4 and (up to Δ = 160°) also the standard Ms calibration function are nowadays commonly used for Ms determination from vertical component surface-wave records.

Δ°	0°	1°	2°	3°	4°	5°	6°	7°	8°	9°
0°		3.30	3.80	4.09	4.30	4.46	4.59	4.70	4.80	4.88
10°	4.96	5.03	5.09	5.15	5.20	5.25	5.29	5.34	5.38	5. 42
20°	5.46	5.50	5.53	5.56	5.59	5.62	5.65	5.68	5.71	5. 73
30°	5.75	5.78	5.80	5.82	5.84	5.86	5.88	5.90	5.92	5. 94
40°	5.96	5.98	5.99	6.01	6.03	6.04	6.06	6.07	6.09	6. 10
50°	6.12	6.13	6.14	6.16	6.17	6.18	6.20	6.21	6.22	6. 24
60°	6.25	6.26	6.27	6.28	6.30	6.31	6.32	6.33	6.34	6. 35
70°	6.36	6.37	6.38	6.39	6.40	6.41	6.42	6.43	6.44	6. 45
80°	6.46	6.47	6.48	6.49	6.49	6.50	6.51	6.52	6.53	6. 54
90°	6.55	6.55	6.56	6.57	6.58	6.58	6.59	6.60	6.61	6. 61
100°	6.62	6.63	6.64	6.64	6.65	6.66	6.66	6.67	6.68	6 .69
110°	6.69	6.70	6.70	6.71	6.72	6.72	6.73	6.74	6.74	6 .75
120°	6.75	6.76	6.76	6.76	6.77	6.77	6.78	6.78	6.78	6 .79
130°	6.79	6.79	6.80	6.80	6.80	6.81	6.81	6.81	6.81	6 .81
140°	6.82	6.82	6.82	6.82	6.83	6.83	6.83	6.83	6.83	6 .83
150°	6.84	6.84	6.84	6.84	6.84	6.84	6.84	6.84	6.84	6 .84
160°	6.84	6.84	6.83	6.83	6.83	6.82	6.82	6.82	6.82	6 .82
170°	6.81	6.81	6.80	6.79	6.77	6.74	6.71	6.69	6.64	6 .59
180°	6.49									

Surface-wave magnitudes are determined from the maximum amplitude or A/T ratio measured in the surface-wave train. This is usually the Airy phase of Rayleigh waves (R_{max}, see 2.3 in Chapter 2). It is well developed for shallow earthquakes (depth h < 70 km). Table 5 gives the time difference between the R_{max} and the P wave as a function of distance.

Table 5 Time interval (t_{Rmax} - t_P) between the arrival of the maximum phase of the Rayleigh wave and the first onset of P waves as a function of Δ according to Archangelskaya (1959) and Gorbunova and Kondorskaya (1977) (From Willmore, 1979).

Δ°	t_{Rmax} - t_P (min)	Δ°	t_{Rmax} - t_P (min)	Δ°	t_{Rmax} - t_P (min)
10	4-5	55	26	100	45-46
15	6-8	60	28-29	105	47-48
20	9-10	65	31	110	48-50
25	10-12	70	33	115	53
30	13-14	75	35	120	55
35	15-16	80	37	125	57
40	18-19	85	39-40	130	60
45	21	90	42	140	64
50	24	95	43	150	70

3 Teleseismic body-wave magnitudes mB

Gutenberg (1945) developed a magnitude relationship for teleseismic body waves such as P, PP and S in the period range 0.5 s to 12 s (i.e., mostly based on medium-period readings):

$$mB = \log (A/T)_{max} + Q(\Delta, h).$$

Gutenberg and Richter (1956a) published a table with Q(Δ) values for P, PP and S waves in vertical (V=Z) and horizontal (H) components for shallow events (Table 6) as well as diagrams giving for all these waves Q values as a function of Δ and source depth h (Figs. 1a-c). These Q values are valid only when A is given in μm.

