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DETERMINATION OF BASIC PHYSICAL SOURCE PARAMETERS AND SCALING RELATIONS FOR KALABSHA EARTHQUAKES, ASWAN, EGYPT

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ABSTRACT

Seismically the study area was considered aseismic till the occurrence of the main shock of 14 November 1981 (M_D 5.3) that occurred in Kalabsha area, west of Aswan reservoir. Installation of the telemetered network around the northern part of Aswan reservoir played an important role in monitoring the seismic activity in the area. That activity concentrated in Kalabsha area appears to be from different sources. The seismic activity can be grouped into five different seismic zones clustering in position and depth (A, B, C, D, and E). Earthquakes recorded by Aswan telemetered network with duration magnitude M_D ranging from 1.5 to 3.1 representing the different seismic zones have been spectrally analyzed. Source parameters were determined using MAG software program. The seismic moment (M_0) ranged from 4.97x10^{11} to 1.11x10^{14} dyne/cm, the source radii (r) spanned from 91.4 to 312 m, whereas the stress drop ($\Delta\sigma$) varied from 0.57 to 74.55 bar and the seismic energy (E) ranged from 8.78x10^{4} to 6.41x10^{7} J. The scaling relations between the different parameters such as M_0 - M_D; M_0 - $\Delta\sigma$; M_0 - corner frequency (f_o) and moment magnitude (M) - M_D were made and the empirical relations were obtained which will help in the fast calculation of the different source parameters for the earthquakes in the region without any need of running any spectral analysis programs.

KEYWORDS: Source parameter; scaling relation; seismic moment; source radius stress drop; moment magnitude; Kalabsha; Aswan.

INTRODUCTION

The study area, Kalabsha, is located to the west of Aswan reservoir between lat. 23°- 24° and long. 32° –32.85° (Fig. 1). No instrumentally earthquakes have been reported in the area before the occurrence of the November 1981 earthquake (M_D 5.3) and the installation of the Aswan telemetered network in 1982. The continuous monitoring and recording of the seismic activity in the area through this network lead to many seismological studies in the area (e.g. Kebeasy et. al., 1987; Fat-Helbary, 1995; Haggag, 1997 and Haggag et. al., 2001). The seismic activity in the area is concentrated in Kalabsha area and can be clustered in five seismic zones (A - E; different position and depth). The 14 November 1981 earthquake occurred in zone A (Kebeasy et. al., 1987). In earthquake engineering, an earthquake source has often been regarded as a "point" whose strength is represented by an earthquake magnitude. When an earthquake takes place, certain amount of strain energy is released resulting in a sudden drop of accumulated stress.

Brune (1970) has given a model to calculate source parameters using near and far field displacement amplitude spectrum as a function of the physical parameters at the source. Abercombie and Leary (1993); Zobin and Hasakov (1995) and several others are notable recent contributors in the field of source parameter studies (Pandey et. al., 2001).

To obtain further information about earthquakes in addition to geographical coordinates of epicenters, depth of focus, time of origin and magnitude, it is necessary to determine other parameters describing the individual shocks. Amplitude spectra of seismic waves allow us to compute additional physically defined parameters, for instance the seismic moment M_0 which describes the source strength, the source dimension r defined the radius of an equivalent circular source area, and the stress drop $\Delta\sigma$ describing the difference between the shear stress on the fault surface before and after the shock

There has been substantial progress in the mathematical description that relates seismic spectrum to source parameters, and several studies (e.g. Fletcher, 1980; Iio, 1986, 1992 and Badawy, 1995) calculating source size, seismic moments and stress drop have been published.

This study is an attempt to provide a data set of source parameters such as seismic moment M_0, source radius r, stress drop $\Delta\sigma$, P- and S- wave energies for some microearthqukes occurred in the different seismic zones of Kalabsha area. Also the scaling relations among these parameters were determined which can be used in fast determination of the source parameters in the area without need to run any spectral analysis program.

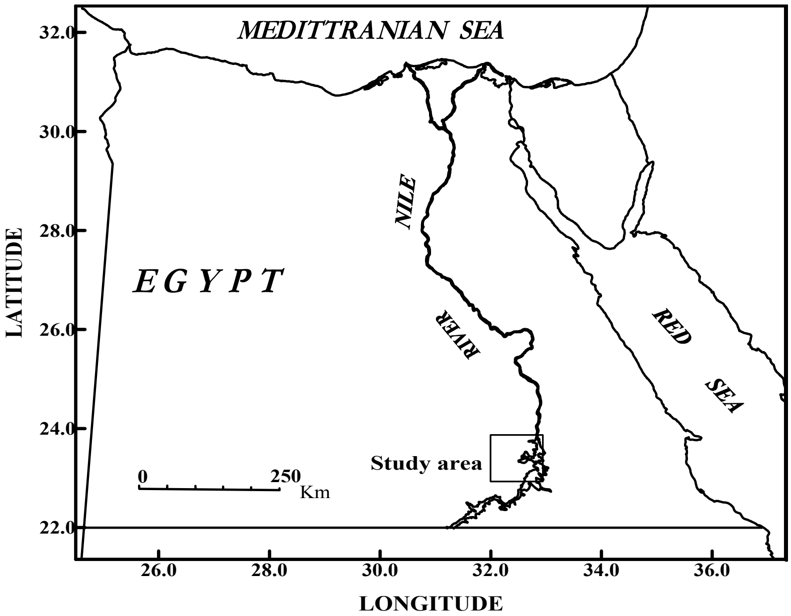

Fig. 1 Location map of the study area

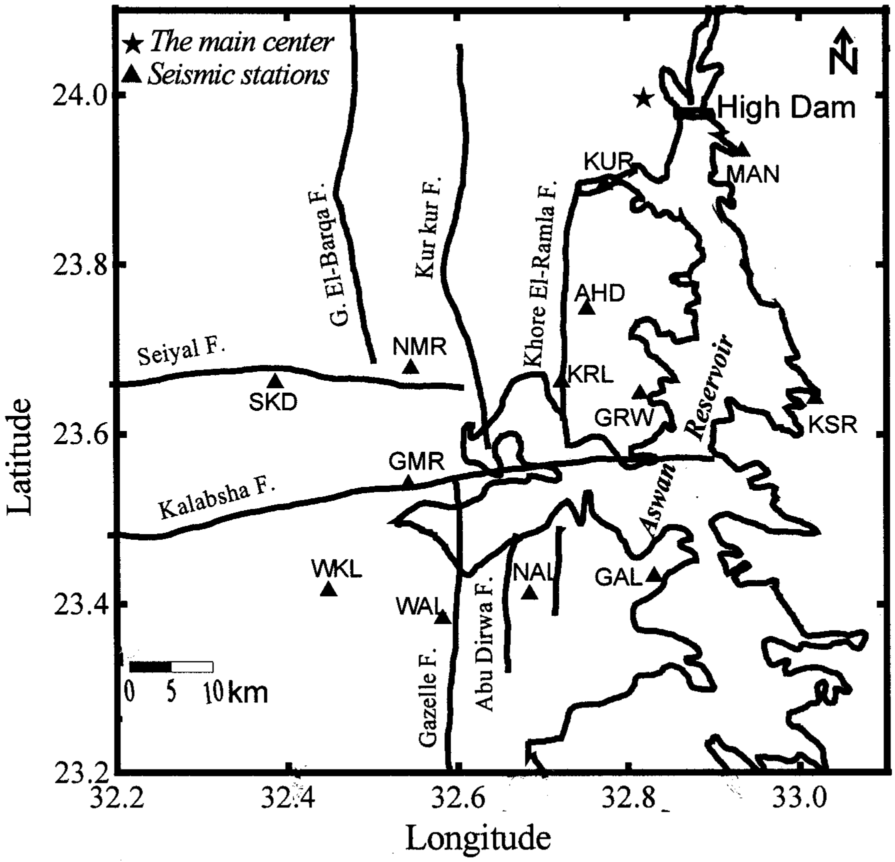

Fig. 2 Geographical location of the telemetered seismic stations and the significant faults in the area. (Modified from EGSMA, 1981)

