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EXECUTIVE SUMMARY

The most heavily populated areas of Israel, Jordan and West Bank/Gaza are vulnerable to strong earthquakes, which are inevitable in the region. A strong damaging earthquake is a real, as well as a current, threat to the safety, social integrity, and economic wellbeing of the people in the region. Reduction of damage from earthquake ground shaking requires modern building codes that are continuously updated to reflect the improvement in our understanding of the physical effects of earthquake ground shaking on buildings. This research project produced maps and charts that provide up-to-date, essential, and basic seismological data for use in the development and implementation of modern building codes and regulations in Jordan, Israel and the Palestinian National Authority. The most important product, for immediate application by practitioners and policy makers in the region, is the newly developed regional seismic hazard map, which displays peak ground acceleration (PGA) levels that have a probability of 10% of being exceeded at least once within a period of 50 years. This map provides the basic seismic input parameter that is considered in all modern building codes containing a-seismic design provisions.

During the course of developing the new probabilistic ground shaking hazard map, the multi-national project participants: (1) created a unified earthquake catalogue for the period 1900–2004, (2) developed an epicenter map, (3) developed a seismogenic zone scheme for the region, (4) compiled and integrated all relevant, existing geological and geophysical information for the region and (5) enhanced the monitoring capabilities in both Jordan and the territories of the Palestinian Authority.

These products laid the scientific and technical foundation for significantly improving the relevance of future hazard assessments by improving the quantification of local site effects. Local site effects reflect variations in the physical properties of the near surface geology and are a major causative factor for damage to buildings and infrastructure. Neglecting site effects leads to unnecessary loss of function, and loss of life.

The project increased understanding of the response of buildings typical in the region to earthquake ground shaking and facilitated empirical determinations of the dynamic characteristics of existing buildings.

This project will have a lasting benefit in the region because of the potential for protecting people, buildings, and infrastructure. It will save lives and protect the built environment from the inevitable damaging earthquakes. It will also provide a basis for long-term capacity building through educational programs, such as those envisioned during the Decade on Education for Sustainable Development (2004-2014).

Unfortunately, unrest, hostility and curfews in the region have had a severe impact on the project regarding scheduled meetings, workshops, etc., causing delays in reaching the project's final

objective. These difficulties were partially solved by developing a project web site (**www.relemr-merc.org**) which now includes a rich body of information relevant to the project and region. This includes, but is not limited to; research tasks performed by the multi national participants, presentations made by the participants during meetings and workshops, the project results and products, references, and bibliographic lists and lists of participating institutions and individuals.

One important task remains incomplete. It is the development of probabilistic seismic hazard maps for different areas within the region at different frequency ranges and damping ratios. Within that task site response effects as well as the dynamic characteristics of existing buildings need to be determined, and used as a basis for recommending the next generation of building codes for the region.

This project has already had a very positive benefit-to-cost-ratio. The modern hazard map and the increased awareness of the earthquake threat by the national and regional engineering communities and policy makers have great value now because of the investment in this project. This value will increase rapidly with time as *the project outcomes are integrated into the building codes throughout the region, providing a basis for earthquake-resistant buildings in the region for years to come.*

RESEARCH OBJECTIVES

The overall aim and specific objective of the project is to produce maps and charts that will provide the necessary seismological data for the implementation of building codes and regulations in Jordan, Israel and the Palestinian National Authority.

The Jordan valley, which constitutes a major part of the Dead Sea Transform (DST), is the most seismically active region in the Middle East, having a history of four thousand years of documented destructive earthquakes. Regional cooperation is a basic requirement for a better assessment and, consequently, mitigation of the possible effects of earthquakes that will most definitely occur in this region. The occurrence of strong earthquakes along the Dead Sea transform fault system becomes a major threat to the safety, social integrity and economics for the peoples of the Middle East. The only remedy to earthquake loss is proper planning and building: "Earthquakes do not kill people - houses do!". A-seismic building code requirements are based on seismological assessments of the spatially distributed seismic hazard parameters. These assessments are the prime objective of the research project.

