IMPROVEMENT IN DETECTION, LOCATION, AND IDENTIFICATION OF SMALL EVENTS THROUGH JOINT DATA ANALYSIS BY SEISMIC STATIONS IN THE MIDDLE EAST/EASTERN MEDITERRANEAN REGION

Yefim Gitterman,[1] Vladimir Pinsky,[1] Avi Shapira,[1] Mehmet Ergin,[2]
Dogan Kalafat,[3] G. Gurbuz,[3] Kyriakos Solomi[4]

Geophysical Institute of Israel (GII);[1] TUBITAK Marmara Research Center,
Earth and Marine Sciences Research Institute, Turkey;[2] Bogazici University,
Kandilli Observatory and Earthquake Research Institute, Istanbul, Turkey;[3]
Geological Survey Department of Cyprus[4]

Sponsored by Defense Threat Reduction Agency

Contract No. DTRA01-00-C-0119

ABSTRACT

The joint project of Israel, Cyprus, and Turkey is devoted to the collection of the Ground Truth (GT) data for calibration of the regional International Monitor ting System (IMS) stations, characterization of the national regional networks, and development of the data-processing software. During the second year of the project activity, we have extended the GT database and checked (by a relocation experiment) 70 collected calibration GT events in the East Mediterranean region. These included 19 explosions within the footprint of the ISN (13 GT0 explosions and six GT2 quarry blasts), and 51 GT5 earthquakes from Israel, Cyprus, and three seismic provinces - Izmit, Duzce and Adana - in Turkey.

For each of the calibration events, a computational relocation experiment was performed to make a quality tuning of the obtained source parameter estimates: coordinates (X, Y, Z) and origin time T0, and ensure that these estimates are reliable and accurate enough. For this experiment we have elaborated special software "RELOC," including the "SEIS" hypocenter search program, and new codes for estimation of the 90% hypocenter error ellipsoid. For EIL, MRNI and BRAR IMS stations, station-specific source corrections (SSSC) have been computed using GT coordinates and origin times, obtained through the relocation experiment. Most deviations of the observed P, S travel times from the IASPEI91 velocity model for Israel GT events were compensated by application of the local 1-D model. However, the similar attempt on regional scale to explain deviations from the 1-D model by the 3-D model CUB of the Colorado University did not provide the expected improvement.

Errors observed in SSSCs, constructed directly from empirical travel times, can be reduced by using more accurate velocity model. For updating the 1-D velocity models in the GT events, the VELEST joint epicenter solution program was applied in the area of Adana Basin (Cilician network, TUBITAK) and ISN region (GII). The data set contained 244 reliable Adana events and 170 ISN events of ML > 2.5 with good P and S readings. Initial RMS was 0.5 and 0.67 sec for each of the networks respectively and after a number of iterations, new 1-D velocity models have been achieved with RMS value of 0.3 sec for both of the networks.

In order to extend the Middle East GT0 database, GII conducts a series of large (20-25 tons) inland blasts, using the facilities of Israeli quarries. These explosions will provide data complementary to the Dead Sea underwater calibration shots of November 1999. A 25-ton single-fired calibration explosion of special experimental design was conducted at Rotem phosphate quarry in Negev, Southern Israel, on May 21, 2002. It was preceded by smaller trial shots, for estimating safety conditions and seismic efficiency of the large shot. Obtained results confirmed the estimations. The expected magnitude 3.0 was achieved. Records were obtained at numerous permanent and portable short-period (SP) and broadband (BB) seismometers as well as accelerographs, in the distance range 0.3 – 450 km, in Israel, Jordan and Cyprus. Compared to other calibration shots, the Rotem 25-ton blast showed seismic strength similar to the same size Balapan (STS, Kazakhstan) explosion, and 0.5-ton Dead Sea shot. For all controlled quarry blasts, a detailed GTI was collected. The recorded explosions and earthquakes provided data for corrections of regional travel times for regional networks and IMS stations EIL and the new array AS049 at Mt. Meron, verification and improvement of velocity models, attenuation (amplitude-distance) and magnitude-yield relations, characterization of new seismic sources and local mining practices, and multi-station discrimination analysis.

OBJECTIVE

The main objective of the project is to characterize and enhance the Comprehensive Nuclear-Test-Ban Treaty (CTBT) monitoring potential of small events in the eastern Mediterranean area, based on a jointly collected GT0-GT5 database of earthquakes and chemical explosions and on development and implementation of improved signal processing techniques.

RESEARCH ACCOMPLISHED

For this second stage of the project, the main effort was to evaluate travel times from GT sources of the events, jointly collected by the GII (Israel), the KOERI/TUBITAK (Turkey), and the GSDC (Cyprus) and provide direct station-specific source corrections (SSSCs) for the IMS stations EIL, MRNI (Israel) and BRAR (Turkey). For this purpose we needed to relocate and verify GT sources and fulfill quality measurement of arrival times to the IMS stations. Additional GT earthquakes, quarry blasts and calibration explosions were introduced in the database with corresponding assessment of yield magnitude and distance-time relationships. New 1-D velocity models for the area covered by the Israel Seismic Network (ISN) and Cilician network (Turkey) were obtained via application of the VELEST joint hypocenter inversion module.

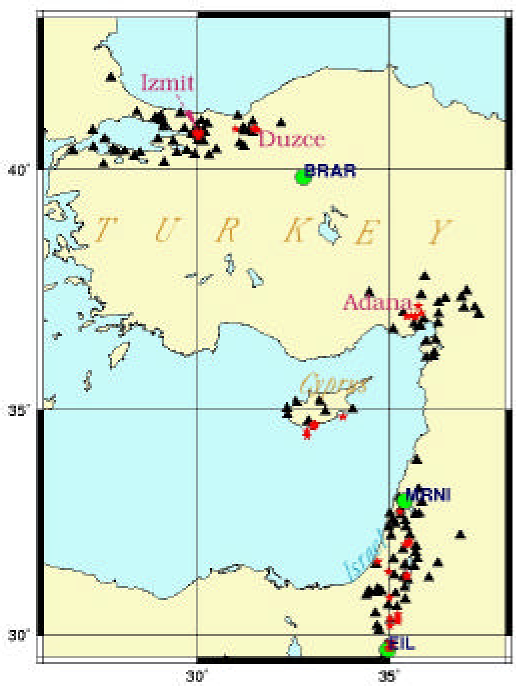


Figure 1. Location of the GT events. and Networks used for the location.