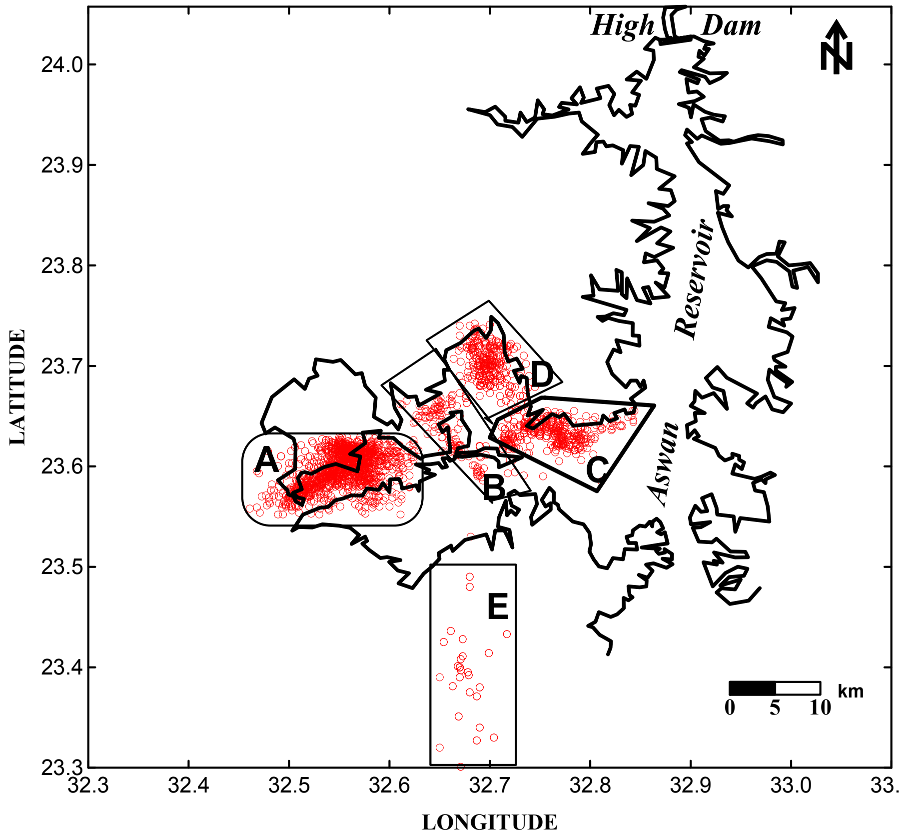

Fig. 3 Seismicity map of Kalabsha area as recorded by Aswan telemetered network during the period 1982-2002.

SEISMICITY OF THE STUDY AREA

After the occurrence of the main shock on 14 November 1981 (M_D 5.3), it was of great importance to monitor and study the seismic activity in this area particularly for the safety and stability of the Aswan High Dam. Thus, in late June 1982 a telemetered network of eight seismic stations was installed around the northern part of Aswan reservoir. Later, this network was expanded to thirteen stations, eleven of them are distributed in the western side of the reservoir around the active faults (Fig. 2). The main purpose of this network is to monitor the seismic activity around the northern part of Aswan reservoir, which continuous to occur after the magnitude 5.3 main shock (Kebeasy et. al., 1987) in the area particularly along the most active Kalabsha fault (Fig. 2). Before that main shock the area was considered aseismic where no instrumental events were reported.

Figure 3 shows the epicentral distribution of the seismic activity, which is concentrated in Kalabsha area. This activity can be divided according to the seismicity level into different seismic zones. The zone A, of the highest seismic activity in the area, is characterized by hypocenter depth ranging from 15-25 km. The November 14, 1981 earthquake is located in this zone (Kebeasy et. al., 1987). Zone B, is located to the east of zone A, characterized by shallow activity where the focal depth in the range of 2-7 km. Epicenter cluster of the zone C lies east of zone B, with focal depth ranging from 1-3 km. The zone D is considered as the second active one after zone A. It is characterized by a focal depth range down to 8 km. The zone E, the general character of this zone suggests that it has low degree of seismic activity (WCC, 1985), it lies to the south of zone B.

DETERMINATION OF THE SPECTRAL PARAMETERS

The physical source characteristics of Kalabsha earthquakes area have been evaluated from the gross spectral properties of the recorded P- and S- waves by Aswan seismic network.

In this study some well located earthquakes covering the local magnitude intervals ranging from 1.5 to 3.1 and digitally recorded, during the period 1995 to 2002, from the different seismic zones at a sample rate of 100 sample /sec were used to calculate both P- and S-wave displacement spectra. Before this period the digital data were not available. These earthquakes represent the typical events that distributed in the different seismic zones as shown in Table 1. For all the events, the clearest and available stations

Table 1 List of earthquakes used in this study

Area	*Event No.*	*Date* *Y M D*	*O. T.* *H M*	*Location* *Lat.*	 *Long.*	*Epicentral Dist.(km)*	*Depth (km)*	*Mag (M_D)*
Zone A	1	95 10 10	14 50	23.56	32.56	23.2	16.3	2.4
	2	96 01 10	11 25	23.55	32.57	22.2	15.6	2.0
	3	97 10 11	08 41	23.57	32.66	11.8	3.5	1.8
	4	98 04 03	04 16	23.54	32.57	9.9	6.1	2.1
	5	98 12 12	03 28	23.53	32.54	28.8	10.7	3.14
Zone B	1	97 08 01	07 59	23.57	32.67	22.3	2.7	2.0
	2	97 09 10	17 43	23.57	32.66	20.8	3.0	2.3
	3	00 03 07	11 31	23.57	32.67	20.1	3.82	2.9
Zone C	1	99 09 14	23 22	23.59	32.75	19.4	1.5	2.4
	2	00 10 01	04 54	23.57	32.80	16.4	3.3	2.0
	3	00 10 31	19 44	23.58	32.74	22.2	2.77	2.5
Zone D	1	99 06 14	02 43	23.65	32.70	15.5	3.7	2.6
	2	99 07 17	06 52	23.68	32.71	9.6	3.4	2.9
	3	00 09 19	01 44	23.68	32.71	8.2	2.67	2.7
	4	00 11 20	10 05	23.67	32.71	18.4	2.53	2.9
Zone E	1	99 11 02	23 49	23.32	32.69	27.5	4.24	2.0
	2	00 11 05	07 31	23.35	32.68	8.0	0.54	2.1
	3	02 02 23	23 39	23.35	32.67	12.3	3.0	1.5

record were used and an average was made to calculate the source parameters of P- and S- waves.