In order to achieve this overall aim, certain research activities had to be completed;

1) Collect different earthquake catalogues for the region and compile a unified catalogue of earthquakes.
2) Collect available geological and seismological information to define seismogenic zones and assess of their seismic potential.
3) Test and/or develop scaling laws of dynamic source parameters of local and regional earthquakes and attenuation of seismic energy across the region.
4) Implement state of the art procedures for earthquake hazard assessments and testing new approaches.
5) Characterize dynamic properties of sites and buildings common in the region.

This wide spectrum of subjects and research topics are part of previously conducted and on going research in the academic and the engineering establishments of Jordan, Israel and the Palestinian National Authority (PNA). Consequently, research activities during the project, and especially the workshops have attracted participation and contributions from other institutions such as the Building Research Center of the Jordanian Royal Scientific Society of Jordan, the Faculty of Civil engineering of the Technion (Institute of Technology, Israel), the National Building Research Center of Israel and the Geological Survey of Israel.

Thanks to the RELEMR initiative, the project was conducted in close cooperation with scientists from countries bordering the Dead Sea transform fault and thus reaching a wide consensus with regards to the earthquake sources and their activity rates and bridging potential disagreements on hazard evaluations across border regions.

METHODS AND RESULTS

1. The unified earthquake catalogue.

The unified earthquake catalogue is used in the assessment of earthquake hazards in the region. The unified catalogue covers the period 0-2004 AD.

1.1 Information sources

The unified earthquake catalogue was compiled from the following sources:

1) Historical earthquake information is compiled from different Arabic, Islamic, Jewish and Christian historians who assembled descriptions of earthquakes mentioned in ancient literature such as Kashf As-Salsalah and Wasf Al-Zalzalah by As-Soyuti, which contains account of the historical earthquakes of the region from the seventh to the eighteenth century (Al-Sa'dani, 1971), in addition to the works of Sheikh Al-Rabweh Al-Dimashqi, Iben Sina, Iben Asker, Iben Khaldoon, Iben Tagree Badri, Al-Maqrizi, Al-Sheikh Abed Al-Gani Al-Nablsi. These sources also contain detailed descriptions about damage and destruction (Al-Hakeem, 1988).

2) Lists of historical earthquakes were also compiled from revised earthquake catalogs of the region and added after cross checking the quality and the authenticity of the data sources published. These data were compiled by Ambraseys (1971, 1978), Ben-Menahem (1979, 1981), Poirier and Taher (1980), El-Isa et al (1984), El-Isa et al (1986), El-Isa (1985, 1988), Hasweh (1986), Ambraseys and Barazangi (1989), Abu-Karaki (1987), Ambraseys and Melville (1985), Al-Tarazi (1992), Shapira (1979), Ambraseys and Karcz (1992), Shapira et al. (1993) and Amiran et al. (1994).

3) Instrumental data concerning earthquakes in our region are available from the beginning of the 20th century owing to the operation of seismic stations in Egypt (HLW), Lebanon (KSR), Israel (JER, EIL) and several tens of stations in Europe. Earthquake information for the period 1900-1982 is mainly available from the International Seismological Summary (ISS), England, the International Seismological Center (ISC), England, the National Earthquake Information Service (NEIS), USA, and the compilation of Arieh et al. (1985).

4) Since 1982, earthquake information is available mainly by the national seismic networks of Jordan and Israel (see Fig. 1). The Israel Seismic Network (ISN) was established in 1980 and is operated continuously by the Seismology Division of the Geophysical Institute of Israel (GII). The Jordanian Seismic Network (JSN) was established in 1983 and is operated continuously by the Seismology Division, the Natural Resources Authority (NRA) of the Hashemite Kingdom of Jordan.

All together, the seismicity of the Dead Sea Rift system is a unique example of an area for which information and documentation on historical earthquakes cover a time span of more than four millennia. Evidently, with respect to source parameters of the events, the period from which instrumental data became available is by far more reliable. Hence, the unified earthquake catalogue for the Dead Sea Rift system covers the 20^{th} century (1900-1999). The map of epicenters is shown in Fig. 2.