GT events database. The GT database, collected mostly at the project first stage (Shapira et al., 2001), consists of bulletin information and waveforms of around 70 events from five regions (see Fig.1): (1) Israel-Jordan events: GT0 explosions (13), GT2 explosions, GT2-GT5 earthquakes (all these data are recorded by the ISN); (2) Cyprus earthquakes; and three regions of Turkey recently stricken by the destructive earthquakes and the series of strong aftershocks: (3) Adana, (4) Izmit, and (5) Duzce.

Relocation experiment. Each of the selected GT events has been relocated on the basis of the corresponding local 1-D model and P,S readings with optimal weights (RW) (see Table 1), eliminating influence of the outliers and poor signal-to-noise ration (SNR) data. In addition, a computational experiment was completed with each event for verification and quality tuning of the obtained source parameter estimates: coordinates (X,Y,Z) and origin time OT. For this experiment we have designed special software "RELOC," using the "SEIS" hypocenter search program by A. Shapira, and a new hypocenter error estimation program. The program conducts a series of relocation tests, creating for each event a separate bulletin file and finally the characteristic table compiling results of all the relocations (see Table 1): (a)- with different fixed depths (RH), (b) with stations within 100-km radius only (RL); (c) based on P readings only (RP); (d) – relocation, with Gaussian random noise (σ=0.5 sec) added to the P, S readings (RN). The output parameters are: (a) coordinates, time and depth and their deviations dX, dY, dH and dT from the original bulletin, (b) minimum R_{min} and maximum R_{max} station distance from the source, (c) the total number of stations N used in the location procedure and those within 100 km - N100, (d) RMS – standard deviation of observed minus calculated arrival time, the 90% errors for the corresponding eT, eY, eX, eH parameters. In addition to the table we supply each of the experiments with three figures: (a) configuration of the recording network within ±50 km of the epicenter; (b) 90% error epicenter ellipse with major (Lmax) and minor semi-axes (Lmin) and the major axes azimuth (AZ), spotted by the 100 Monte-Carlo test epicenters; (c) the levels of the RMS. The estimated source coordinates and origin time were used for the travel-time calculations and derivation of the SSSCs.

Table 1. Example of relocation experiment.

TYPE	Lat	Long	H km	HH:MM:SEC	RMS sec	dY, km	dX, km	dH km	dT, sec	N, N100	Rmin, Rmax	gap deg	eY km	eX km	eH km	eT, sec
RW	30.399	34.994	9.	15:39:15.40	.2	-0.1	1.2	0.	-0.1	32, 16	5. 325.	79.	0.7	0.8	0.4	0.3
RH	30.404	34.985	12.	15:39:15.00	.2	0.4	0.2	2.	-0.5	32, 16	5. 325.	79.	0.9	1.9	0.9	0.1
RL100	30.403	34.989	8.	15:39:15.40	.2	0.3	0.7	0.	-0.1	19, 16	5. 292.	79.	0.8	1.6	0.5	0.1
RP	30.402	34.990	9.	15:39:15.40	.2	0.2	0.8	0.	-0.1	32, 16	5. 325.	79.	1.0	1.8	0.8	0.4
RN	30.398	35.002	10.	15:39:14.90	.5	-		1.	-0.6	32, 16	5. 325.	79.	2.0	3.9	2.1	0.3

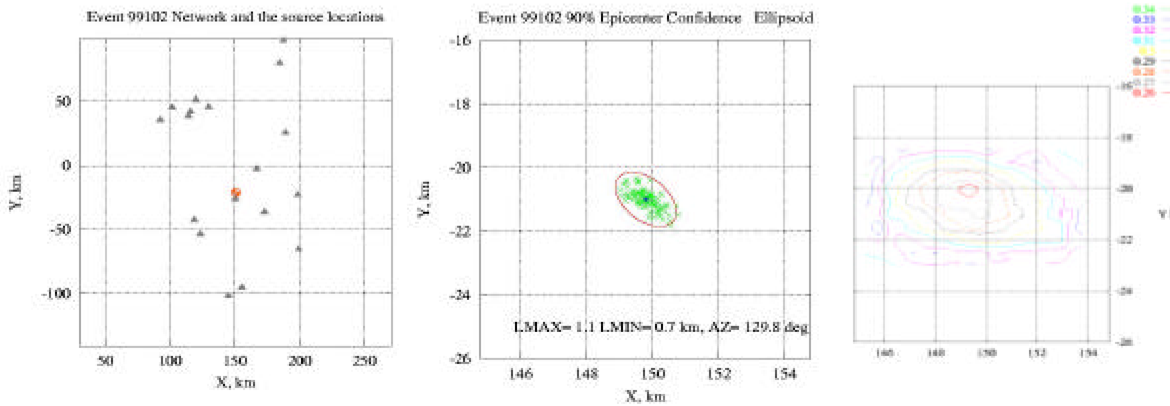


Figure 2. Example of the relocation experiment for the ISN event.(a) station configuration, (b) epicenter 90% error ellipsoid; (c) RMS contour graph.

Travel-time corrections for IMS stations EIL, MRNI relative local GT events. For calculation of the theoretical travel time *Tcalc* ($T_{IASPEI91}$) to the EIL and MRNI stations from Israel GT0, GT2, GT5 events, and earthquakes from Cyprus, we used both standard local T_{GII}, and Earth average $T_{IAPEI91}$ velocity models. In all other cases for calculation of the theoretical travel times from the GT events to the IMS stations, the IASPEI91 model was used. The results of comparison of experimental and model travel-time calculations are shown in Figs. 3 and 4. For the GT0 events, source coordinates and origin time were known exactly. We have taken EIL recordings with good SNR and measured travel times *Tobs* of the first P arrivals from the GT0 events to the EIL station, presented in Fig 3.

