USING GROUND TRUTH EXPLOSIONS FOR STUDYING SEISMIC ENERGY GENERATION AND PARTITIONING INTO VARIOUS REGIONAL PHASES

Yefim Gitterman, Vladimir Pinsky, and Abraham Hofstetter

Geophysical Institute of Israel

Sponsored by Air Force Research Laboratory

Contract F19628-03-C-0124

ABSTRACT

During the first year of the project numerous data were collected to study empirical features of seismic energy generation (especially for S waves from explosions) for different seismic sources; and how this energy is partitioned between P, S, and surface waves, in specific geological conditions and tectonic settings of the Middle East. The sources include experimental land and underwater explosions, military detonations, and routine quarry blasts, for which Ground Truth information (GT0) and blast design parameters were collected. Some earthquakes were included in the database, for comparative waveform analysis.

We analyzed quantification of the source coupling for contained (with different scaled depth), single-fired, chemical experimental explosions observed at regional stations. An extensive dataset was collected from selected seismic events recorded by national network short-period, and International Monitoring System (IMS) broadband stations in Israel (EIL, MMAI) and Jordan (ASF), providing different characters of S-waves at regional distances up to 390 km. Based on the charge-weight explosion series conducted in Sayarim Valley (June 2004), similar power law scaling parameters for charge weight were determined for the amplitude of each of the dominant regional phases: P (0.93), S (0.87) and Rg (0.93).

A series of experimental shots of 0.5, 2, and 20 tons ANFO, and 0.5 ton TNT, in large diameter boreholes was conducted at the basalt quarry Beit-Alpha in Northern Israel in June 2005. The shots provided data for the yield-dependent analysis of regional waveforms, similar to the Sayarim experiment (June 2004), but in a different geological environment. The seismic effect of different explosives (ANFO and TNT) was also examined for close and remote stations.

Data collected for simultaneous ground truth explosions were used for analysis of the magnitude dependence on charge weight. The relation for underwater explosions was validated, and the equation for land shots was modified with a scaling factor similar to the magnitude upper limit for sources of known yield in hard rocks.

We started to evaluate and analyze S/P maximum amplitude and energy ratios for selected events. Existing Geological Institute of Israel (GII) software for visualization and preliminary processing of accelerograms and seismograms was modified and adapted for the project goals, including SEISPECT (analysis of spectra and spectral ratios), and AIST (waveform analysis of different data formats). Appropriate software for S/P amplitude and energy ratio estimation was developed. We estimated and analyzed S/P maximum amplitude and energy ratios for selected events in different time and frequency bands (0.5-3, 3-6 and 6-9 Hz), against distance and charge weight (averaged over recorded stations). The results demonstrate clear dependencies of the S/P ratios on distance and yield. The S/P maximum amplitude ratio calculated in different spectral bands shows a potential for identification of explosion seismic sources.

OBJECTIVES

The main objectives of the project are: 1) conduct of experimental single-fired explosions of special design; 2) determination and verification of empirical source scaling relationships estimating the dependence of seismic wave parameters on different source features; 3) quantifying coupling and specific seismic source features, including energy generation and partitioning into various regional phases.

RESEARCH ACCOMPLISHED

Collection of data and Ground Truth information.

During the first year of the project an initial dataset was collected to study empirical features of seismic energy generation (especially for S waves from explosions) for different seismic sources; and how this energy is partitioned between P and S waves, in specific geological conditions and tectonic settings of the Middle East. The sources include experimental explosions (mostly in single boreholes), strong routine quarry blasts and a military detonation, where GT0 and blast design parameters were collected.

Sayarim charge weight series. A series of three experimental explosions (S1-S3) of variable charge (ANFO explosives) was conducted in the Sayarim Valley near Eilat, Israel (Figure 1, Table 1). The largest single-fired shot of 32.5 tons, in 11 large-diameter (60-70 cm) boreholes of ~20 m depth, was designed as a large-scale land calibration explosion for a MERC project aimed at improving regional velocity models for calculating regional travel times and calibration of an IMS station (MMAI at Mt. Meron). Two smaller explosions of 0.3 ton and 2 tons were conducted at the same site, in single boreholes of the same depth and diameter, thus providing (together with the calibration shot) a series for the yield-dependent analysis of regional waveforms. The large hole diameter resulted in smaller linear charge size (approaching near-spherical form) and in more explosive concentration for the largest shot. Geologically the area is a graben filled by Quaternary alluvial conglomerates, underlain by consolidated rocks. Clear signals were observed for the largest shot at MMAI (r~350 km).

For comparison of data obtained with other observations, ANFO charges were converted to TNT equivalent (Table 1). We also calculated the scaled (burial) depth, characterizing seismic energy generation and surface effects (Table 1): $\hat{h}\ (m/kg^{1/3}) = H(m)/(W, kg)^{1/3} = 0.01H(m)/(W, kT)^{1/3}$ where H=depth, W=charge weight in kg or kT.

Mehola and MERC experimental shots. A number of experimental explosions were conducted in October 2004 (Figure 1). Two shots in single holes of large diameter (80 cm) and various depth (Mehola experiment, shots M1A, M1B, Table 1) were conducted. Explosion M1A produced anomalously small amplitudes relative to M1B, which was of similar charge but placed in a hole full of water and using a large (250 kg) TNT booster. Field observations, video and close-in records from M1A suggest that the explosives did not completely detonate, resulting