Relation of the source parameters of the used events to the spectral parameters implied the correction of the shear wave spectrum for the effects of instrument sponse, free surface effect, and the partition of vector into horizontal components. The spectrum was not corrected for the effect of the anelastic attenuation because this parameter is only important for frequencies $f >> f_0$ (McGuire and Hanks, 1980). A key parameter in quantifying source parameter is the corner frequency f_0, which is defined at each spectrum as the frequency at the intersection of low frequency and high frequency trend. The coded software program MAG by Niewiadomski (personal communication, 2002) was used to complete the spectral analysis technique. The output of the program such as f_0, M_0, r, Ω_o, E, and $\Delta\sigma$ were used in this study. Examples of the displacement amplitude spectra for some earthquakes were shown in Fig. 4. The deduced source parameters as seismic moment M_0, source radius r, and stress drop $\Delta\sigma$ are given in Table 2. While the average values of all the parameters are given in Table 3.

Values for f_0 from both P- and S- waves obtained for each of the used events were analyzed. The corner frequency from P-wave f_0 (p) and the corner frequency from S-wave f_0 (s) values are in the range of 7.1 to 11.9 Hz and 4.0 to10.2 Hz, respectively. The corner frequencies estimated from P-waves were always larger than those from S-waves.

Correlation between the total P- and S- wave seismic energies showed that the P- wave energy values E (p) are in the range of 1.55×10^5 to 8.13×10^7 J, while that for S- wave E (s) are 1.96×10^5 to 1.75×10^8 J. The total energy E (p,s) ranged from 8.78 $\times 10^4$ to 6.41 $\times 10^7$J.

DETERMINATION OF SOURCE PARAMETERS

Seismic Moment (*Mo*)

Many procedures are in common use to estimate M_0 (Bullen, 1993). The formula derived for far-field measurements of ground displacement by Brune (1970,1971) is available as follows:

$$M_o = 4\pi\rho\beta^3 R\Omega_o / R_{(\Theta,\varphi)}$$

where

β is the shear wave velocity,

ρ is the density of source material,

$R_{(\Theta,\varphi)}$ is the source radiation pattern,

R is the source distance to the receiver, and

Ω_o is the spectral amplitude at low frequency on a broad band displacement eismogram.

The physical meaning of Ω_o is the product of pulse- width and amplitude. In this study it is automatically computed by the MAG program and the seismic moment is related to the low-frequency limit of the spectrum of ground displacement as indicated by Brune (1970, 1971). The moment values were calculated for the average crustal properties (Boore and Atkinson, 1987), using the following parameters, β = 3.5 km/sec, ρ = 2.7 gm/cm^3 and the average radiation pattern $R_{(\theta, \varphi)} = 0.55$ (Boore and Boatwright, 1984). The calculated moment values for each event are listed in Table 3. It was found that the seismic moment M_0 (p) estimated from P-wave spectra ranged

Table 2 Calculated source parameters of events listed in Table 1.