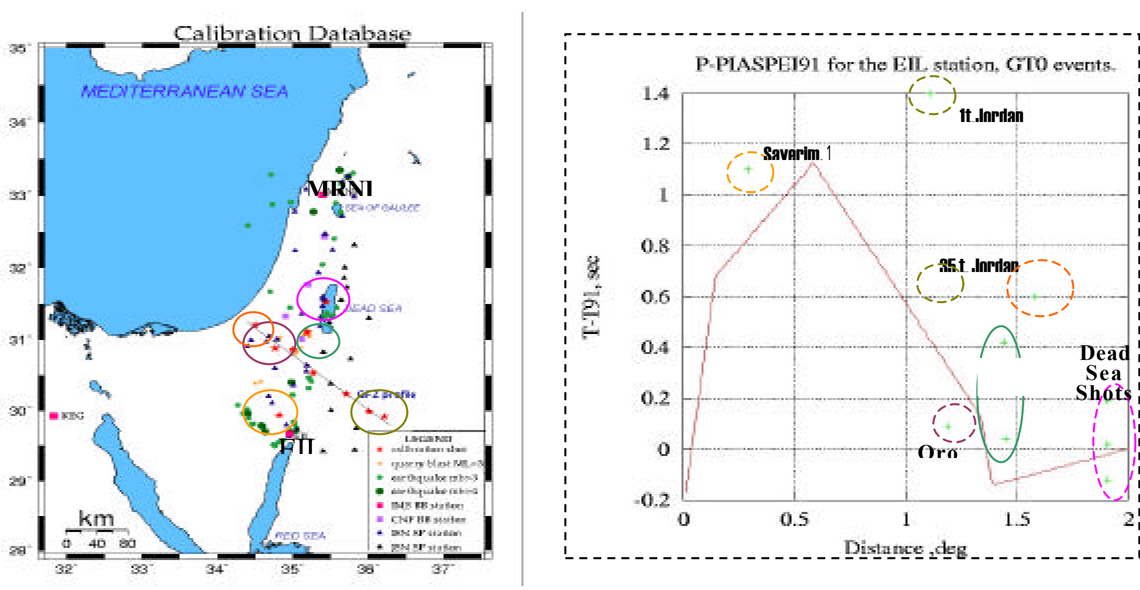


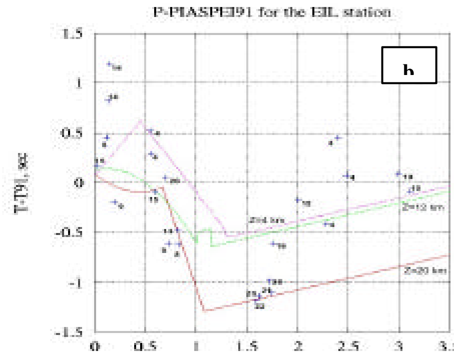
Figure 3. GT0 events and observed minus calculated time at station EIL using IASPEI91 velocity model. The curve shows T_{GII}-$T_{IASPEI91}$ dependency for the P (Pn, Pg) first arrivals.

Comparison of the *Tobs–Tcalc* for the two velocity models: GII and IASPEI91 shows that an essential difference (more than 1 sec) is observed for the Jordan 1-ton calibration explosion (DESERT2000 Group, 2000) and the close Sayerim shot. For the rest of the GT0 events, both models show good agreement with observations. For the MRNI station GT0 travel-time measurements are available now only for the Dead Sea shots of 1999, presented in Table 2 and showing ~0.3 sec early arrivals relative to both 1-D models.

Chosen GT5 events are shown in Fig. 4 (a). Figures 4 and 5 show T-$T_{IASPEI91}$ for the P and S first arrivals respectively for different distances from stations EIL and MRNI. Comparison of the measurements with the T_{GII}-$T_{IASPEI91}$ curves (calculated for the three depths: 4, 12 and 20 km), show that much of the travel-time error is explained by the difference between the IASPEI91 model (used for location by the International Data Centre), and the GII local model. Most of the measurements fit to the GII model better. Thus, in general, we prefer using the GII model instead of the IASPEI91 for the EIL in the (0 –3.5°) distance range.

Table 2. P arrivals from the Dead Sea shots to MRNI.

N	Distance, deg	Azimuth	Phase	Date	Tobs-T_{GII}, sec	Tobs-$T_{IASPEI91}$, sec
Ex1	1.4740	358	Pn	1999/11/08	-0.33	-0.31
Ex2	1.4740	358	Pn	1999/11/10	-0.35	-0.29
Ex3	1.4740	358	Pn	1999/11/11	-0.30	-0.31



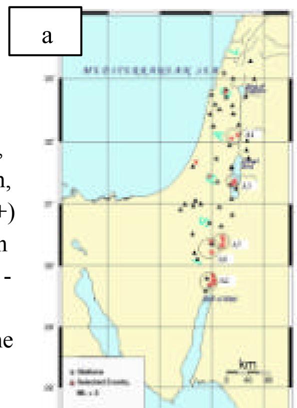
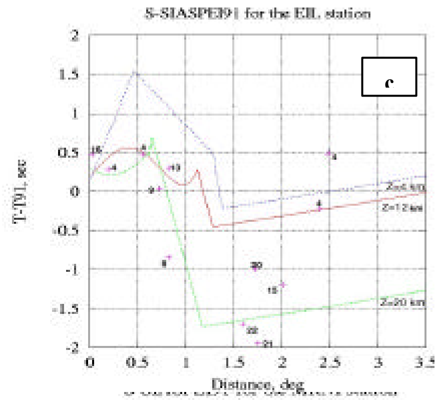
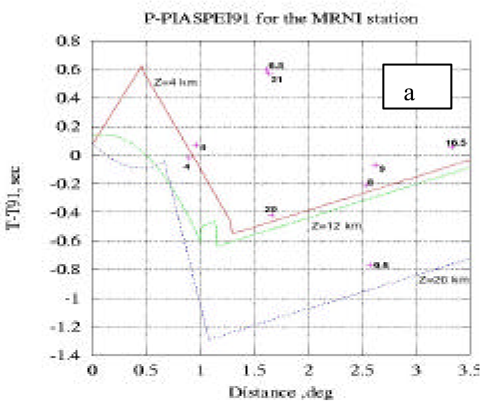


Figure 4. ISN GT5 earthquakes of ML>3, grouped in circles A1-A5 of R = 10 km, (a) and corresponding T_{obs}- $T_{IASPEI91}$ (+) for the EIL observed first arrivals P, Pn (b) and S, Sn (c), compared to the T_{GII} - $T_{IASPEI91}$ TT curves for the three depths: Z=4 km, 12 km and 20 km. The numbers, close to + show estimated source depth.