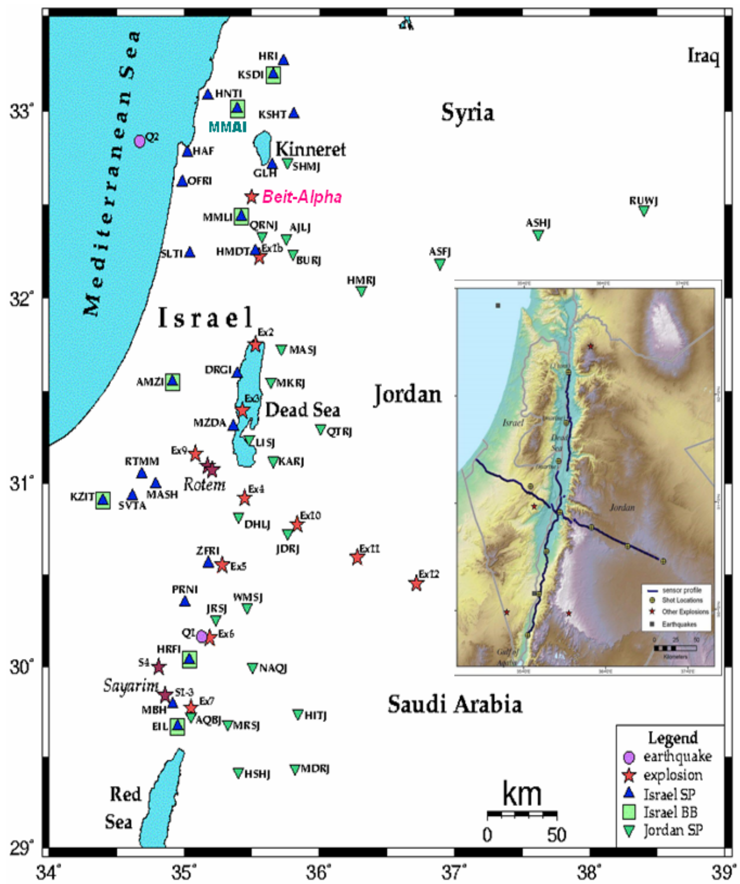

Figure 1. Location of selected seismic events and observed seismic stations (on the insertion - two profiles of ~800 IRIS SP sensors deployed in October 2004).

in reduced seismic signals (see below).

Other explosions were carried out in a MERC project (ten Brink et al., 2004): two underwater shots in the Dead Sea, and land detonations in single holes, in dry or water-saturated media, in different geological and tectonic settings in Israel and Jordan on both sides of the Dead Sea Fault zone. IRIS blast boxes provided detonations at pre-determined times. Ground Truth (GT0) information was collected for all the explosions, with broad variety of blast design parameters, charge geometry, geological settings, and shot media (Gitterman et al., 2005).

Beit-Alpha experiment. GII recently conducted (June 6, 2005) a series of experimental explosions at Beit-Alpha basalt quarry, Lower Galilee (Figure 1, Table 1), in boreholes of large diameter (0.5-0.55 m) at depth of ~15 m, drilled in the cover basalt flow, weathered and cracked in the subsurface layer. The largest shot Bα4 of 20 tons, designed as a large-scale land calibration explosion, was executed as a MERC project, complementary to the Southern Sayarim shot S3 of 32.5 tons of similar design. The local magnitude was M_L~2.6; clear signals were observed at BB EIL (322 km).Three smaller shots of 0.5 ton ANFO, 0.5 ton TNT and 2 tons ANFO in boreholes of the same design, together with the large explosion, provided a series for yield-dependent analysis of regional waveforms, similar to the Sayarim experiment, but in a different geological environment. The two 0.5 ton shots were fully contained, whereas the two larger shots were poorly contained, resulting in reduced magnitudes. Preliminary analysis shows a small (~4-5%) increase in signal vector amplitude and energy for the TNT shot comparing to the ANFO shot (at BB station MMLI, r~13 km), less than expected.

Table 1. Parameters of experimental shots conducted in the project and large quarry/military blasts collected.

Ex. No.	Date	Lat. Lon.	Origin Time, GMT	M_L	ANFO charge, kg	TNT equiv., kg	Hole depth, m	Scaled depth, $m/kg^{1/3}$	No. of holes	Comments
S1	13.06.04	29.84334 34.85866	12:20:01.192	-	300	262	20	3.05	1	fully contained, no crater
S2	15.06.04	29.84244 34.85860	11:49:39.349	2	2000	1635	20	1.40	1	partially contained, crater R~13-14m)
S3		29.84188 34.85851	13:00:01.493	3	32500 (single ~3000)	26860 (2442)	17-20.5	1.11	11	poorly contained, non-symm. craters
M1A	20.10.04	32.22269 35.55644	11:15:00.0	-	3000(?) henamit	-	25	1.5	1	partially detonated, fully contained
M1B			12:15:00.0	2.4	3000 henamit	-	35	2.2	1	water-filled hole, fully contained
Bα1	06.06.05	32.54499 35.46868	10:05:01.422	1.5	500	-	14.7	1.5	1	fully contained
Bα2		32.54506 35.46850	10:30:01.604	1.5	-	500	16	1.7	1	
Bα3		32.54522 35.46883	11:00:01.330	1.4	2000 (1000)	-	14.7-15.5	1.0-1.1	2	poorly contained
Bα4		32.54549 35.46914	12:00:01.532	2.6	20000 (1000)	-	14-16	1.0-1.2	20	
R1	25.04.04	31.093 35.173*	9:15:18.5*	2.7	13278	-	3-7	~1-1.5	211	ripple-fired blasts at Rotem quarry
R2	22.07.04	31.072 35.207*	9:54:46.9*	2.9	~15000	-	-	-	-	
S4	07.06.04	29.991 34.798*	15:06:28.4*	2.5	-	~10000	surface shot in 0.5-1m deep trench at Sayarim range			

* estimated from records of Israel Seismic Network (ISN)

All the experimental explosions were observed at the dense network of SP and BB stations in Israel, including IMS and CNF stations. For some strong events records and phase data from Jordan and Lebanon were collected.

Large controlled land blasts and selected earthquakes. We also collected GT information and records for three large land quarry/military blasts conducted in 2004 (Table 1). Specific feature of these sources is the unusually high seismic energy released, shown by high local magnitude M_L values estimated from ISN observations. The Rotem quarry blast R2 of 15 tons (ANFO) in several dozen holes with many delays produced a seismic event with magnitude 2.9, very close in magnitude to Sayarim shot S3 of 32.5 ton in 11 holes (located ~120 km to the South), that yielded magnitude ~3.0. Likewise, the military shot S4 of ~10 ton of TNT, intended to destroy out-dated ammunition, in a trench open to the air, produced a significant magnitude of 2.5, and clear seismic signals are observed up to 160 km, along with very strong acoustic waves. Some earthquakes, recorded in the same period and co-located with the explosion sources, were included in the project database for comparative waveform analysis (see Figure 1).

Near-source observations.