Area	*Even. No.*	*Stat. Code*	f_0 (*Hz*)		M_0 (*dyne/cm*)		M_0	*r* (*m*)	*Δ σ* (*bar*)	Ω_o (*m/s*)		*M*	*E(J)*		*E*
			P-	*S-*	*P-*	*S-*				*P-*	*S-*		*P-*	*S-*	
Zone A	1	GMR	10.2	4.0	1.65E+12	1.65E+12	1.65E+12	183	1.17	4.06 E-4	1.83 E-3	2.04	2.23E+6	1.56E+6	3.79E+6
		GRW	13.8	13.4	9.12E+12	1.02E+12	5.07E+12	68.1	70.1	1.16 E-3	5.86 E-4	2.37	4.67E+7	7.44E+6	5.41E+7
		NMR	9.7	6.4	7.53E+12	3.98E+12	5.76E+12	142	8.81	9.6 E-4	2.3 E-3	2.41	1.11E+7	1.26E+7	2.37E+7
		WKL	13.8	13.1	2.11E+12	1.52E+12	1.82E+12	69.7	23.5	2.7 E-4	8.77 E-4	2.07	2.5E+6	1.56E+7	1.81E+7
	2	GMR	6.1	1.5	6.7E+11	1.23E+12	9.51E+11	500	0.03	1.65 E-4	1.37 E-3	1.89	7.87E+4	4.3E+4	1.22E+5
		WKL	10.7	7.3	3.75E+12	2.35E+12	3.05E+12	124	7.01	4.78 E-4	1.35 E-3	2.22	3.62E+6	6.6E+6	1.02E+7
	3	GMR	4.0	3.1	1.72E+12	3.04E+11	1.01E+12	235	0.34	4.25 E-4	3.39 E-4	1.9	1.46E+5	2.52E+4	1.71E+5
		NMR	12.3	5.3	2.11E+12	8.97E+11	1.5E+12	172	1.30	2.69 E-4	5.17 E-4	2.02	1.77E+6	3.63E+5	2.14E+6
		KRL	5.9	3.5	3.57E+12	1.27E+12	2.42E+12	260	0.06	4.55 E-4	7.33 E-4	2.16	5.53E+5	2.09E+5	7.62E+5
	4	GMR	4.3	2.2	2.59E+12	9.55E+11	1.77E+12	337	0.20	6.39 E-4	1.07 E-3	2.07	4.15E+5	8.45E+4	4.99E+5
		WKL	5.1	3.0	3.45E+12	2.17E+12	2.81E+12	308	0.42	4.39 E-4	1.25 E-3	2.2	3.29E+5	3.65E+5	6.94E+5
		AHD	11.9	9.4	1.63E+12	5.97E+12	1.11E+12	97.2	5.31	2.08 E-4	3.44 E-4	1.93	9.56E+5	8.85E+5	1.84E+5
	5	SKD	11.1	8.3	6.25E+12	8.46E+12	7.35E+12	87.4	48.1	1.54 E-3	9.43 E-3	2.48	4.08E+7	3.78E+8	4.19E+8
		GRW	9.1	8.6	4.18E+13	1.29E+13	2.74E+13	106	101.0	5.33 E-3	7.46 E-3	2.86	2.84E+8	3.21E+8	6.05 E+8
Zone B	1	NAL	12.6	8.3	9.65E+11	9.01E+11	9.33E+11	88.4	5.92	2.38 E-4	1.0 E-3	1.88	1.45E+6	4.16E+6	5.61E+6
		KRL	10.1	4.6	2.41E+12	1.99E+12	2.2 E+12	196	1.28	3.07 E-4	1.14 E-3	2.13	1.27E+6	1.19E+6	2.46 E+6
	2	NAL	10.3	8.9	1.93E+12	1.38E+12	1.66E+12	82.4	12.9	4.77 E-4	1.54 E-3	2.05	3.1E+6	1.2E+7	1.51E+7
		KRL	9.0	7.8	3.36E+12	1.39E+12	2.37E+12	117	6.43	4.28 E-4	7.99 E-4	2.15	1.72E+6	2.71E+6	4.43 E+6
	3	NAL	10.6	6.2	1.54E+12	2.8E+12	2.17E+12	117	5.88	3.81 E-4	3.12 E-3	2.12	2.19E+6	1.72E+7	1.93E+7
		KRL	8.7	3.4	3.36E+12	3.72E+12	3.54 E+12	270	0.79	4.29 E-4	2.14 E-3	2.27	1.57E+6	1.61E+6	3.17E+6
Zone C	1	GAL	14.5	12.6	1.85E+12	2.18E+12	2.02E+12	58.1	45	4.55 E-4	2.43 E-3	2.1	7.94E+6	8.6E+7	9.39E+7
		KRL	8.0	6.2	6.54E+12	1.2E+12	3.87E+12	146	5.47	8.33 E-4	6.94 E-4	2.29	4.63E+6	1.07E+6	5.69E+6
	2	GAL	16.4	14.5	1.37E+12	8.99E+11	1.13E+12	50.3	39.1	3.37 E-4	1.0 E-3	1.94	6.36E+6	2.25E+7	2.88E+7
		KRL	9.9	7.5	3.54E+12	6.53E+11	2.1E+12	121	5.15	4.51 E-4	3.76 E-4	2.11	2.58E+6	5.44E+5	3.12E+6
		GRW	10.6	9.8	1.24E+12	8.72E+12	1.06E+12	92.4	5.86	1.58 E-4	5.02 E-4	1.92	3.9E+5	2.19E+6	2.58E+6
		AHD	9.4	8.9	3.87E+12	1.08E+12	2.48E+12	102	10.2	4.93 E-4	6.25 E-4	2.16	2.67E+6	2.51E+6	5.18E+6
	3	NAL	12.5	8.3	1.45E+12	1.82E+12	1.63E+12	88.3	10.4	3.59 E-4	2.03 E-3	2.04	3.19E+6	1.7E+7	2.02E+7
		GAL	13.7	12.4	7.35E+12	2.97E+12	5.16E+12	73.6	56.6	9.38 E-4	1.71 E-3	2.38	2.97E+7	5.03E+7	8.0E+7
		AHD	9.4	2.1	1.1E+13	1.32E+13	1.21E+13	438	0.63	1.4 E-3	7.58 E-3	2.62	2.15E+7	4.7E+6	2.62E+7
Zone D	1	KRL	10.9	4.3	4.36E+12	4.24E+12	4.3E+12	170	3.8	1.08 E-3	4.73 E-3	2.32	1.91E+7	1.28E+7	3.19E+7
		GRW	8.5	4.0	4.54E+12	4.76E+12	4.65E+12	227	1.74	5.78 E-4	2.74 E-3	2.34	2.65E+6	4.4E+6	7.06E+12
		AHD	9.4	9.0	1.12E+13	2.46E+12	6.83E+12	101	29.4	1.43 E-3	1.42 E-3	2.46	2.23E+7	1.35E+7	3.58E+7
	2	KRL	12.7	4.6	1.62E+12	2.45E+12	2.03E+12	157	2.28	4.01 E-4	2.73 E-3	2.11	4.16E+6	5.43E+6	9.59E+6
		GAL	11.9	11.9	9.26E+12	3.05E+12	6.16E+12	76.4	60.5	1.18 E-3	1.76 E-3	2.43	3.05E+7	4.77E+7	7.82E+7
	3	KRL	9.2	7.1	2.11E+12	1.64E+12	1.88E+12	102	7.64	5.2 E-4	1.83 E-3	2.08	2.65E+6	8.88E+6	1.15E+7
		NAL	9.4	8.3	8.59E+12	7.87E+12	8.23E+12	109	27.4	1.1 E-3	4.54 E-3	2.51	1.31E+7	1.08E+8	1.21E+8
		SKD	8.9	8.7	7.17E+12	4.26E+12	5.71E+12	105	21.6	9.14 E-4	2.45 E-3	2.4	7.75E+6	3.57E+7	4.34E+7
		WKL	11.1	10.9	9.33E+12	5.13E+12	7.23 E+12	83.7	54.0	1.19 E-3	2.96 E-3	2.47	2.51E+7	1.02E+8	1.28E+8
	4	KRL	9.2	7.8	9.56E+12	5.42E+12	7.49E+12	93.4	40.3	2.36 E-3	6.04 E-3	2.48	5.47E+7	1.28E+8	1.82E+8
		WAL	4.6	3.0	1.98E+13	1.16E+13	1.57 E+13	304	2.45	2.52 E-3	6.68 E-3	2.7	8.01E+6	1.09E+7	1.89E+7
		KUR	8.7	8.5	3.28E+13	9.56E+13	2.12 E+13	107	75.4	4.18 E-3	5.51 E-3	2.78	1.48E+8	1.69E+8	3.18E+8
Zone E	1	NAL	11.2	5.8	4.95E+11	1.01E+12	7.52E+11	127	1.61	1.22 E-4	1.13 E-3	1.82	2.63E+5	1.76E+6	2.03E+6
		GAL	5.6	3.2	1.25E+12	1.14E+12	1.2 E+12	143	1.77	1.22 E-3	5.01 E-3	1.95	3.14E+6	3.89E+6	7.03E+6
	2	NAL	8.5	3.4	1.74E+12	4.13E+12	2.94E+12	215	1.3	4.29 E-4	4.61 E-3	2.21	1.43E+6	6.1E+6	7.53E+6
		WKL	11.3	6.2	2.9E+12	2.87E+12	2.88 E+12	148	3.91	3.69 E-4	1.65 E-3	2.21	2.55E+6	5.81E+6	8.36 E+6
		WAL	8.7	7.4	9.05E+12	3.46E+12	6.26 E+12	123	1.46	1.15 E-3	1.99 E-3	2.43	1.14E+7	1.46E+7	2.59 E+7
		AHD	5.9	5.1	5.12E+12	2.09E+12	3.61 E+12	177	2.85	6.52 E-4	1.21 E-3	2.27	1.15E+6	1.8E+6	2.95 E+6
	3	NAL	12.0	3.4	6.65E+11	8.96E+11	7.8E+11	218	0.33	1.64 E-4	9.98 E-4	1.83	5.8E+5	2.75E+5	8.56E+5
		GAL	8.0	7.7	4.44E+11	3.77E+11	4.1E+11	118	1.1	5.65 E-5	2.17 E-4	1.64	2.17E+4	1.97E+5	2.19E+5
		WAL	12.5	8.7	2.01E+11	3.97E+11	2.99E+11	105	1.14	2.56 E-5	2.29 E-4	1.55	1.69E+4	3.12E+5	3.29E+5

f_0 = corner frequency, M_0 = seismic moment, *r* = radius, Δ σ = stress drop, Ω_o = spectral amplitude, *M* = moment magnitude, *E* = seismic energy, P- = P wave, and S- = S wave.