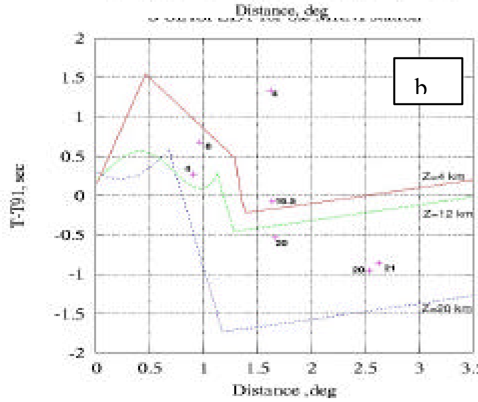


Figure 5. T_{obs}-$T_{IASPEI91}$ (+) from the ISN GT5 Israel earthquakes for the MRNI first arrivals of P, Pn (a) and S, Sn (b) compared to the (T_{GII} - $T_{IASPEI91}$) curves for the three depths: Z=4, 12 and 20 km.

However, there are a few remaining outliers with dt>0.5 sec that don't fit well with any model. For example, at small distances R<0.4° (area A2), the measurements exhibit positive delay relative to both models. For most other events application of the local model provides a reasonable travel-time correction. For the IMS station MRNI, we notice two suspicious outliers at a distance of ~1.6°, prompting correction of 0.6–1 sec for events from the area. It is interesting that these relatively deep (H > 16 km) events are almost at the same distance from EIL, but EIL arrivals from the same area show very good fit to the local model curves. For other MRNI arrival time measurements, shown on Figure 5, none of the models is preferable.

Travel-time corrections for IMS stations EIL, MRNI and BRAR relative to Izmit, Duzce, Adana, and Cyprus events. Empirical T_{obs}-$T_{IASPEI91}$ (for Pn first arrivals) for the given GT5 events from the collected database have been compared with T_{CUB}- $T_{IAPEI91}$, where T_{CUB} is the Pn travel time calculated using the D2tracerdn software by M. Barmin and the Colorado University (Boulder) 3-D global velocity model (2° step) based on surface wave dispersion analysis (Ritzwoller and Levshin, 1998). The T_{CUB} curves are shown on Figure 6 together with Pn readings at the IMS stations from the corresponding GT regions.

Unfortunately, many of the Pn readings are not reliable enough due to low SNR. Those are marked with "?" sign. The numbers close to the points denote source depth estimated in the relocation analysis.

Figure 6 shows that travel times from Cyprus have early arrivals (relative to IASPEI91) at the three IMS stations and fit well with the CUB for EIL and MRNI. The TT correction at the stations is about -0.5 sec. Pn travel times at EIL and BRAR from Adana are close to the IASPEI91 model. Large systematic positive deviations (1 – 1.8) sec of TT from Duzce are observed at EIL and not explained by the CUB model. Present Izmit TT observations look close to the IASPEI91 for EIL and BRAR, but at MRNI they are large positive: 2-3 sec. Thus, unfortunately, there are no observations in our database even with clear onsets (except Cyprus events at EIL) that could explain discrepancies between observations for the 1-D IASPEI91 model and the CUB 3-D model.

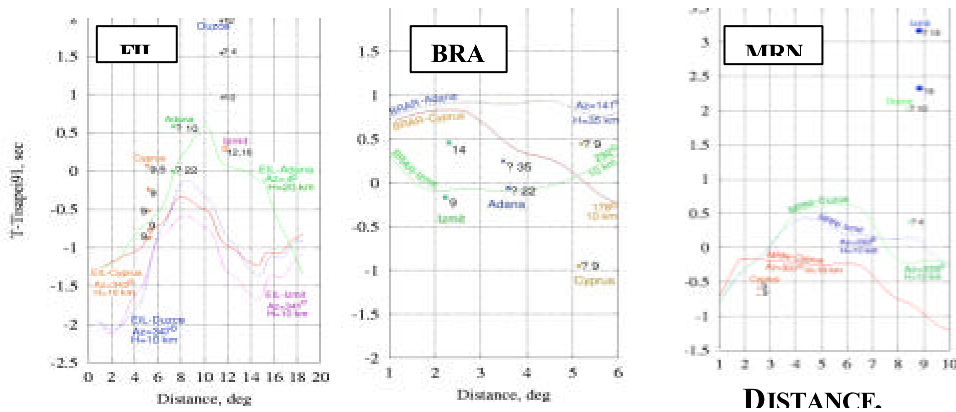


Figure 6. T_{obs}-$T_{IASPEI91}$, at the IMS stations EIL, BRAR and MRNI, from the Cyprus, Adana, Izmit and Duzce earthquakes, compared to the T_{CUB}-$T_{IASPEI91}$, calculated for the CUB10 model in the given directions from the IMS stations and at given source depth.

Calibration of the inland 25-ton explosion in the Negev desert, southern Israel.

Estimation of safety conditions and conducting preliminary test blasts. Blasts of this size without delays were never conducted at the quarry; therefore, the Rotem quarry managers requested from GII an estimation of safety ground motion conditions near the structures, located at ~ 4km, and for a high quarry wall located very close to the blast site (~ 220 m). To estimate ground motions (Peak Ground Velocity – PGV) for the planned explosion, we used an empirical relationship for single-fired blasts (Pergament et al., 1998):

$$PGV_{(mm/sec)} = 1000^* \; Kv * \mathbf{R}^{-2.21*R^{-0.05}} \qquad (1)$$

where the scaled distance $R = r_{(m)}/W_{(kg)}^{1/3}$, r is epicentral distance, m, W – is charge weight, kg, rock condition coefficient Kv = 8.5, with variation ~ 30% (V. Pergament, e-mail communication).

For verification of safety analysis estimations, we conducted a test single-fired blast on 12/05/2002 (see Table 3 and Fig. 9), located close to the planned calibration shot. The blast ground motions were measured at several sites near the specified objects. The charge design (see below) was the same as for the calibration blast.

Table 3. Parameters of controlled ripple-fired and instantaneous quarry blasts at the Rotem quarry. Hole diameter $7^{7/8}$ inch, hole depth 13-14 m, exploded soft rocks - kaolins.

#	Date	Origin time (O.T.), GMT	M_L ˣ	Measured coordin. X, Y, km		Charge tons	Delay msec	No. of delays	No. of holes
				X, km	Y, km				
1	08.05.2002	12:19:48.4ˣ	2.5	167.86	57.33	~7.0	0	0	7
2	12.05.2002	10:33:57.46*	2.5	167.89	57.33	6.64**	0	0	7 (+20)
3	19.05.2002	12:05:10.8ˣ	2.8	167.95	57.38	20	30	1	23
4	21.05.2002	13:00:05.554*	3.0	167.976	57.427	25	0	0	29

ˣ - Local duration magnitude M_L, and origin time from ISN records.
* - Location and origin time provided by GPS.
** - This blast included 20 small charges for preparation of "onion" cavities (see Fig. 9).