An extensive dataset of high-quality records was acquired from ETNA accelerometers, installed mainly at 0.1-0.5 km from the explosions, and portable short-period 3C seismic stations deployed at a distance range of 1-15 km.

Seismic source complexity for the Sayarim explosion S3 conducted in 11 boreholes was observed at the closest accelerometer. Two wave groups separated by ~0.2 sec were found on all three components (Figure 2); the first group is like the signal from single-hole shot S2. The accelerogram is similar to near-field strong-motion data from the Lyaur explosions with delayed detonations in multiple rows (Negmatullaev et al., 1999). All borehole charges were detonated simultaneously, but due to the hole spacing, the distance difference from the closest and remotest charges to station ACC3 was ~60-70 m, and the time shift could reach ~0.2 sec (assuming S-wave velocity ~300-350 m/s).

We estimated attenuation of Peak Ground Acceleration (PGA) with distance for the vertical component and the vector. The PGA data are fit with the power relation: $\mathbf{PGA_{(cm/s/s)} = a*r_{(m)}^{-b}}$. Similar attenuation factors $\boldsymbol{b_i}$ were obtained for all three Sayarim explosions (Figure 2), therefore we applied an average fixed value $\boldsymbol{b}$=1.74 to estimate the scale coefficients $\boldsymbol{a_i}$, used for estimation of the yield W scaling relation: $\mathbf{PGA \sim W^{0.58}}$.

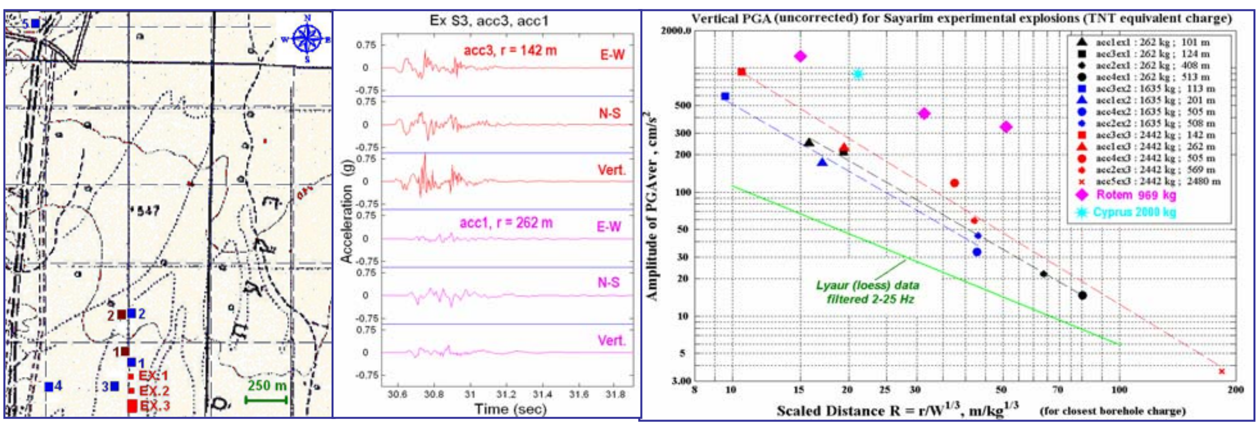

Figure 2. Location of Sayarim shots and accelerometers (left), sample records of the two closest ETNA (center) and data analysis (right): attenuation of vertical peak accelerations vs scaled distance for different shots and geological settings. For two multiple-hole shots (S3 and Rotem 25ton) we used single-hole charge.

Using the scaled distance $R=r/W^{1/3}$ (instead of distance r,m) reduced but did not remove the offset of the three attenuation lines. The discrepancy is caused by different scaled depths and the large total charge for S3. The amplitudes of the 3 Sayarim shots (in dry alluvium/conglomerates) are higher than values for blasts in loess (Negmatullaev et al., 1999), and lower than for shots in consolidated sediments (Rotem) and hard rock (Cyprus) (Gitterman et al., 2004).

Near-source seismic data were used to investigate the characteristics of the anomalous single-fired shot M1A, that produced small amplitudes (as mentioned above, Table1), and to estimate a detonated charge equivalent, similar to the case of two partially detonating blasts in the Wyoming experiment (Stump et al., 2003). Spectral ratios for the pair (M1A and fully detonated M1B) were calculated using data from the portable short-period 3C seismic station #1 in the near-source area (r=3 km) (Figure 3).

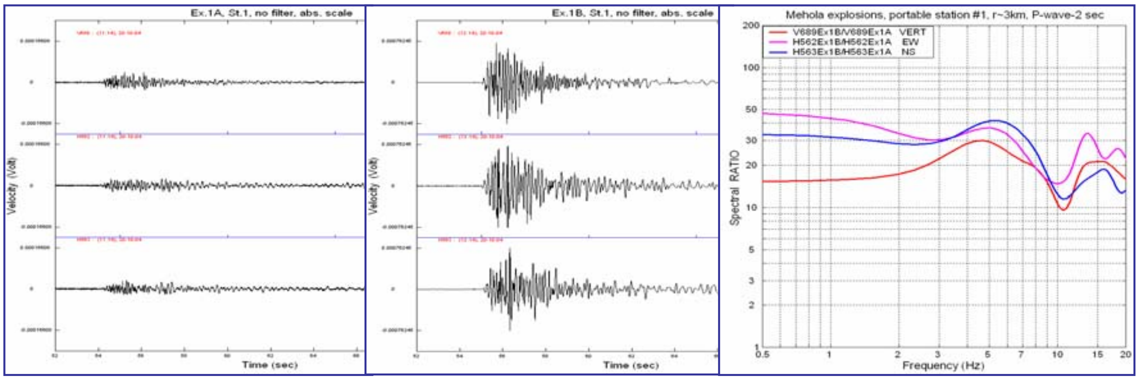

Figure 3. Seismograms and spectral ratios of P-waves for the two Mehola shots at portable 3C seismic station #1 (EW - about transverse) (analyzed by SEISPECT software).

The roughly flat ratio in the low-frequency range suggests that the explosion M1A was reduced by a factor of ~20, resulting in a detonated charge equivalent W~150 kg. An observed decrease of the spectral ratios at ~7-8 Hz can be related to the estimated corner frequency for the strong shot M1B of 3 tons, close to the value f_c~9 Hz from an empirical corner frequency-yield relation for single-fired contained explosions (Gitterman et al., 2004):

$$f_c = 266*W^{-0.4161}$$

S-wave character at close and remote stations.