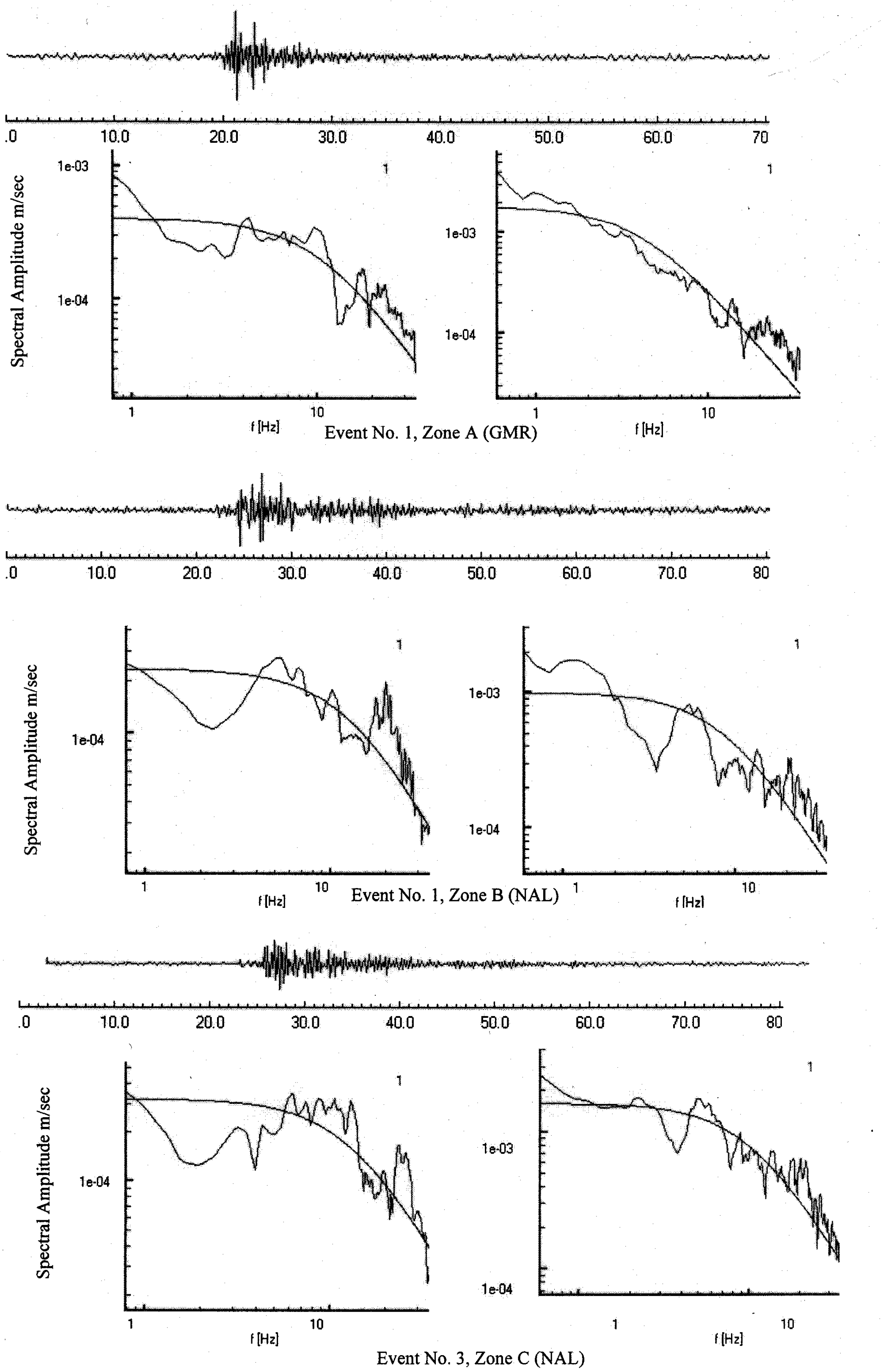

Fig. 4 Examples of digital velocity record and its displacement amplitude spectra from P- (left) and S- wave (right) for the event No. 1, zone A (GMR); No. 1, zone B (NAL) and No. 3, zone C (NAL).

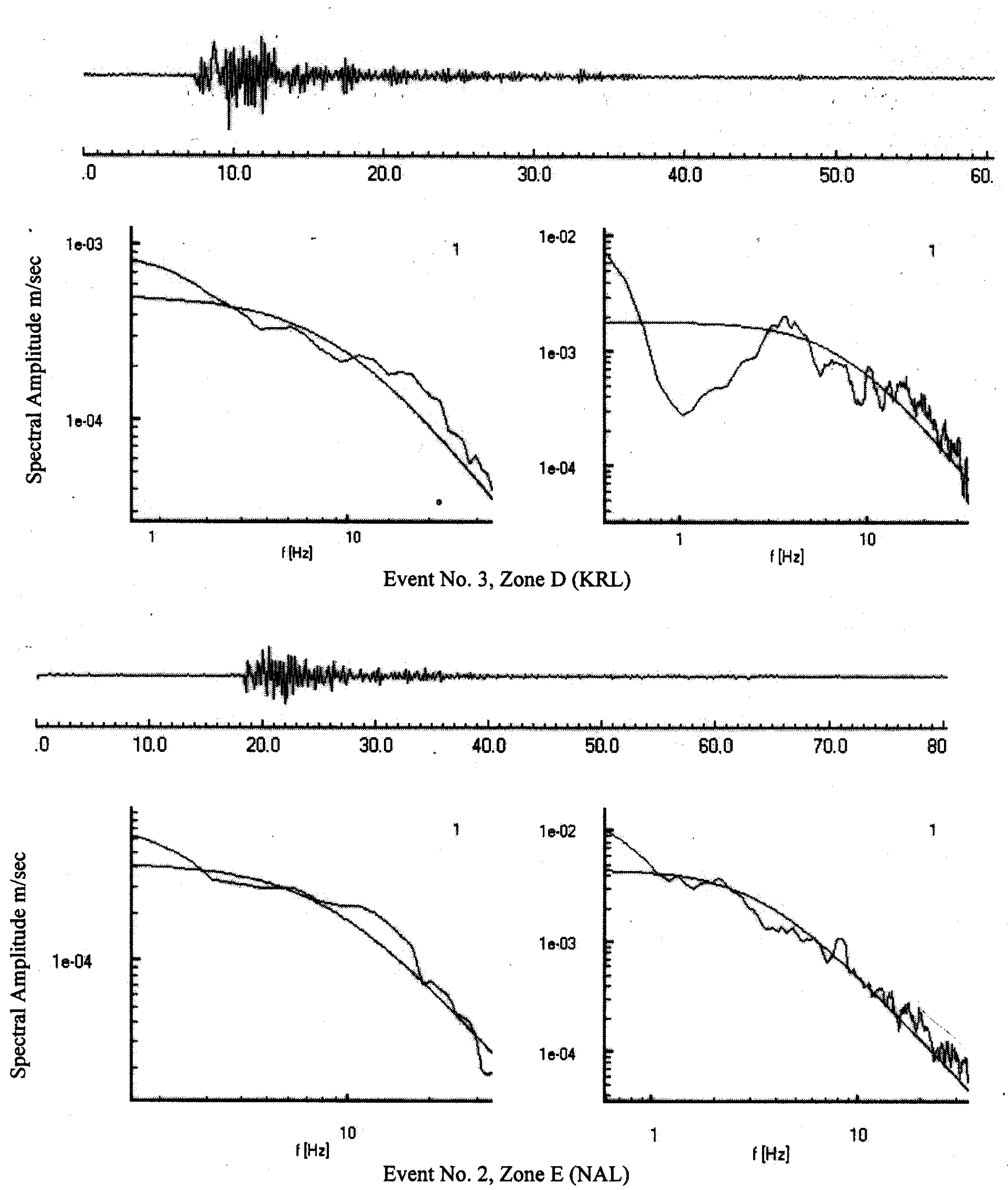

Fig. 4 Continue: for the event No. 3 zone D (KRL) and No. 2, zone E (NAL).

from 4.37x10^{11} to 2.21x10^{14} dyne/cm, and M_0 (s) from S-w spectra ranged from 5.57x10^{11} to 3.77x10^{13} dyne/cm. While the average M_0 (p,s) ranged from 4.97x10^{11} to 1.11x10^{14} dyne/cm.