Ground motions were measured by the Instantel BlastMate III equipment that provided 3-C records of ground velocity and calculated PGV vector and dominant frequencies. PGV values calculated by (1) fit well the measurements (Table 5). For the two closer sites the estimation errors are less than 10%, for the distant point the error is higher, but the PGV value is overestimated, thus providing more safety.

Table 4. Measurements and estimations for a test single-fired blast on 12/05/2002

Station	Distance km	Measurement site	Dominant frequency f_0, Hz	Vector PGV, mm/sec		Error %
				measured	estimated by Eq.(1)	
BM11	0.22	~5m from quarry wall	7.1-18.0	75.0	***69.4***	7.5
BM13	1.33	a middle point	6.9-10.0	3.88	***4.22***	8.8
BM15	3.69	near the structure	6.0-7.9	0.833	***1.09***	30.9

According to the most severe German code DIN 4150, used in Israel for safety estimations for quarry blasts, the threshold safety ground motions value for buildings PGV_{build} = 5 mm/sec (for frequencies f < 10 Hz), yielding a safe distance estimation for the planned 25-ton blast of 2.55 km (based on $+2\sigma$ level), i.e. less than the closest structure distance. Considering a threshold safety PGV value for the quarry wall of 400 mm/sec, we obtained from Eq. 1 that the maximal possible PGV near the wall is much lower.

During preparation of the calibration explosion, we collected data for two additional quarry blasts located at the same site. Blast design parameters, measured and estimated coordinates, and origin time are presented in Table 3 (including data for the test blast mentioned above). These preceding smaller blasts were used for a preliminary feasibility analysis of the planned experiment, and obtained results confirmed that the expected magnitude 3.0 can be achieved.

Blast design parameters, preparation and conducting the 25-ton calibration explosion. A special experimental design of a buried (contained) single-fired explosion (the “onion” method) was implemented by an Israel company. In this method a small initial charge (10-12 kg) is detonated on the bottom of a small diameter borehole, creating a near-spherical cavity with volume sufficient in which to place 1-2 tons of explosives (Fig. 7). The inner walls and space of created cavities are monitored by a special computerized video camera (Fig. 8), measuring cavity dimensions and checking for the presence of large cracks and voids. Then the boreholes are filled by a specified amount of explosives, forming near-spherical charges. The rest of the borehole volume is stemmed, providing a contained (or almost-contained) source with full coupling. Basic parameters of the 25-ton experimental explosion are presented in Table 5.

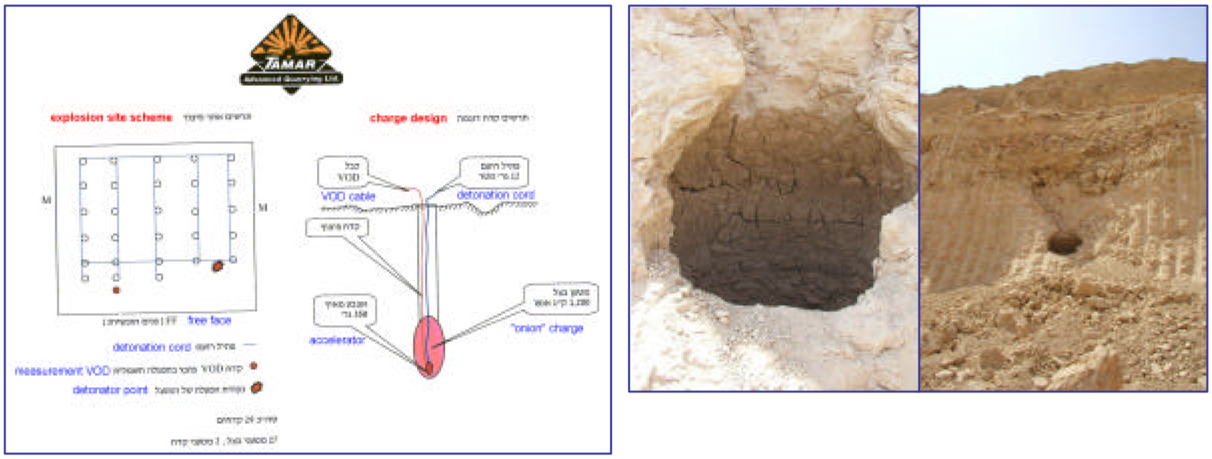


Figure 7. The “onion” charge design of the 25-ton blast. Photos show a cavity sample created during preparation for the blast and uncovered by an excavator.

Figure 8. Created borehole cavities are monitored by a special computerized video camera to measure cavity dimensions and check for the presence of large cracks and voids.

Table 5. Details of the calibration explosion design.

Borehole depth	13-14 m
Borehole diameter	$7^{7/8}$ in.
Number of boreholes	29 (27 "onions")
Distance between hole rows	17 m
Distance between holes in rows	17 m
Ammonium Nitrate	25000 kg
Main explosive - ANFO	26600 kg (incl.~8% Fuel Oil)
In-situ measured detonation velocity of ANFO (VOD)	3977 m/s
Explosive accelerator-Magnum X3	25 kg
Type of charge	concentrated – "onion"
Borehole predominant charge	1000 – 1200 kg
Stemming	12 m
Exploded rocks	kaolin (soft rocks)

Figure 9. Experimental blasts by the "onion" method at Rotem quarry (Negev). Upper photo shows initial small shots, to create near-spherical cavities ("onions"), used for the 25-ton calibration shot on 12/5/2002 (down photo).

A snapshot from the GII video-clip presented in Fig. 9 shows that the calibration explosion was almost contained. The "onion" charge design provided a small energy loss into the air. Only two holes of 29 were of usual (not "onion") design with a cylinder charge and a short (3-4 m) stemming. A rock outburst (on the left) corresponds to the location of these boreholes.

Near-source observations. For studying source function parameters and waveforms, three accelerographs K2-Etna (Kinemetrics) and two BlastMateIII seismometers, were placed in a close vicinity of the explosion on the basement layer of the exploded bench (Fig. 10). For verification of ground motion safety conditions, we installed also two BlastMateIII stations near the closest quarry structures at about 4 km.