Different detonation features and a water component in one of the boreholes may have caused different S-wave character for the Mehola explosions (Figure 4), rather than different borehole depth: S-wave amplitudes for the weak M1A are comparable with the P-waves, whereas for the strong M1B shot the S-wave is negligible. We note that S-waves are more pronounced on velocigrams than on accelerograms (Figure 5). Preliminary estimates from strong-motion data (Figure 5) showed velocities of ~1380 m/s for P-waves, and ~300 m/s for S-waves, corresponding satisfactorily to the geology of the area, Quaternary alluvium deposits.

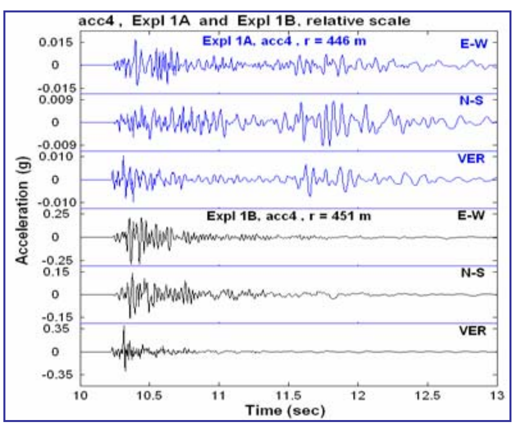

Figure 4. Different S-wave character for the two Mehola explosions recorded at ~450 m (relative scale).

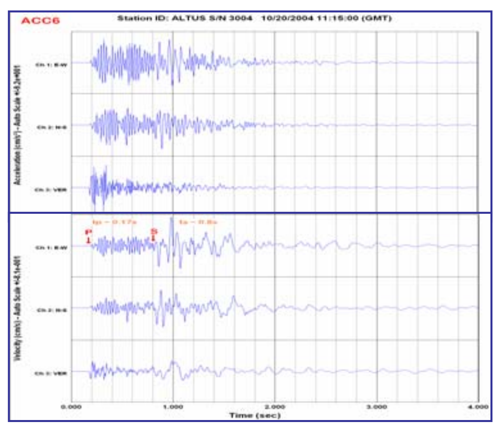

Figure 5. Velocity transform (bottom) of acceleration at ACC6 (top) emphasizes the S-wave for shot M1A (distance 235 m).

Distinctive S-waveforms and S/P amplitude ratios were observed at vertical network SP stations from two experimental explosions of similar design (1 ton in a single hole) in Jordan (Ex.7) and Israel (Ex.9) conducted in the MERC project, in October 2004 (see Figure 6). The Jordanian shot produced strong dominant amplitude P-waves and significant surface wave energy (at some close stations), but a clear S-phase was not observed. The Israeli explosion showed considerable S-waves and S-coda amplitudes and energy, and unexpectedly weak P-waves. The difference between the Jordan and Israel explosion recordings may be related to different geological settings in the near-source area, and location in diverse tectonic units separated by the Dead Sea Transform zone, where the shots were located (Figure 1), as well as different features of the explosion design.

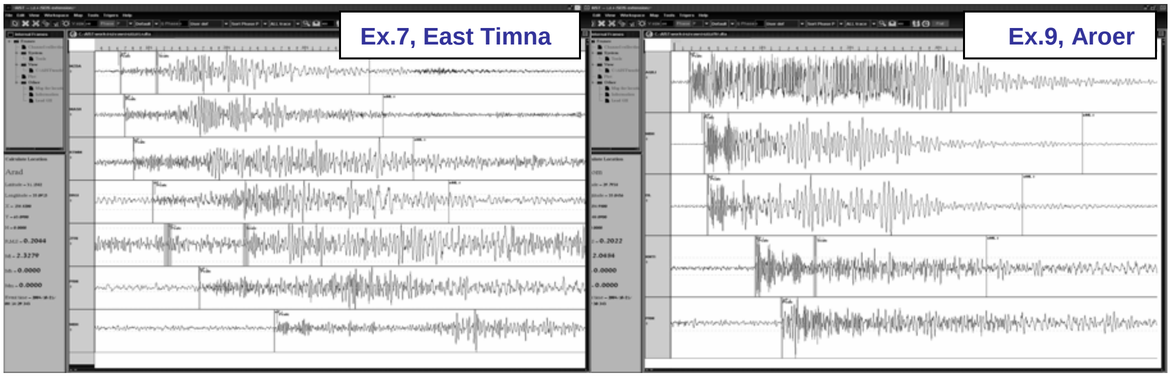

Figure 6. Sample of distinct S-waves for two explosions of similar design (charge 1 ton in a single hole), observed at ISN stations (analyzed by AIST software).

<u>Peak Amplitude scaling.</u>

All three experimental explosions of the Sayarim charge-weight series were well recorded at IMS BB station EIL (r~20 km), providing data for source-scaling analysis. Inspection of the waveforms observed on the 3C record (Figure 7) allows identification of regional phases P, S and Rg (surface waves).