Source Radius (r)

In this study, the source radius r was determined related to the corner frequency, f_o, by using Brune's (1970, 1971) model as follows;

$$r = (2.34\beta)/2\pi f_o$$

The determined values of r were listed in Table 3, it ranged from 91.4 to 312 m.

Stress Drop (Δσ)

The stress drop Δσ is simply thought as a parameter controlling the strength of high-frequency radiation. It can be defined as the difference between the stress before and after occurring the earthquake over the fault plane. The earthquake stress drop Δσ can be estimated through its relating with the seismic moment M_0, and the source radius r, as mentioned in the Brune's (1970, 1971) model as follows:

$$\Delta\sigma = 7M_0/16r^3$$

The determined values of the stress drop were listed in Table 3. These values ranged from 0.57 to 74.55 bar.

Table 3 The average values of the source parameters calculated in Table 2.

Area	*Even . No.*	*f_0 (Hz) P-*	*S-*	*M_0 (dyne/cm) P-*	*S-*	*M_0*	*r (m)*	*Δ σ (bar)*	*M*	*E (J) P-*	*S-*	*E*
	1	11.9	9.2	5.10E+12	2.04E+12	3.57E+12	115.7	25.90	2.22	1.56E+07	9.30E+06	6.23E+06
	2	8.4	4.4	2.21E+14	1.79E+12	1.11E+14	312.0	3.52	2.06	9.25E+05	1.66E+06	6.46E+05
Zone	3	7.4	4.0	2.47E+12	8.23E+11	1.65E+12	222.3	0.57	2.03	6.18E+05	1.49E+07	3.88E+06
A	4	7.1	5.5	2.56E+12	3.03E+12	2.8E+12	247.4	1.98	2.07	4.25E+05	3.33E+07	8.43E+06
	5	10.1	8.5	4.91E+13	1.07E+13	2.99E+13	96.7	74.55	2.67	8.13E+07	1.75E+08	6.41E+07
	1	11.5	6.5	1.69E+12	1.45E+12	1.57E+12	142.2	3.60	2.01	6.80E+05	1.34E+06	5.05E+05
Zone	2	9.7	8.4	2.65E+12	1.39E+12	2.02E+12	99.7	9.67	2.10	1.21E+06	3.68E+06	1.22E+06
B	3	9.7	4.8	2.45E+12	3.26E+12	2.86E+12	193.5	3.34	2.20	9.40E+05	4.70E+06	1.41E+06
	1	11.3	9.4	4.20E+12	1.69E+12	2.95E+12	102.1	25.24	2.20	3.15E+06	2.18E+07	6.24E+06
Zone	2	11.5	10.2	2.50E+12	2.85E+12	2.68E+12	91.4	15.08	2.03	3.00E+06	6.93E+06	2.48E+06
C	3	11.9	7.6	6.60E+12	6.00E+12	6.3E+12	200.0	22.54	2.35	1.36E+07	1.80E+07	7.90E+06
	1	9.6	5.8	6.70E+12	3.83E+12	5.27E+12	166.0	11.65	2.37	1.10E+07	7.68E+06	4.67E+06
Zone	2	12.3	8.3	5.45E+12	2.75E+12	4.1E+12	116.7	31.39	2.27	8.68E+06	1.33E+07	5.50E+06
D	3	9.7	8.8	4.48E+12	4.73E+12	4.61E+12	100.0	27.66	2.37	1.22E+07	6.38E+07	1.90E+07
	4	7.5	6.4	2.07E+13	3.77E+13	2.92E+13	126.1	29.54	1.99	5.28E+07	7.70E+07	3.25E+07
	1	8.4	4.5	8.75E+11	1.08E+12	9.78E+11	135.0	1.69	1.89	8.50E+05	1.41E+06	5.65E+05
Zone	2	8.6	5.5	4.70E+12	3.15E+12	3.93E+12	165.8	2.38	2.28	4.13E+06	7.08E+06	2.80E+06
E	3	10.8	6.6	4.37E+11	5.57E+11	4.97E+11	147.0	0.86	1.67	1.55E+05	1.96E+05	8.78E+04

SCALING RELATIONS

MAGNITUDE RELATIONS

The seismic moment M_0 and moment magnitude M are plotted versus Aswan magnitude M_D in order to estimate the empirical relations between these important source parameters that represent the source size.

M_D (Aswan) is the Aswan duration magnitude that is calculated from the relation given by Lee et. al. (1981) as follows:

$$M_D = 2\log D - 0.87 + 0.00035\Delta$$

where D is the duration of oscillation in sec, and Δ is the epicentral distance in km.

Seismic Moment (M_0) and Magnitude (M_D)

The seismic moment M_0 is fundamentally superior to any magnitude scale, since it quantifies a parameter of the commonly accepted earthquake source model. The only limitation for M_0 is the difficulty in properly processing seismic records on a large routine scale to determine the size of a seismic event. For this purpose, a variety of magnitude scales has been proposed. Magnitude by definition quantifies, the energy radiated over a fixed frequency band (e. g. Aki, 1967). Since the frequency distribution of radiating seismic energy changes with earthquakes size, magnitude scales suffer intrinsic limitations such as saturation and discrepancies between various scales (e. g. Hanks and Kanamori, 1979)

The empirically found seismic moment - magnitude relations have always been written as a linear relation between log M_0 and magnitude as follows:

$$\log M_o = aM_m + b$$

where M_m in general, can be any magnitude, and a and b are constants. In this study, the relation between the magnitude M_D and the logarithmic values of seismic moment M_0 for P-, S- and both P, S waves are calculated and plotted in Fig. 5. The relation appears to be clearly linear with remarkably small scatter. The $M_0 – M_D$ empirical relations have been estimated from P-waves, S-waves and both. A least squares fit yields the following empirical relations:

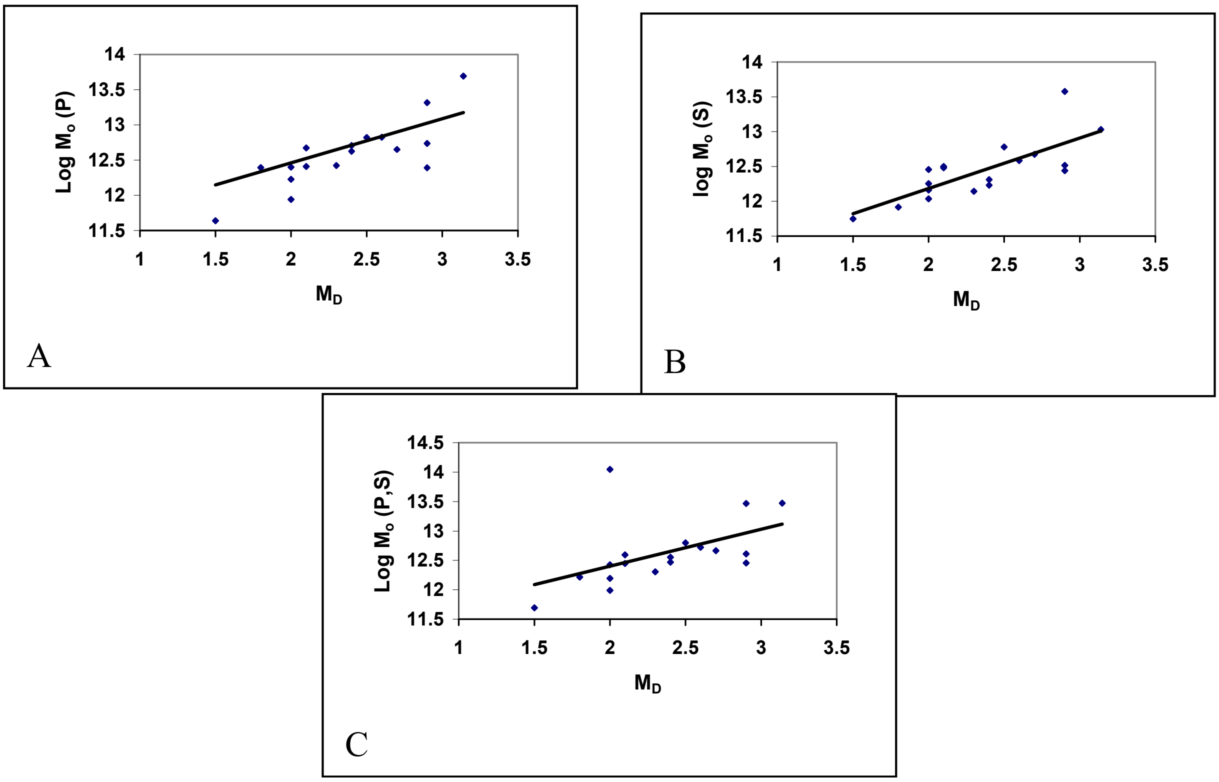

Fig. 5 Plot of the seismic moment M_0, as determined from (A) P-waves, (B) S-waves, and (C) P- and S-waves, against duration magnitude M_D. The straight lines represent least squares fits to the data.

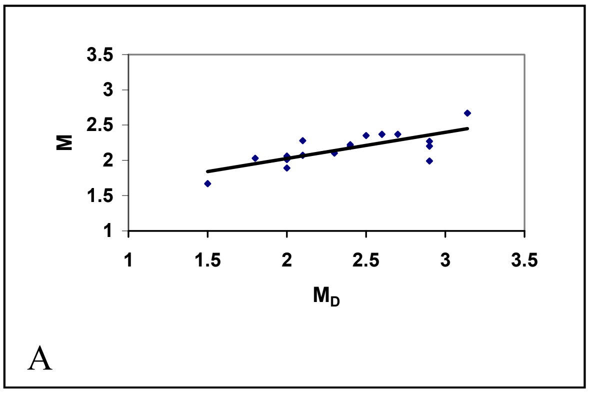

Fig. 6 Plot of moment magnitude M against duration magnitude M_D.

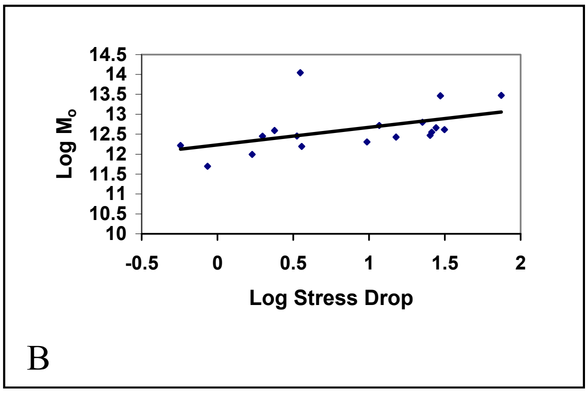

Fig. 7 Plot of seismic M_0 moment against stress drop $\Delta\sigma$.

$$\log M_o(P) = (0.63 \pm 0.30) M_D(Aswan) + 11.21 \pm 0.56$$
$$\log M_o(S) = (0.72 \pm 0.15) M_D(Aswan) \pm 10.74 \pm 0.27$$
$$\log M_o(P,S) = (0.62 \pm 0.27) M_D(Aswan) \pm 11.15 \pm 0.5$$

A plot of local magnitude versus seismic moment for some events gives systematically large seismic moments for relatively small magnitudes. These results are explained by the laboratory experiments done by Vinogradov (1978). He reported that the displacements along a smooth fault are a possible mechanism of earthquakes with large seismic moments and a relatively small magnitude.

Moment Magnitude (M) and Duration Magnitude (M_D)

In recent years, the moment magnitude M instead of seismic moment itself, became a frequently used measure of the earthquake strength. This has been formally defined by Hanks and Kanamori (1979) as:

$$M = 2/3 \log M_o - 6.0$$

where M_0 is in N. m (Newton by meter).

M values that are given in Table (3) are plotted versus M_D as shown in Fig. 6. The empirical relationship between M and M_D (Aswan) is obtained as follows:

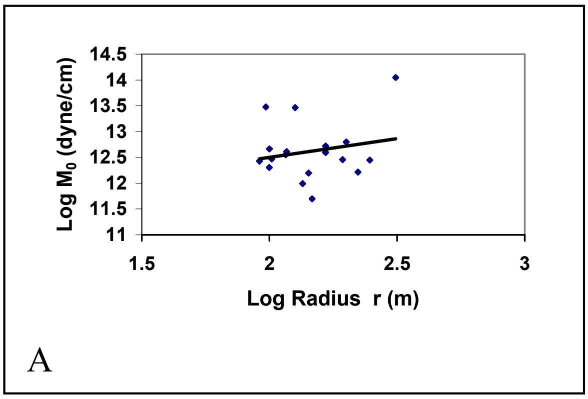

Fig. 8 Seismic moment M_0 plotted as a function of source radius r.

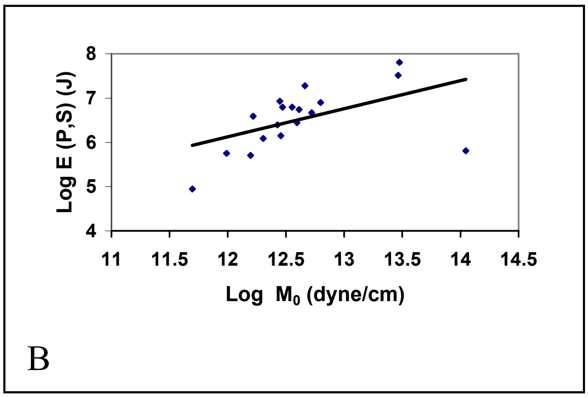

Fig. 9 Plot of total seismic energy against seismic moment M_0.