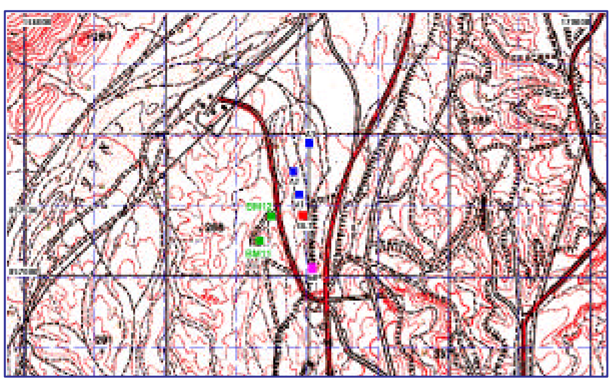


Fig. 10. Location of the calibration explosion (¦), accelerograph sites (¦) and BlastMate stations (¦).

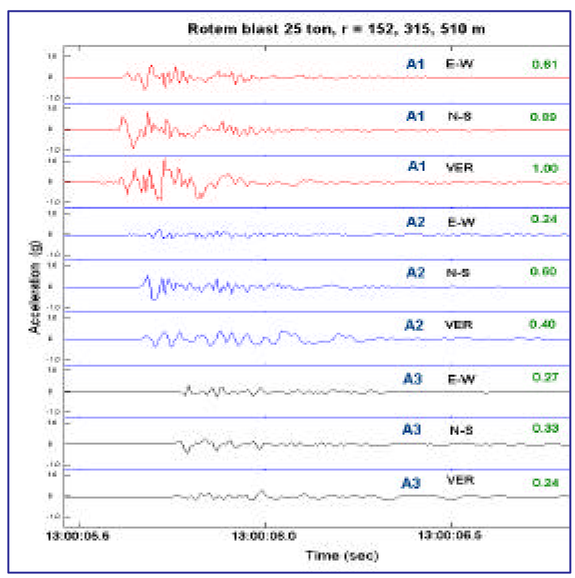


Figure 11. (Right) Recording acceleration ground motion at near-source distances by K2-Etna stations. Plots are in the absolute scale, numbers on the right show channel gain-factors relative to the closest A1 station.

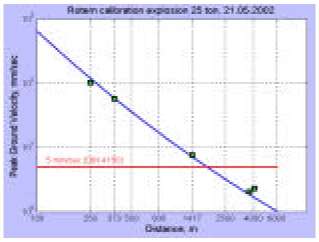


Figure 12. Estimated by Eq.1 (?) and measured (¦) ground velocity.

K2-Etna accelerographs are equipped by a GPS system and enabled estimating first arrival times and P-velocity of subsurface rocks (~ 2600 m/s). Recorded accelerograms are shown in Fig. 11. The closest accelerograph (r = 152 m) registered vertical acceleration more than 1g (1.234 g).

Like the case of the test blast on 12/05/02, PGV estimations correspond very well to the measurements (Fig. 12). For four sites estimation errors < 10%, for the station, located near the quarry structure, the measured value is significantly higher than the prediction, but it is still much lower than the safety threshold 5 mm/sec. No damage to the quarry walls or work structures was observed or reported after the 25-ton explosion.

Local and regional recordings. The four blasts (Table 3) were recorded at many ISN SP and BB stations and microarray EILESA (Fig. 13). The 25-ton calibration explosion was also well observed at many Jordanian stations, including IMS BB station AS056 (ASF) (Fig. 14). We revealed a weak signal after a heavy filtration at Cyprus BB station CSS (Fig. 14) at r=460 km, but failed to find a reliable signal at the closest Turkish station SMD (r=558 km). Several temporary seismometers were deployed during the calibration shot including surrogate stations at the site of a new IMS AS049 at Mt. Meron (under construction), providing GT0 data for the station calibration.

Comparing to other calibration explosions. The same specific charge design and source location for the series of blasts provide a basis for comparative analysis of amplitudes and waveforms for different source parameters, and estimating amplitude-distance and charge-magnitude relationships. We found that local magnitudes (for the Rotem blasts in soft rocks) estimated from the ISN records fit roughly the equation for single-fired quarry blasts in Israel (Gitterman, 1998) (Fig. 15). A small magnitude deficit ~0.5 unit relative to the upper limit for hard rock explosions (Khalturin, 1998) is observed.

Naturally, the Rotem blasts have much lower seismic efficiency than the Dead Sea calibration explosions (Gitterman and Shapira, 2001). However, the 25-ton Rotem ANFO blast, having a little smaller magnitude than the 0.5-ton Dead Sea shot (M_L=3.1), shows little bit stronger P-waves at different distances, and more important – demonstrates a better quality of first arrivals (Fig. 16).

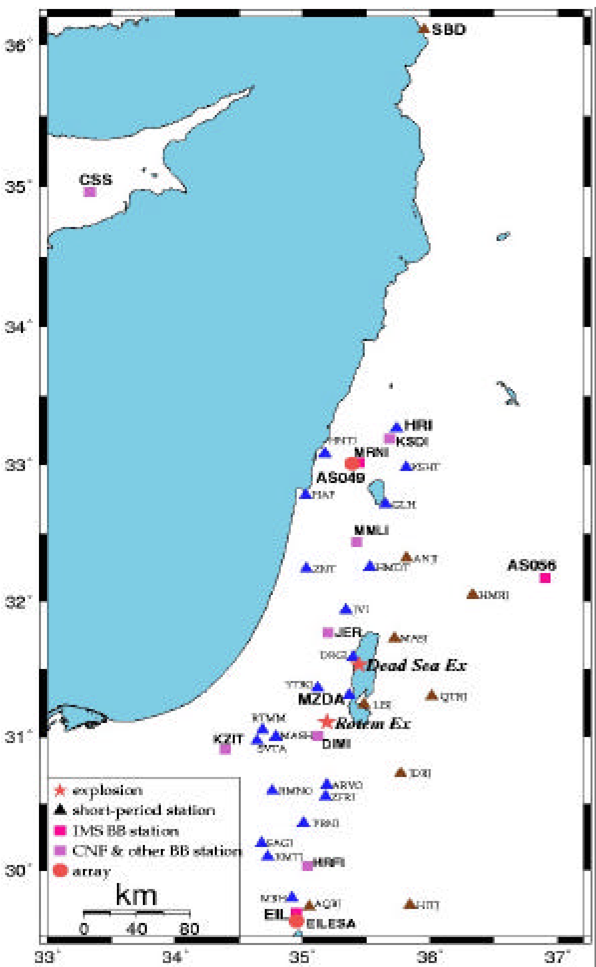
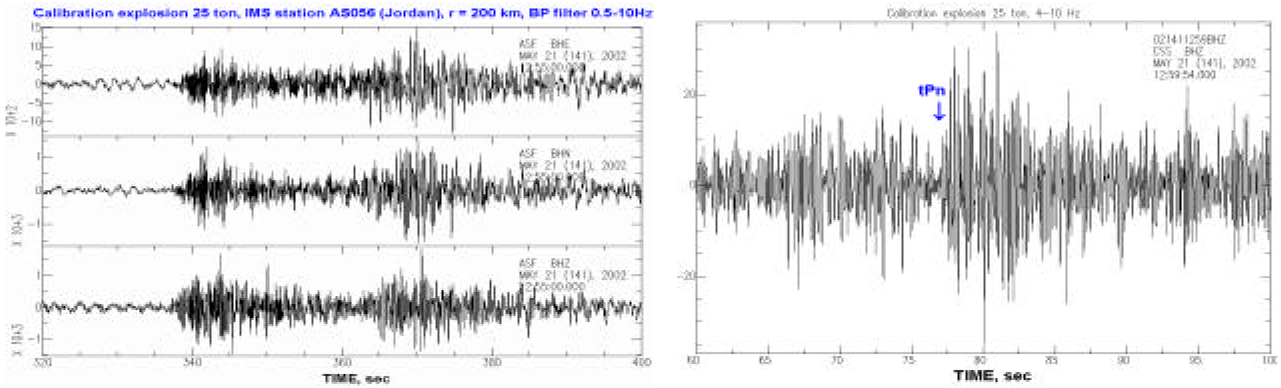