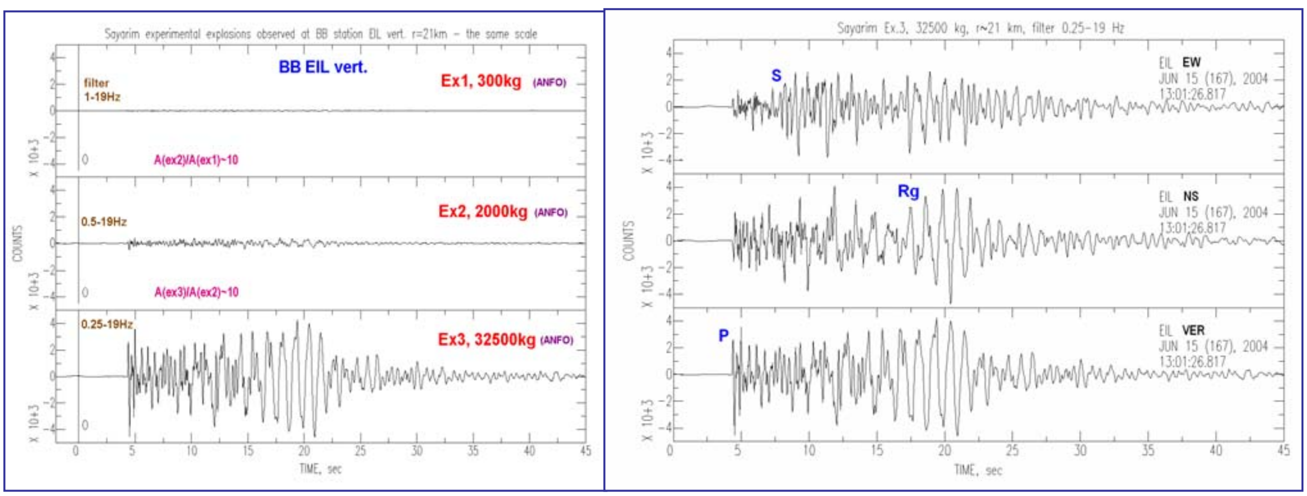

Figure 7. Vertical record of the Sayarim series at EIL (absolute scale, left) and 3C record of shot S3 (right).

Vertical Peak Amplitudes (VPA, micron/sec) were measured for each of the phases and plotted against charge weight for shots S1-S3 (Figure 8). TNT equivalent charges were used (Table 1) and for the multiple-hole explosion S3 the total charge was taken.

The data for each phase are fit with the power law equation:

$$VPA_{(mic/sec)} = A*W_{(kg)}^{B} \quad (1)$$

An r.m.s. procedure provided estimates of ***A*** and ***B*** for each of phases P, S and Rg (see Figure 8): similar power law scaling parameters were determined for each of the dominant regional phases.

Power law fits to each phase demonstrate little difference between the source yield scaling parameter ***B*** for the different phases P (0.93), S (0.87) and Rg (0.93). The ***B***-values obtained are in close agreement with the scaling parameter of Vergino and Mensing (1983) for Pn waves from nuclear explosions in Nevada, and Stump et al. (2003)

for Pn, Pg, and Lg regional phases (0.84-0.91) from chemical explosions in Wyoming. The ***A*** value depends on distance and site conditions and for station EIL is comparable for all three phases, similar to estimations of Stump et al. (2003) for Pg and Lg phases.

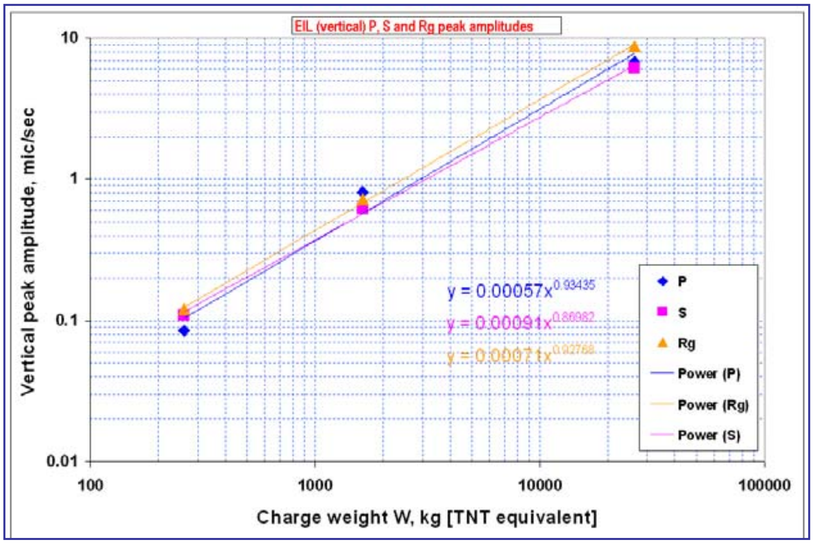

Figure 8. Peak vertical amplitude source scaling for different wave phases at local distances (EIL at ~21 km).

Magnitude scaling.

We used Ground Truth data of simultaneous explosions conducted for the project (Table 1) for analysis of magnitude dependence on charge weight. Some other experimental land and underwater shots conducted previously by GII in DSWA/DTRA projects (Gitterman et al., 2002, 2003) and in the MERC project in October 2004 were also included. The analysis results are shown in Figure 9, where the observation values and different curves fit for simultaneous shots are presented for comparison. Three of the curves were developed earlier for different types of explosive seismic sources:

a) Under-Water Explosions (UWE) includes calibration and experimental shots in the Dead Sea conducted by GII (Gitterman, 1998): M = 0.285 + log10 (W, kg). Two recent experimental shots in the Dead Sea (October 2004), correspond well to previous data and the fit curve (1).

b) Upper limit of magnitude for known yield sources in hard rocks (Khalturin, 1998): M=2.45+0.73*log10(W, ton). All values for the land explosions are below the curve (2).

c) Single-fired commercial blasts at Israel quarries, including a limited dataset (Gitterman, 1998): M = -1.42 + 0.99*log10(W, kg). New data for experimental simultaneous land explosions demonstrate a slightly different curve (3), therefore we developed a new equation fitting the observed data:

M = -0.2937 + 0.7327*log10 (W, kg) (4)

Note, the estimated scaling parameter (the curve slope) 0.7327 is very similar to the upper limit curve (2).

Analysis of the results leads to the following conclusions:

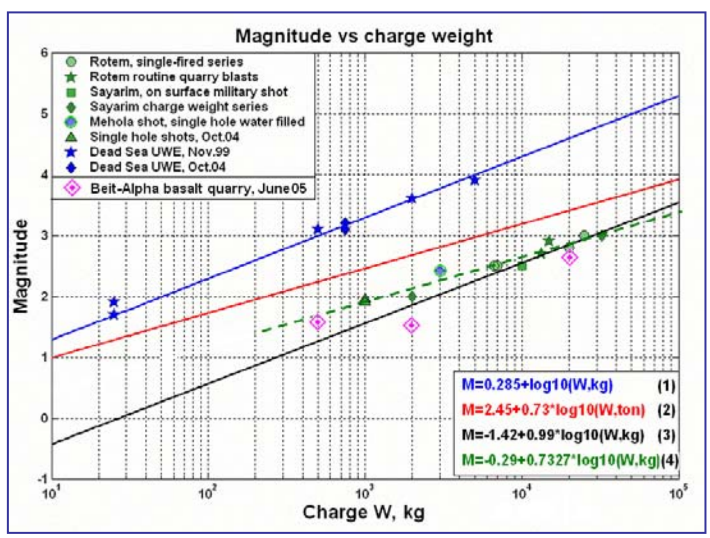

Figure 9. Magnitude vs charge for collected single-fired explosions and quarry blasts in Israel and Jordan

