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By
A. Kr. Nilsen (ed.)

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VI.8 Earthquake Spectrum Scaling Law - Source Parameters for the Meløy Earthquakes

The prime motivation for deployment and operation of regional seismic networks is that of detecting and locating small events which otherwise are very seldom reported by stations in the teleseismic distance range. The design of such networks in terms of sampling frequency and station spacing is critically dependent on the 'expected' source spectra for the events in question, say, in the M_L magnitude range 0-3. Surprisingly, adequate spectral data here are available for very few areas, notably California and Japan (Aki & Chouet, 1975), while to our knowledge hardly any from typical shield areas like Fennoscandia and Western Russia. The reason for this appears to be a lack of digital, high-frequency recording capabilities and/or that the standard analog recording equipment used have not been suitable for subsequent digitalization.

During the height of the Meløy, N. Norway, microearthquake activity in November/December 1978 (Bungum et al, 1979; Bungum and Husebye, 1979), the Seismological Observatory, University of Bergen, deployed in short time intervals a set of 3 seismometers (3-comp.) having a flat response in the 5-100 Hz frequency range (Vaage, 1980). The data were recorded on analog tape and subsequently digitized at a 500 mHz sampling rate. Preliminary results from studies relevant to source spectra and its scaling with magnitude (or moment) are depicted in Fig. VI.8.1. The seismic moment corresponds to the zero frequency value of the source-displacement spectrum (Bakun and Lindh, 1977)

$$M_\omega = 4\pi\ \rho R \beta^3\ P_s^{-1}\ R_s^{-1}\ \Omega(s) \qquad \text{(VI.8.1)}$$

where ρ = density, R = hypocentral distance, β = shear wave velocity, P_s = path correction (involving Q among other factors), R_s = radian pattern coefficient, and $\Omega(s)$ = S-wave displacement spectrum. For the Meløy earthquakes the hypocentral distance R is near 10 km, and with proper assumptions for the rest of the coefficients, we find seismic moment values in the range 10^{18} to 10^{20} dyne-cm. By comparing with local magnitudes in the range 0-2 M_L units calculated from signal duration we find the following M_0/M_L relationship (see Fig. VI.8.2):

$$\log M_0 = 18.7 + 0.85\, M_L \qquad \text{(VI.8.2)}$$

which implies a larger a-value (18.7) and a smaller b-value (0.85) than what is observed at least from California (Suteau and Whitcomb, 1979).

Now, assuming a simple circular source, we can calculate source radius (r), stress drop ($\Delta\sigma$) and average displacement ($\bar{u}$) from the following relationships (Hanks and Wyss, 1972; Brune, 1970, 1971)

$$r(S) = \frac{2.34\beta}{2\pi f_c} \qquad \text{(VI.8.3)}$$

$$\Delta\sigma = \frac{7}{16} \cdot \frac{M_0}{r^3} \qquad \text{(VI.8.4)}$$

$$\bar{u} = \frac{M_0}{\pi r^2 \cdot \mu}$$

where μ = shear modulus and f_c = corner frequency.

The critical parameter is clearly the corner frequency f_c, to be obtained from the set of displacement spectra in Fig. VI.8.1. The most probable interpretation of those curves leads to the following (i) corner frequencies are very high, probably in the range 18-30 Hz, (ii) the corner frequency rolloff is very steep, i.e., the frequencies increase only slightly with decreasing moment, and below 10^{19} dyne-cm the curve is almost vertical. Using the above formulae, with appropriate parameters, we find source parameters as given in Table VI.8.1. We see there that the largest events (for which spectra are estimated) have a source radius of about 70 m, a stress drop of about 100 bars, and an average displacement across the fault of about 1.2 cm. These numbers look reasonable for events this size, while a stress drop of 100 bars is typically observed for intraplate areas (Kanamori and Anderson, 1975; Richardson and Solomon, 1977). It is important to note here, however, that in order to keep

M_0 (dyne-cm)	M_L	f_c (Hz)	r(s) (m)	$\Delta\sigma$ (bars)	$\bar{u}$ (cm)
10^{20}	1.5	19	68	99	1.2
10^{19}	0.4	26	50	28	0.3
10^{18}	-0.8	31	42	5	0.04