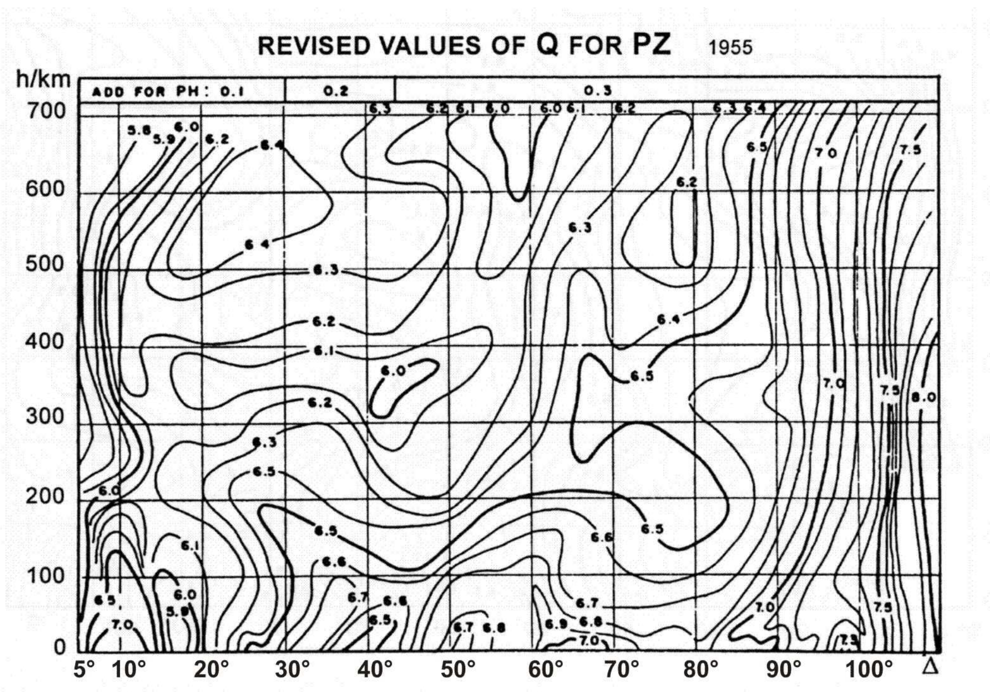

Figure 1a

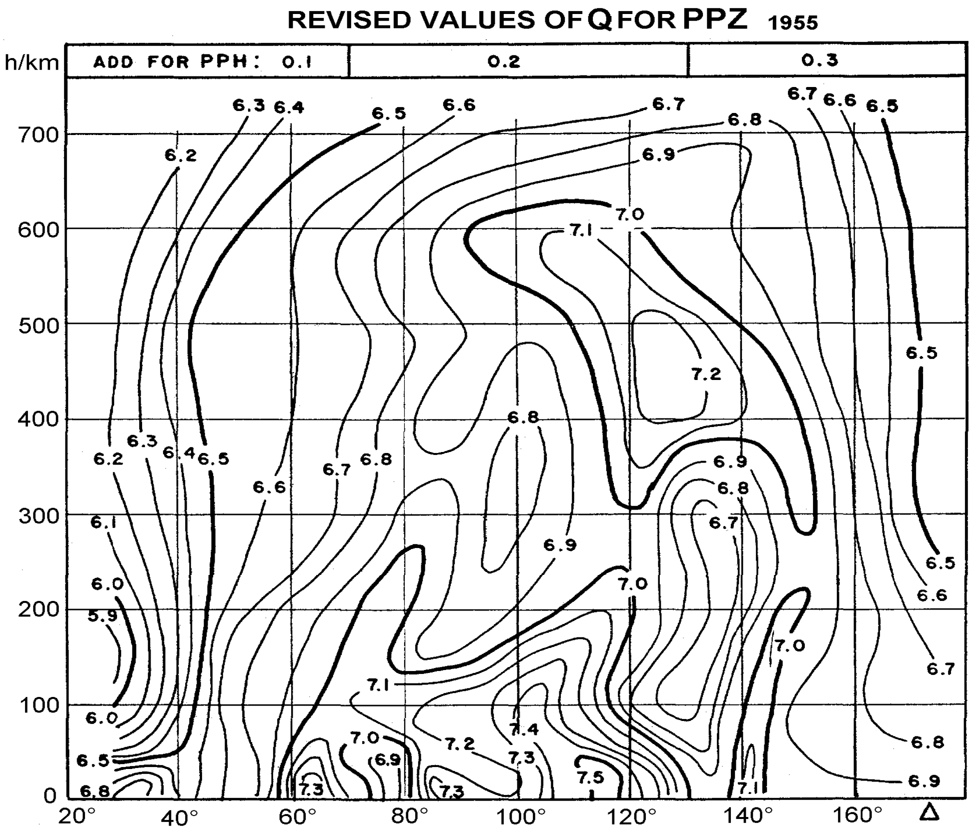

Figure 1b

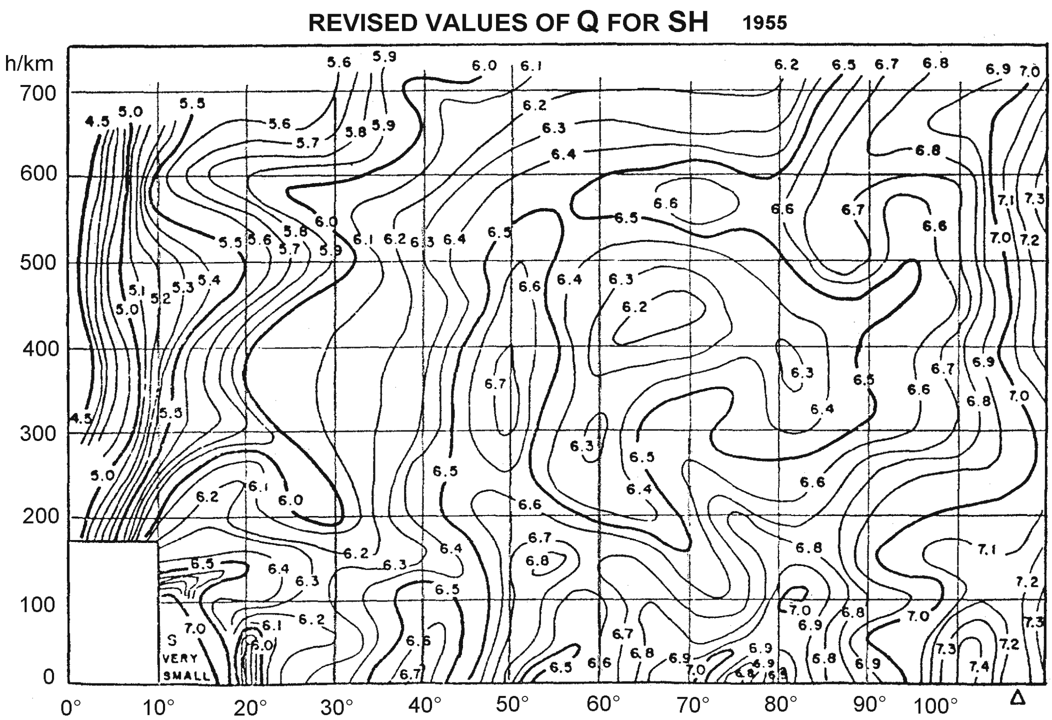

Figure 1c

Table 6 Values of Q(Δ) for P, PP and S waves for shallow shocks (h < 70 km) according to Gutenberg and Richter (1956a) if the ground amplitude is given in μm.