1) Comparison of local magnitude values for Sayarim explosions (June 2004) with the Rotem series data (Gitterman et al., 2002) conducted in consolidated rocks (caolin) with a special design of concentrated near-spherical charges does not show any significant magnitude difference. As shown from regional observations, significant seismic strength was achieved (M_L~2 for S2 and M_L~3 for S3) in spite of the non-consolidated media, dry alluvium, commonly considered low-coupling material (e.g. US Congress, 1988), and shallow burial depth that caused poorly contained explosions (scaled depth 1.1-1.4 m/kg$^{1/3}$).

2) Three large land quarry/military blasts conducted in 2004 (see Table 1) showed unusually large seismic energy release, shown by high local magnitude M_L values estimated from Israel network observations. The Rotem quarry blast R2 of 15 ton ANFO in several dozen holes with delays produced a seismic event with magnitude 2.9, very close to the energy produced by the Sayarim large experimental simultaneous explosion of 32.5 ton ANFO in 11 holes (located ~120 km to the South) that yielded magnitude ~3.0.

3) Likewise, the military explosion of ~10 ton of TNT, intended to destroy out-dated ammunition, in a trench and open to the air, produced a significant magnitude 2.5, and clear seismic signals are observed up to 160 km, along with very strong acoustic waves.

4) The Dead Sea underwater shots in October 2004 with charges of 750 kg of TNT at 50 m agree well with the previously developed curve (1) for UWE with less-energetic explosives "Henamon" at a larger depth of 70 m.

5) The Beit-Alpha explosions were conducted after the new magnitude-charge curve (4) was developed. An anomalously low seismic effect for the 2-ton shot Bα3 is seen, evidently resulting from poor containment observed clearly on the video-record, due to locally fractured basalt rocks. Three other shots fit curve (4).

Software development.

To evaluate and analyze S/P maximum amplitude and energy ratios for selected events, existing GII software for visualization and preliminary processing of accelerograms and seismograms was modified and adapted for the project goals, including SEISPECT (analysis of spectra and spectral ratios), and AIST (waveform analysis of different data formats). Software application samples are shown in Figures 3 and 6. Appropriate programs for S/P amplitude and energy ratio estimation were also developed (see below).

S/P maximum amplitude ratios in different frequency bands.

Different amplitude and spectral ratios for different wave phases are used for discrimination purposes (see e.g., review of Blandford, 1995, and more recent research of Walter et al., 2004). We analyzed the S/P maximum amplitude ratio in different frequency bands, using software (Kurpan, 2004) based on SEISPECT program. As a case study we used four explosions in the Sayarim area. Seismograms at Israel Seismic Network (ISN) vertical stations were filtered in three spectral bands: 0.5-3 Hz (low filter), 3-6 Hz (medium filter) and 6-9 Hz (high filter), and maximum amplitudes were measured in windows 3-5 sec after the P and S arrivals. A wide band filter (0.5-12 Hz) including the whole recording frequency range is also used in the analysis.

The S/P maximum amplitude ratios obtained for different ISN stations, presented in Figure 10, do not show a clear dependence on distance and frequency band. If the ratio values for a fixed shot are averaged over the stations, then two tendencies can be observed: a decrease with charge (especially for the low and medium filters) and higher ratios for the lower frequency band (Figure 11). Note that the explosion S4 of 10 tons TNT on surface is consistent with three other borehole ANFO shots located in the same area.

The S/P parameter shows a potential for identification of explosion seismic sources and discrimination between earthquakes and explosions, and will be tested on other explosions and earthquakes.

Estimating energy partitioning for observed phases.

A number of programs and scripts were developed to calculate seismic energy of different regional phases observed on seismograms As a case study we used the large (32.5 tons) explosion S3 (Table 1) and applied the processing procedure. As a first effort we analyzed signals in a broad frequency range, with a filter applied to the records.

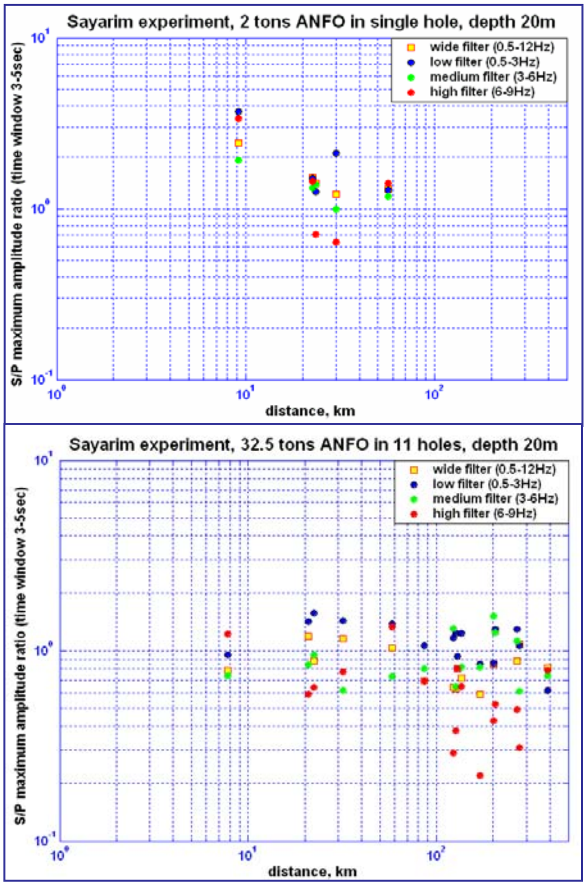

Figure 10. S/P maximum amplitude ratios vs distance for observations at different SP ISN stations from single-fired explosions S2 (up) and S3 (down) in Sayarim area.