Table VI.8.1

Relations between seismic moment (M_0), local magnitude (M_L), corner frequency (f_c), source radius (r), stress drop ($\Delta\sigma$) and average displacement ($\bar{u}$) for the Meløy earthquakes.

the stress drop within reasonable limits for larger events, it is necessary that the rolloff of the corner frequency curve approaches a ω^{-3} relationship as the moment values go above 10^{20} dyne-cm. Even though the largest Meløy event recorded on tape had a magnitude of about 2.0, the largest one in the sequence had an M_L value of 3.2, corresponding to a seismic moment $M_0 = 2.6 \times 10^{21}$ dyne-cm. The stress drop for that event would then be in the range 100-250 bars if we assumed a corner frequency in the range 6-8 Hz.

In conclusion, we have found for the Meløy earthquakes that (i) the M_0/M_L relationship has a lower slope than usually observed, (ii) for events in the moment range 10^{18}-10^{20} dyne-cm corner frequencies are in the range 20-30 Hz, (iii) for a seismic moment of about 10^{20} dyne-cm (corresponding to M_L = 1.5) we have calculated a source radius of about 70 m, a stress drop of about 100 bars, and an average displacement of about 1.2 cm, (iv) for decreasing magnitudes, the corner frequency curve falls off steeply, implying decreasing stress drops.

H. Bungum

S. Vaage, University of Bergen

E.S. Husebye

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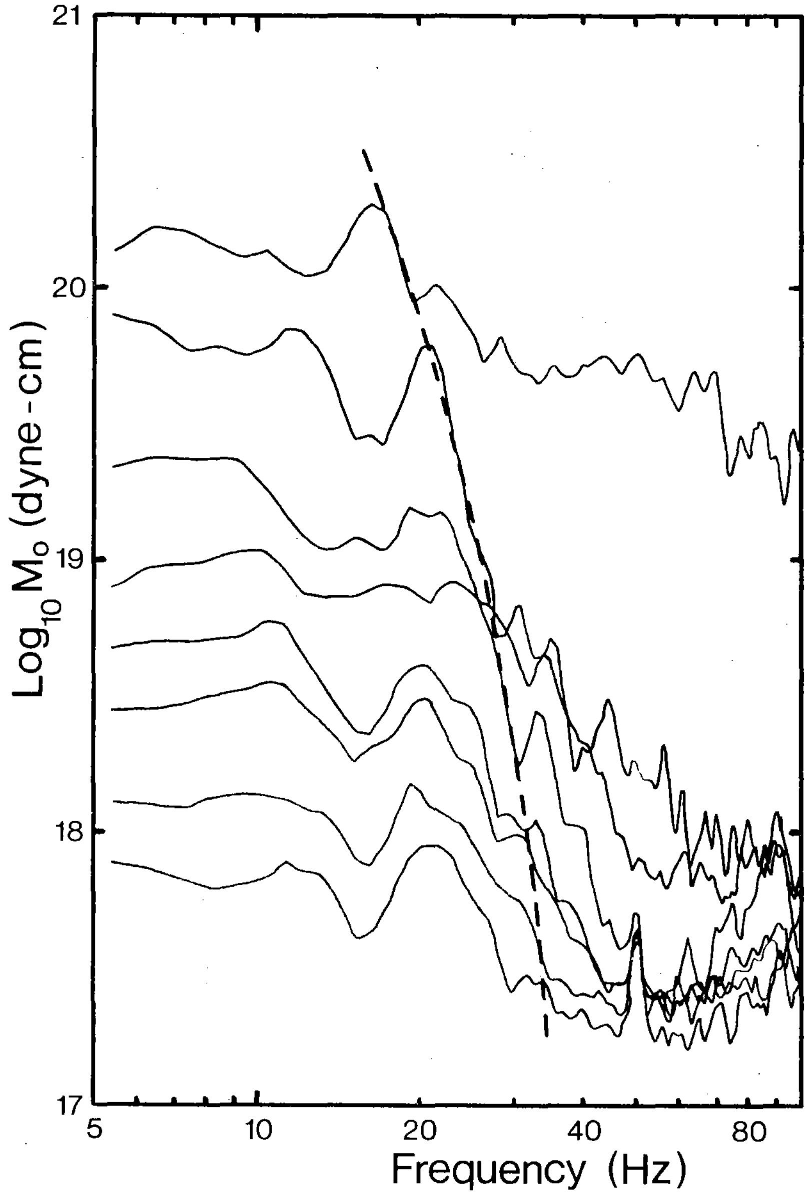

Fig. VI.8.1 S-wave displacement spectra for the Meløy earthquakes. The spectra are scaled with respect to seismic moment (M_0), and each curve represents data from 5 events in average (altogether 40 events). The dashed line indicates the corner-frequency curve.