Δ°	PV	PH	PPV	PPH	SH	Δ°	PV	PH	PPV	PPH	SH	Δ°	PV	PH	PPV	PPH	SH
16	5.9	6.0			7.2	56	6.8	7.1	6.9	7.0	6.6	96	7.3	7.6	7.2	7.4	7.1
17	5.9	6.0			6.8	57	6.8	7.1	6.9	7.0	6.6	97	7.4	7.8	7.2	7.4	7.2
18	5.9	6.0			6.2	58	6.8	7.1	7.0	7.1	6.6	98	7.5	7.8	7.2	7.4	7.3
19	6.0	6.1			5.8	59	6.8	7.1	7.0	7.2	6.6	99	7.5	7.8	7.2	7.4	7.3
20	6.0	6.1			5.8	60	6.8	7.1	7.1	7.3	6.6	100	7.4	7.7	7.2	7.4	7.4
21	6.1	6.2			6.0	61	6.9	7.2	7.2	7.4	6.7	101	7.3	7.6	7.2	7.4	7.4
22	6.2	6.3			6.2	62	7.0	7.3	7.3	7.4	6.7	102	7.4	7.7	7.2	7.4	7.4
23	6.3	6.4			6.2	63	6.9	7.3	7.3	7.4	6.7	103	7.5	7.9	7.2	7.4	7.3
24	6.3	6.5			6.2	64	7.0	7.3	7.3	7.5	6.8	104	7.6	7.9	7.3	7.5	7.3
25	6.5	6.6			6.2	65	7.0	7.4	7.3	7.5	6.9	105	7.7	8.1	7.3	7.5	7.2
26	6.4	6.6			6.2	66	7.0	7.4	7.3	7.4	6.9	106	7.8	8.2	7.4	7.6	7.2
27	6.5	6.7			6.3	67	7.0	7.4	7.2	7.4	6.9	107	7.9	8.3	7.4	7.6	7.2
28	6.6	6.7			6.3	68	7.0	7.4	7.1	7.3	6.9	108	7.9	8.3	7.4	7.6	7.2
29	6.6	6.7			6.3	69	7.0	7.4	7.0	7.2	6.9	109	8.0	8.4	7.4	7.6	7.2
30	6.6	6.8	6.7	6.8	6.3	70	6.9	7.3	7.0	7.2	6.9	110	8.1	8.5	7.4	7.6	7.2
31	6.7	6.9	6.7	6.8	6.3	71	6.9	7.3	7.1	7.3	7.0	112	8.2	8.6	7.4	7.6	
32	6.7	6.9	6.8	6.9	6.4	72	6.9	7.3	7.1	7.3	7.0	114	8.6	9.0	7.5	7.7	
33	6.7	6.9	6.8	6.9	6.4	73	6.9	7.2	7.1	7.3	6.9	116	8.8		7.5	7.7	
34	6.7	6.9	6.8	6.9	6.5	74	6.8	7.1	7.0	7.2	6.8	118	9.0		7.5	7.7	
35	6.7	6.9	6.8	6.9	6.6	75	6.8	7.1	6.9	7.1	6.8	120			7.5	7.7	
36	6.6	6.9	6.7	6.8	6.6	76	6.9	7.2	6.9	7.1	6.8	122			7.4	7.6	
37	6.5	6.7	6.7	6.8	6.6	77	6.9	7.2	6.9	7.1	6.8	124			7.3	7.5	
38	6.5	6.7	6.7	6.8	6.6	78	6.9	7.3	6.9	7.1	6.9	126			7.2	7.4	
39	6.4	6.6	6.6	6.7	6.7	79	6.8	7.2	6.9	7.1	6.8	128			7.1	7.4	
40	6.4	6.6	6.6	6.7	6.7	80	6.7	7.1	6.9	7.1	6.7	130			7.0	7.3	
41	6.5	6.7	6.5	6.6	6.6	81	6.8	7.2	7.0	7.2	6.8	132			7.0	7.3	
42	6.5	6.7	6.5	6.6	6.5	82	6.9	7.2	7.1	7.3	6.9	134			6.9	7.2	
43	6.5	6.7	6.6	6.7	6.5	83	7.0	7.4	7.2	7.4	6.9	136			6.9	7.2	
44	6.5	6.7	6.7	6.8	6.5	84	7.0	7.4	7.3	7.5	6.9	138			7.0	7.3	
45	6.7	6.9	6.7	6.8	6.5	85	7.0	7.4	7.3	7.5	6.8	140			7.1	7.4	
46	6.8	7.1	6.7	6.8	6.6	86	6.9	7.3	7.3	7.5	6.7	142			7.1	7.4	
47	6.9	7.2	6.7	6.8	6.6	87	7.0	7.3	7.2	7.4	6.8	144			7.0	7.3	
48	6.9	7.2	6.7	6.8	6.7	88	7.1	7.5	7.2	7.4	6.8	146			6.9	7.2	
49	6.8	7.1	6.7	6.8	6.7	89	7.0	7.4	7.2	7.4	6.8	148			6.9	7.2	
50	6.7	7.0	6.7	6.8	6.6	90	7.0	7.3	7.2	7.4	6.8	150			6.9	7.2	
51	6.7	7.0	6.7	6.8	6.5	91	7.1	7.5	7.2	7.4	6.9	152			6.9	7.2	
52	6.7	7.0	6.7	6.8	6.5	92	7.1	7.4	7.2	7.4	6.9	154			6.9	7.2	
53	6.7	7.0	6.7	6.8	6.6	93	7.2	7.5	7.2	7.4	6.9	156			6.9	7.2	
54	6.8	7.1	6.8	6.9	6.6	94	7.1	7.4	7.2	7.4	7.0	158			6.9	7.2	
55	6.8	7.1	6.9	7.0	6.6	95	7.2	7.6	7.2	7.4	7.0	160			6.9	7.2	
												170			6.9	7.2	