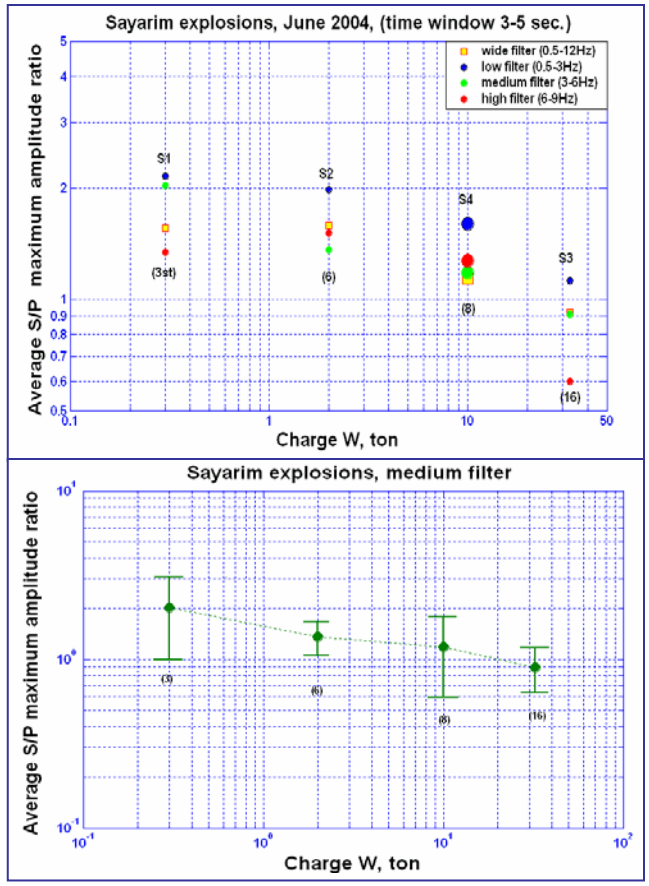

Figure 11. S/P maximum amplitude ratios vs charge averaged for different ISN stations for Sayarim explosions (up); mean and standard deviation estimations for the medium filter (3-6Hz) (down). Number of processing stations (in) is also shown.

Considering the recording range for ISN short-period stations, and observed frequencies for local distances and magnitudes, we can say that seismic energy was calculated for unfiltered signals. The analysis was focused on four portions of the signal: 1) All the signal – 60 seconds from the P phase start; 2) P-waves – 2 seconds after the P arrival; 3) S-waves – 2 seconds after the S arrival; 4) surface waves – starting 2.5 sec after the S-arrival to twice the S-arrival lapse time. The P and S first arrival times are computed from the local 1D velocity model.

The seismic waveform energy was computed as sum of squares of amplitudes over the specified time interval for two groups of data separately: 3C network short period and BB stations, and vertical component stations (see the map in Figure 1). For the 3C stations amplitudes are the square root of the sum of the squared component amplitudes. The results of computations for the 6 available 3C stations are presented in the Figures 12 and 13. The stations range from 21 km (EIL) up to 187 km (AMZI). Energy partitioning for the 3C stations is shown in Figure 13 as percent of the total energy computed in the [P arrival, P+60 sec] time intervals (Figure 12). The estimates show that the energy in 3C motion is larger in the S time interval relative to the P time interval and undulates within 10%. The surface waves accommodate most of the signal energy, and increases with distance.

Energy of P waves on vertical channels is dominant over S wave energy. Surface waves annex almost all the seismic energy of the signal at larger distances. The stations used in the analysis range from 8 to 388 km.

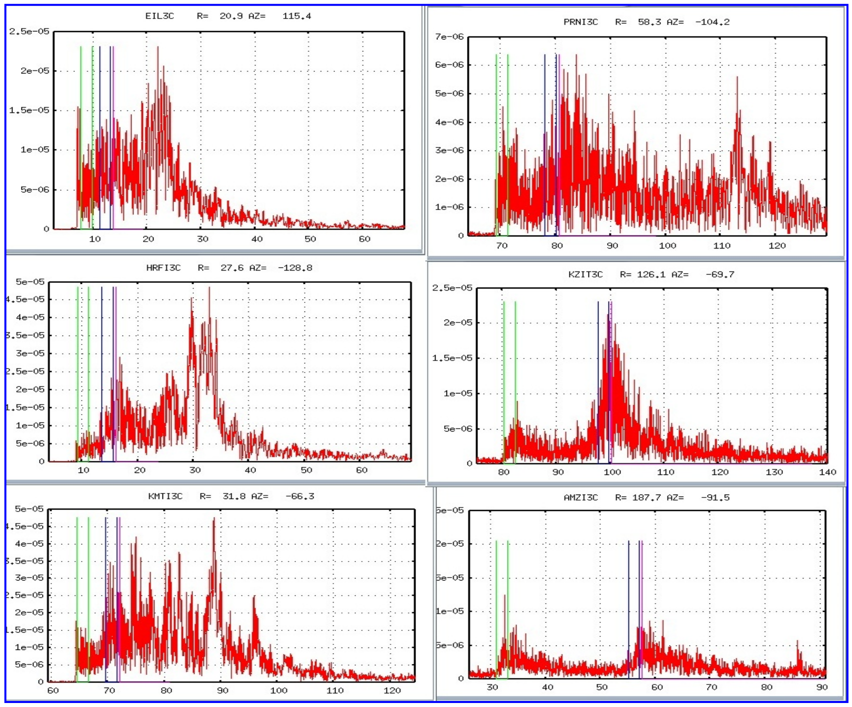

Figure 12. Amplitudes (m/sec) versus time (sec) for six 3C stations (3 BB and 3 SP stations) (shot S3). Vertical lines mark time intervals for energy computation.