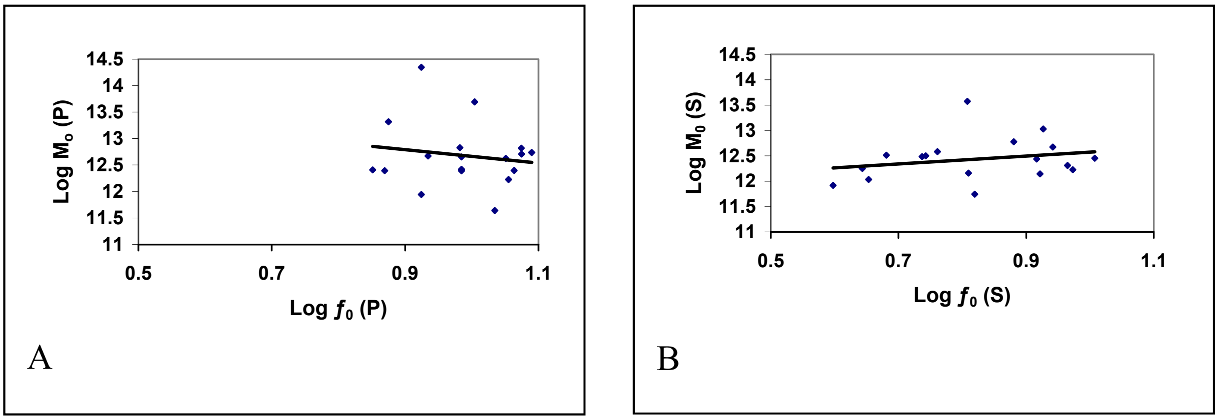

Fig. 10 Relation of seismic moment as determined from (A) P-wave and (B) S-wave, against corner frequency f_0 of P- and S-wave respectively.

$$M = (0.37 \pm 0.08) M_D (Aswan) + 1.27 \pm 0.15$$

Seismic Moment (M_0) – Stress Drop ($\Delta\sigma$)

The relation between seismic moment (log M_0) and the stress drop $\Delta\sigma$ was calculated and plotted in Fig. 7. A linear least squares fit through the data gives:

$$\log M_o = (0.44 \pm 0.19) \log \Delta\sigma + 12.23 \pm 0.50$$

Seismic Moment (M_0) – Source Radius (r)

The empirical relation between the total seismic moment of both P- and S- waves (log M_0) and the source radius (log r) is obtained (Fig. 8) in the following linear relation:

$$\log M_o (P,S) = (0.7 \pm 0.04) \log r + 11.06 \pm 0.56$$

Seismic Moment M_0 - Total Seismic Energy E

Values of the total seismic energy are plotted against the average seismic moment as shown in Fig.9. The following empirical relation was found:

$$\log E(p,s) = (0.64 \pm 0.26) \log M_o - 1.51 \pm 0.62$$

The seismic Energy, which ranged from 1.22x10^5 to 4.19x10^8 J, showed variation with respect to seismic moment.

Seismic Moment (M_0) - Corner Frequency (f_0)

Corner frequencies obtained from the spectra are listed in Table 3. Plots of log seismic moment relative to log corner frequency, Fig. 10, clearly show a relation between M_0 and f_0 for both P- and S- wave data. The linear least squares fits to these data are:

$$\log M_o (P) = (13.93 \pm 0.67) - (1.27 \pm 1.9) \log f_o (P)$$

$$\log M_o (S) = (11.79 \pm 0.42) + (0.78 \pm 0.80) \log f_o (S)$$

Corner frequency (f_0) – Duration Magnitude (M_D)

The following linear log corner frequency – duration magnitude relations were obtained for both

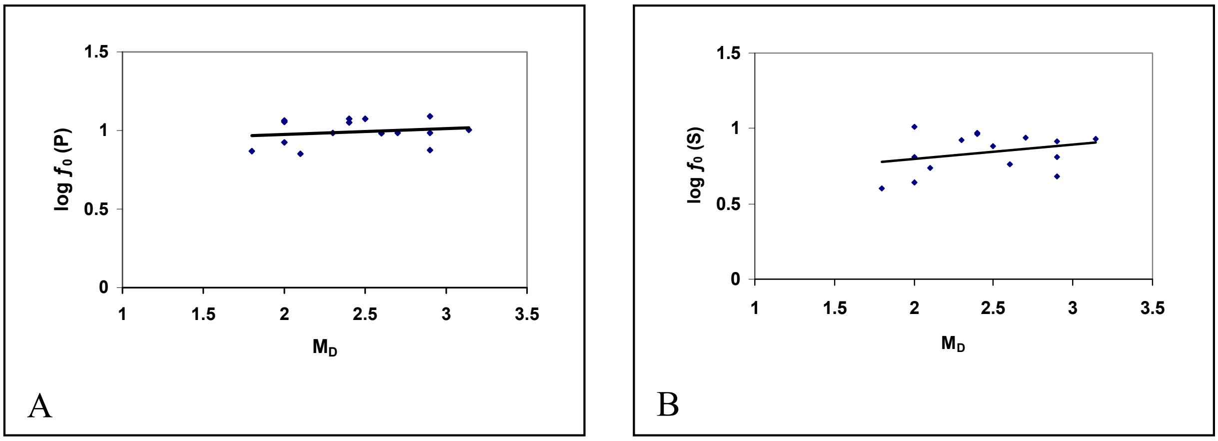

Fig. 11 Plot of corner frequency f_0 as determined from (A) P-waves and (B) S-waves, against duration magnitude M_D.

P- and S- wave using the more reliable corner frequency estimates as shown in Fig. 11.

$$\log f_o(p) = (0.92 \pm 0.08) - (0.027 \pm 0.04) M_D (Aswan)$$

$$\log f_o(s) = (0.60 \pm 0.12) - (0.10 \pm 0.07) M_D (Aswan)$$

CONCLUSIONS

After the occurrence of the famous Aswan earthquake on 14 November 1981 (M_D 5.3) in Kalabsha area, a telemetered network was installed to monitor the seismic activity around the northern part of Aswan reservoir. The continuous operation of this network allowed in categorizing the seismicity pattern into five seismic zones.

Amplitude spectra of seismic P- and S- waves allow us to compute additional physically defined parameters, such as the seismic moment M_0, source dimension r and stress drop $\Delta\sigma$. Estimates of these source parameters was obtained using Brune (1970, 1971) model. The spectral analysis technique was completed using the MAG software program.

The results obtained from these analyses can be concluded as follows:

- Values of the seismic moment M_0 ranged from 4.97×10^{11} to 1.11×10^{14} dyne/cm.
- Values of the source radius r varied from 91.4 to 312 m.
- Values of the stress drop $\Delta\sigma$ ranged from 0.57 to 74.55 bar.
- Seismic energy E values ranged from 8.78×10^4 to 6.41×10^7 J.
- The corner frequency from P-wave f_0 (p) ranged from 7.1 to11.9 Hz.
- The corner frequency from S-wave f_0 (s) are in the range of 4.0 to10.2 Hz.

The scaling relations between the different parameters were made and the empirical relations were obtained. These relations can be used for Kalabsha microearthqukes without need to run the spectral analysis programs.

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