At the IASPEI General Assembly in Zürich (1967) the Committee on Magnitudes recommended stations to report the magnitude for all waves for which calibration functions are available, as well as to publish amplitude and period values separately. **$Q(\Delta, h)_{PZ}$ is now the accepted standard calibration function for mb** magnitude determinations at international data centers based on short-period vertical component P-wave readings. This is not fully correct because the Q values have been derived mainly from intermediate-period seismic recordings.

4 Complementary short-period body-wave magnitude scales

Another calibration function P(Δ, h) for mb determination has been elaborated by Veith and Clawson (1972). It is based on large sets of short-period vertical-component P-wave amplitudes from large explosions at 19 different sites. Although specifically derived from short-period data it is not yet accepted as IASPEI standard for mb. It looks much smoother than $Q(\Delta, h)_{PZ}$ and resembles better an inverse A-Δ relationship for short-period P as shown in Fig. 3.13. It is currently used by the preliminary International Data Center established for the monitoring of the Comprehensive Test-Ban Treaty (CTBT) however with a non-standard instrument response.

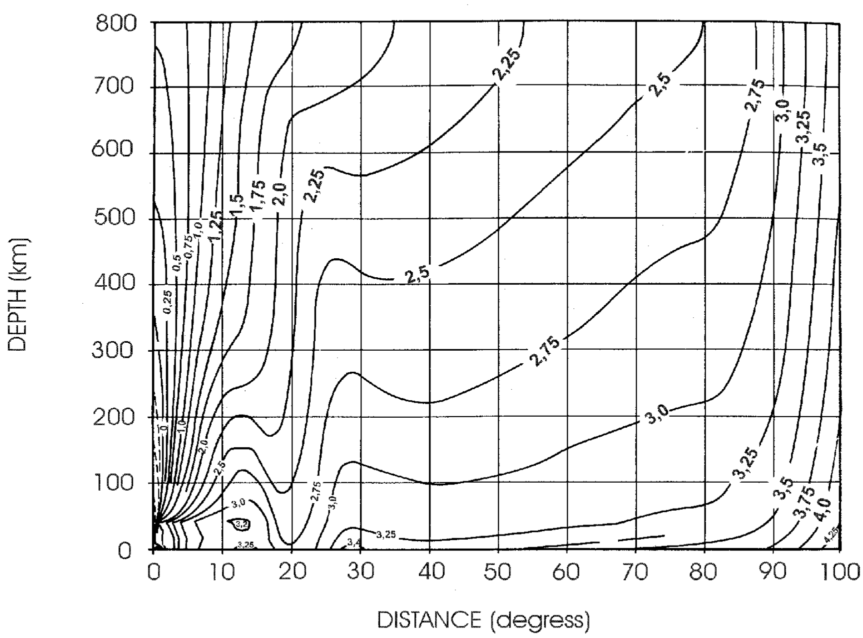

Figure 2 Calibration functions P(Δ, h) for mb determination from narrow-band short-period vertical-component records with peak displacement magnification around 1 Hz (WWSSN-SP characteristic) according to Veith and Clawson (1972). **Note:** P values have to be used in conjunction with maximum P-wave peak-to-trough (2A!) amplitudes in units of nanometers (1 nm = 10^{-9}m) (modified from Veith and Clawson, Magnitude from short-period P-wave data, BSSA, 62, 2, p. 446, © Seismological Society of America).

An experimental calibration function for magnitude determinations based on short-period vertical-component readings of various PKP phases in the distance range 145° to 164° has been developed by Wendt (Bormann and Wendt, 1999). The following relationship is used:

$$mb(PKP) = \log_{10} (A/T) + Q(\Delta, h)_{PKPab,bc,df}$$

with amplitude A in μm (10^{-6} m) (see Figure 3). Extensive use of this relationship at station CLL proved that mb determinations from core phases are possible with a standard deviation of less than ± 0.2 magnitude units as compared to P-wave mb determinations by NEIC and ISC. If more than one PKP phase can be identified and A and T been measured then the average value from all individual magnitude determinations provides a more stable estimate. The applicability of these calibration functions should be tested with data from other stations of the world-wide network.