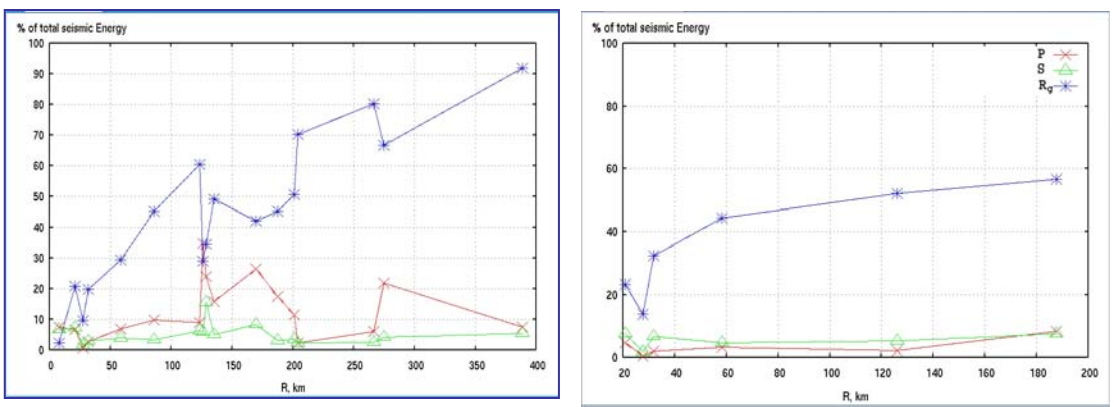

Figure 13. Energy partitioning between P, S and Rg (surface waves) versus distance from the largest Sayarim explosion S3 for sixteen vertical stations (left) and six 3C stations (right)

CONCLUSIONS AND RECOMMENDATIONS

A project event database was created to study empirical features of seismic energy generation and partitioning between P and S waves. Selected explosions present a broad variety of design features, charge weight, burial depth, source rocks and geological settings.

A number of experimental single-fired explosions were conducted and numerous 3C and vertical observations were acquired beginning from the near-source zone at ~0.1 km (by accelerometers) to near-regional distances ~390 km (by seismic stations of local networks in Israel and Jordan).

GT parameters and local seismic stations records were collected for several large controlled quarry and military blasts. The events were recorded by SP and BB instruments, and seismic arrays, including IMS stations. Preliminary analysis showed a diversity of regional phases P, S, and Rg.

To fulfill project goals existing software was modified and new programs and scripts were developed. As a case study analysis the computer procedures were applied to the Sayarim experimental explosion series of variable charge weight. Preliminary results show definite tendencies in dependency of S/P maximum amplitude and energy ratios on distance and yield. The S/P ratios in different frequency bands, averaged over network stations, show a potential for identification of explosion seismic sources and discrimination between earthquakes and explosions. Source scaling estimations based on BB records at local distances of the same series show similar yield scaling parameters (0.87-0.93) for different regional phases. The power law parameter values are in close agreement with the constants for nuclear explosions in Nevada and chemical explosions in Wyoming.

Application of the spectral ratio procedure to data collected from some experimental explosions provided estimates of the corner frequency-charge weight relation, and the equivalent yield of a partially detonated explosion.

The analysis will be continued for other events from the dataset and new planned experimental shots to validate the results obtained.

REFERENCES

Blandford, R.R. (1995), Regional seismic event discrimination, in: E.S. Husebye and A.M. Dainty (Eds.), *Comprehensive Test Ban Treaty, NATO ASI Series, Series E: Applied Sciences* - Vol. 303, 689-719.

Gitterman, Y. (1998), Magnitude-yield correlation and amplitude attenuation of chemical explosions in the Middle East, *Proceedings of the 20th Annual Seismic Research Symposium on Monitoring a CTBT,* Vol. 1, pp. 302-311.

Gitterman, Y., V. Pinsky, A. Shapira, M. Ergin, D. Kalafat, G. Gurbuz, and K.Solomi (2002), Improvement in detection, location and identification of small events through joint data analysis by seismic stations in the Middle East/Eastern Mediterranean region, in *Proceedings of the 24th Seismic Research Review—Nuclear Explosion Monitoring: Innovation and Integration*, LA-UR-02-5048, Vol. 1, pp. 271-283.

Gitterman, Y., V. Pinsky, A. Shapira (2003), Improvements in Monitoring the CTBT in the Middle East by the Israel Seismic Network, Final Report, Rep. DTRA-TR-01-35, October 2003, 196 pp.

Gitterman, Y., V. Pinsky, K. Solomi, R. Hofstetter, C. Gurbuz, and M. Ergin (2004), Using ground truth events for travel time calibration and studying seismic energy generation and partitioning into various regional phases, in *Proceedings of the 26th Seismic Research Review*, *Trends in Nuclear Explosion Monitoring,* LA-UR-04-5801, Vol. 1, pp. 61-72.

Gitterman, Y. and V. Pinsky (2005), Seismic energy generation and partitioning into various regional phases from different seismic sources in the Middle East region, *Annual Report No.1, GII Report No. 542/123/05(2).*

Kurpan J. (2004), Discrimination of seismic events in Israel recorded by national seismic network, M. Sc. Thesis, *Tel-Aviv University*, supervisors Prof. Z. Ben-Avraham and Dr. Y.Gitterman.

Negmatullaev S.Kh., M.I. Todorovska, M.D. Trifunac (1999), Simulation of strong earthquake motion by explosions – experiments at the Lyaur testing range in Tajikistan. *Soil Dynamics and Earthquake Engineering* 18 (1999), 189–207.

Stump, B., D.C. Pearson and V. Hsu (2003), Source scaling of contained chemical explosions as constrained by regional seismograms, *Bull. Seism. Soc. Am*. 93: 1212-1225.

ten-Brink, U., Al-Zoubi, A., Rybakov, M. and Rotstein Y. (2004), Integrated geophysical study of the Dead Sea rift for hazard assessment and mineral resources. MERC program of U.S. AID, Grant No. TA-MOU-01-M21-012.

U.S. Congress (1988), Office of Technology Assessment, Seismic Verification of Nuclear Testing Treaties, OTA-ISC-361 (Washington, DC: U.S. Government Printing Office, Chapter 6, May 1988).

Vergino, E.S., and R.W. Mensing (1983), Yield estimation using regional m_bP_n, *Bull.Seism.Soc.Am*. 80: 1200–1206.

Walter, W. R., K. M. Mayeda, A. J. Rodgers, S. R. Taylor, D. A. Dodge, E. Matzel and M. D. Ganzberger (2004), Regional Seismic Identification Research: Processing, Transportability and Source Models, *Proceedings of the 26th Seismic Research Review: Trends in Nuclear Explosion Monitoring* , LA-UR-04-5801, Vol. 1, pp. 513-523.