Figure 13. Explosion location and recording stations.

Figure 14. (below) Recordings of the calibration shot at regional stations AS056 (Jordan) and CSS (Cyprus).



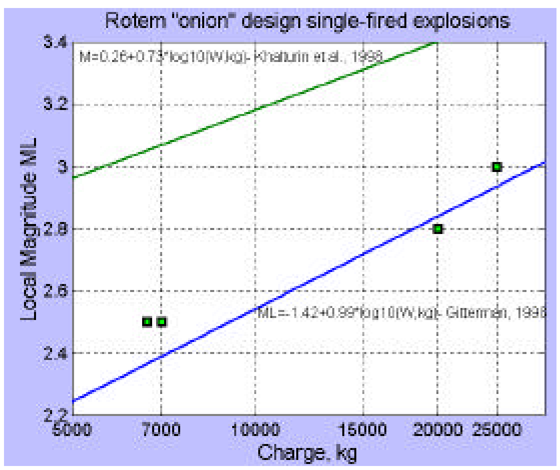


Figure 15. Local magnitudes for the Rotem blasts.

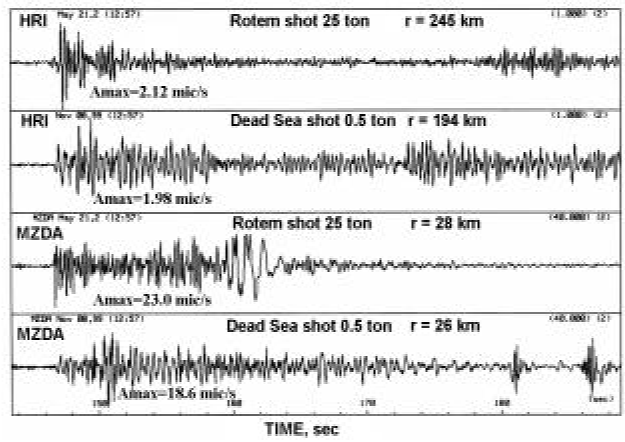


Figure 16. Comparison of amplitudes and waveforms for two Israel shots at close and remotest ISN stations.

We also compared the Rotem blast (in soft rocks - kaolin) with the same size Balapan (Kazakhstan STS) calibration explosion on Sept. 17, 1997, at 30-m depth (Kim, 1998). The Kazakh explosion was conducted under experimental conditions most favorable for generating seismic signals: more concentrated charge in one borehole, placed in crystalline rocks, high Q crust for the Kazakhstan platform. However, we found a rather similar average seismic strength for both explosions (Fig. 17), though the Balapan shot was observed at larger distances (~ 800 km), than the Israel blast (~450 km) in a different regional geology (thick upper crust sediments). The Rotem explosion shows obvious larger peak amplitudes compared to the empirical curve for the Israel single-fired multi-hole quarry blasts (Gitterman, 1998), probably due to the special charge design. It is interesting that the 0.5-ton Dead Sea shot has similar average seismic efficiency to both inland 25-ton shots.

Data for the 25-ton calibration explosion are presented at the GII Website: http://www.gii.co.il.

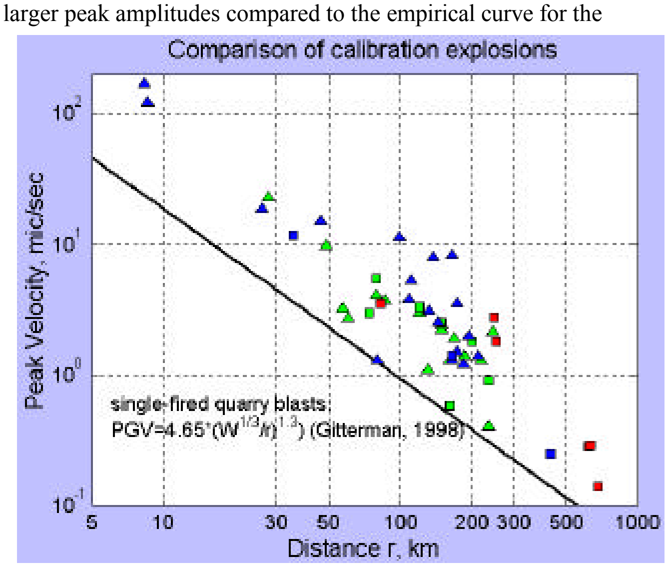


Figure 17. Comparison of peak amplitudes versus distance for three calibration shots: 25-ton Rotem (green), 0.5-ton Dead Sea (blue) and 25-ton Balapan (red) (triangles – SP stations, squares – BB stations).