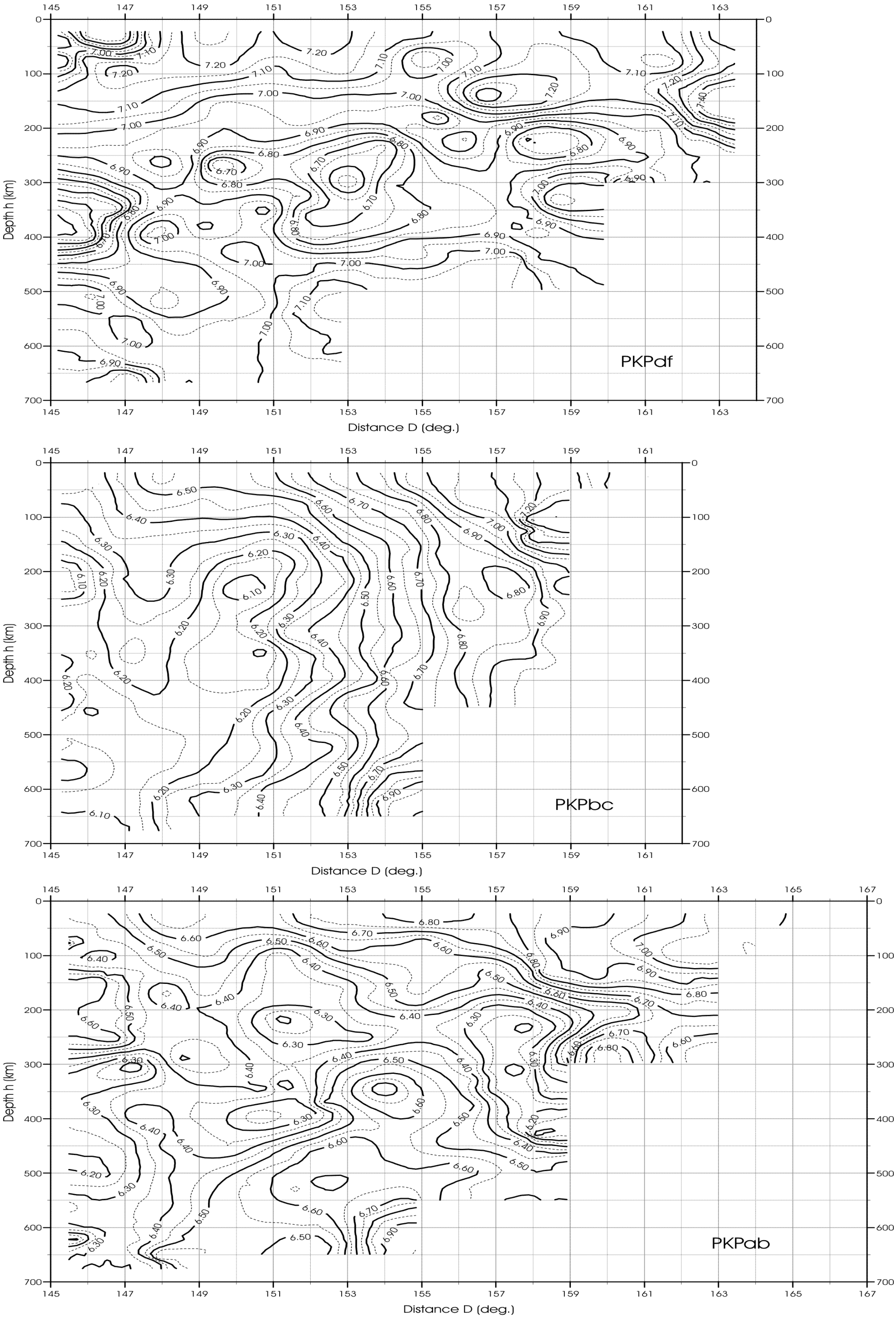

Figure 3 Calibration functions according to S. Wendt for the determination of mb(PKP) for PKPdf, PKPbc and PKPab (see Bormann and Wendt, 1999).

References (see References under Miscellaneous in Volume 2)