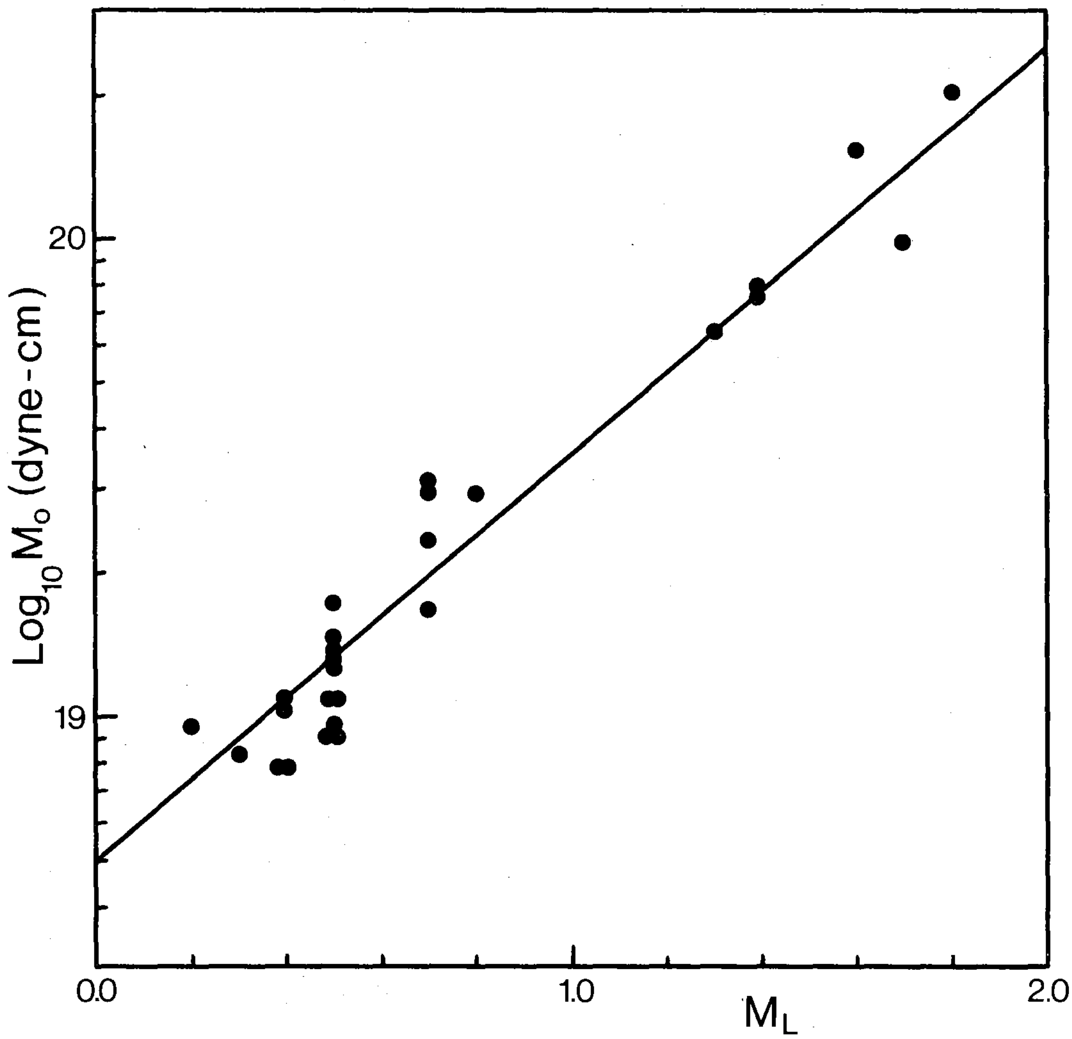

Fig. VI.8.2 M_0/M_L relationship for the Meløy earthquakes. The straight line is fitted by eye and satisfies the equation $\log M_0 = 18.7 + 0.85\ M_L$.