Improvements of local 1-D velocity models. Errors in SSSCs constructed directly from empirical travel times can be caused by the origin time and hypocenter location error. The error may be reduced by using a more accurate velocity model. For improving the 1-D velocity models in the GT events area, we used the VELEST joint epicenter solution program (Kissling *et al*., 1994). The software was applied to the Adana Basin area (Cilician network, TUBITAK) and ISN region (GII). The data set contained 244 reliable Adana events and 170 ISN events of ML > 2.5 with good P and S readings. Initial RMS was 0.5 and 0.67 sec for each of the networks respectively and after 149 iterations of the VELEST for the Cilician and 67 for the ISN network, we achieved the RMS value 0.3 sec for both (see Fig. 18). As the result the existing regional 1-D models for the Cilician network (Ergin, 1999) and ISN (see Tables 6, 7) have been improved and used for relocation of the GT earthquakes. The new Adana model was constructed for the smaller area covered by the aftershocks of the June 27, 1998, earthquake.

Table 6. Crustal models for the Adana Basin

Regional (previous)		Local (new)	
Depth (km)	Vp km/sec	Depth (km)	Vp km/sec
0	4.5	0	2.5
2	5.0	2	4.5
4	6	4	4.9
12	6.15	6	5.8
28	6.6	12	6.5
32	7.8	24	7.2
		36	7.6
		40	8.8

Table 7. Crustal models for the ISN

Previous model		New model	
Depth, km	Vp, km/sec	Depth, km	Vp, km/sec
0	4.36	0	4.78
2.56	5.51	2	5.72
9.76	6.23	9.76	6.27
31.4	7.95	16	6.53
		28	6.97
		32	7.64
		40	

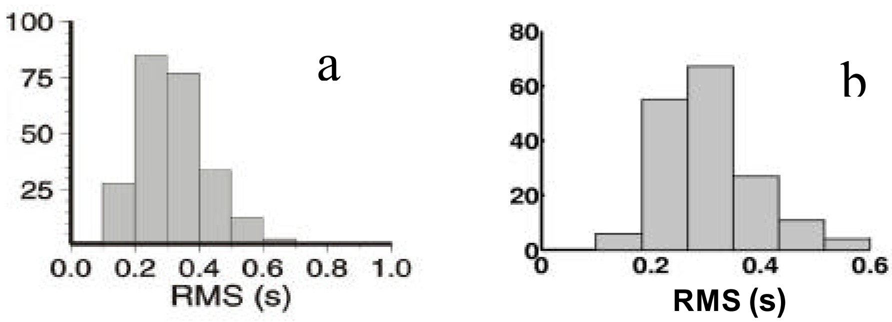


Figure 18. Distribution of event number versus residual Tobs-Tcalc (RMS) after application of VELEST software for the Adanda basin (Turkey) and Israel

CONCLUSIONS AND RECOMMENDATIONS

The newly developed RELOC tools helped to choose, relocate, and verify a number of GT events from Turkey, Cyprus and Israel, reducing travel-time deviation due to the origin time and hypocenter error to a fraction of a second. The GT0, GT2 and GT5 events, collected within ISN, provided SSSC estimation for the IMS stations EIL and MRNI in the distance range of 0 - 400 km and showed that the best travel-time correction in most cases can be obtained due to the local velocity model. However, there are several outliers and suspicious events requiring additional consideration.

GT earthquakes useful to compute direct SSSCs are rare because most of them are too weak to provide reliable first P and especially first S arrivals at the IMS stations. This is a reason for a large scatter in the estimated travel times from a small area, as for example, observed Cyprus readings at BRAR. However, even for good readings, such as Duzce and Cyprus events at EIL the scatter is about 1 sec. Moreover, even for high-quality P, S arrivals, (like Izmit events at MRNI and Duzce events at EIL), we got too large a deviation (2-3 sec) of the TT from the CUB. Thus, we need additional testing and verification of unreliable GT events and travel-time models.

The GII successfully conducted a series of explosions in the Rotem Phosphate quarry (Negev desert, 31.109°N, 35.189°E), including an inland seismic calibration explosion of 25 tons of ANFO on May 21, 2002, at 13:00:05.55 GMT. Magnitude 3.0 was reached owing to a special experimental charge design (the "onion" technique). Records were obtained at numerous permanent and portable SP and BB seismometers as well as accelerographs, in the distance range 0.3–450 km, in Israel, Jordan and Cyprus, with good quality first arrivals. Compared to other calibration shots, the Rotem 25-ton blast showed seismic efficiency similar to the same size Balapan (STS, Kazakhstan) explosion, and 0.5-ton Dead Sea shot. The Rotem series (6.6- to 25-ton) enriched the regional GT0 database of different seismic sources for following discrimination analysis, provided new data for calculating accurate travel times of seismic waves to local and regional seismic stations and thus improved velocity models.

REFERENCES

Desert 2000 Group (2000). Multinational Geoscientific Research Effort Kicks Off in the Middle East, *Eos,* **81**, Num. 50, Dec. 12, 2000.

Ergin, M. (1999), Present day seismicity and seismotectonic characteristics of the Cilician region, Ph. D. Thesis, Istanbul Technical University, pp.312.

Gitterman, Y. (1998), Magnitude-yield correlation and amplitude attenuation of chemical explosions in the Middle East, *Proc. 20th Annual Seismic Research Symposium on Monitoring a Comprehensive Nuclear Test Ban Treaty*, Santa Fe, Sept.21-23, 1998, 302-311.

Gitterman, Y. and A. Shapira (2001), Dead Sea Seismic Calibration Experiment Contributes to CTBT Monitoring, *Seism. Res. Lett.*, **72**, No.2, 159-170.

Khalturin, V.I., T.G. Rautian, and P.G Richards (1998), The seismic signal strength of chemical explosions, *Bull. Seism. Soc. Am.*, **88**, 1511-1524.

Kim, W.-Y. (1998). Waveform data information product: calibration explosions at Semipalatinsk Test Site, Kazakhstan, during August and September, 1998. Lamont Doherty Earth Observatory Report, 9 pp.

Kissling, E., W.L. Ellsworth, D. Eberhart, and U. Kradolfer (1994), Initial reference models in local earthquake tomography, *J. Geophys Res*., **99**, 19,635-19,646.

Pergament, V., I. Malarov, P. Firstov, and Y. Gitterman (1998). Experimental evaluation of near-source seismic effects of quarry blasts. *Abstracts of the XXVI General Assembly of the European Seismological Commission*, Tel Aviv, August 23-28, 1998.

Ritzwoller, M.H. and A.L. Levshin (1998), Eurasian surface wave tomography: Group velocities, *J. Geophys. Res*., **103**, 4839-4878.