1.2 The magnitudes.

In the process of unifying the catalogue, we had to address the problem of unified magnitude determinations. Most of the events (including those measured during 1954-1982) have been assigned the M_L value as determined by the ISN according to the equation:

Local Magnitudes:

$$M_L = 0.7 + 1.54 \log(t) + 0.001R \qquad (1)$$

Modified magnitude formula since 1987:

$$M_L = -0.6 + 2 \log(t) + 0.0015R \qquad (2)$$

The magnitudes of the earthquakes that are recorded by only the JSN are determined according to the formula:

$$M_L = 0.7 + 0.001(D) + 1.54 \mathrm{Log}\, t \qquad (3)$$

Where, t is the duration of the signal and D is the distance (km) from the epicenter.
The Magnitude M_L (Israel) was found to be correlated with the seismic moment Mo (dyne cm):

$$M_L = (0.97 \pm 0.02) \log(Mo) - (16.90 \pm 0.36) \qquad \sigma(M)=0.17 \qquad (4)$$

$$\mathrm{Log}(Mo) = (0.96 \pm 0.02) M_L + (17.59 \pm 0.05) \qquad \sigma(\log Mo)=0.17 \qquad (5)$$

We have correlated between the inferred M_L from Mo estimations (Eq. 4) and the M_L (ISN) and M_L (JSN) magnitudes and obtained the correlation:

$$M_L = 1.01 + 0.66\, M \text{ (Jordan)} \qquad (6)$$

$$M_L = 1.11 + 0.61\, M \text{ (Israel)} \qquad (7)$$

The correlations are valid for the magnitude range 1.0 to 5.0.
These relationships are used to unify the local magnitude M_L. For earthquakes which occurred prior to 1956 or for which local seismograms were not available, we assumed that M_L is equal to the given magnitude value (usually Ms) for M_L>4.8.

1.3 Completeness.

Based on the availability of earthquake data and following previous studies of Shapira (1983, 1984), Marouani and Shapira (1991), Arieh and Rabinowitz (1989) and Hofstetter et al. (1996) we suggest that the earthquake information available for the Dead Sea Rift system or more precisely, to the rectangular region shown on the map in Fig. 3, is complete for the following periods and magnitudes as shown in Table 1.

2. Seismogenic zones and seismicity parameters.

2.1 Definition of the Seismogenic Zones.

The definition and characterization of seismogenic zones is a key element in the process of earthquake hazard assessment and depends on the surface and sub-surface geometric, kinematical and mechanic properties of active faults (e.g. slip rate, typical faulting mechanism, return time, etc.), as well as on the seismicity distribution. Following the determination of zone boundaries, the seismicity pattern of each zone is calculated, most importantly the frequency-magnitude relation and maximum magnitude estimation.
The accuracy and resolution of previous attempts to identify seismogenic zones in the study area, and especially along the Dead sea transform faults and its off branching faults, have increased with improvements in seismic monitoring by the Jordanian and Israeli seismic networks, with the resolution of mapping and kinematical analysis of fault systems and the supporting studies in archaeo-seismology, palaeo-seismology and geodesy. Studies that either emphasized regional zoning, or relied on limited databases (Ben-Menahem et al., 1982; Shapira, 1983, 1984; Rotstein, 1987; Ben-Menahem, 1991; Papazachos et al., 1997; Khair et al., 2000) used rough zonation, with 2-4 earthquake producing regions. Arieh and Rabinowitz (1989) subdivided the Dead Sea Transform (DST) into distinct basin and inter-basin sections, defined second order seismogenic zones (Carmel, Fara'a) and took into account areas of distributed seismicity (Mediterranean, Lebanon coast, Galilee). Yuceman (1992) used line sources to represent known (DST, Suez) or presumed (Mediterranean offshore) fault zones and areas to represent distributed seismicity (Beka'a, Mediterranean). Shapira and Shamir (1994) presented a detailed seismic zonation of Israel based on epicenter distribution for earthquakes that occurred since 1907 and mapped fault geometry, without taking into account the age of faulting. A distinction should be made between these studies, aimed at defining seismic sources at the highest possible resolution, and studies

delineating the overall plate boundaries, e.g. Salamon et al. (1996).

The seismic zonation prepared by Shamir et al. (2001) as part of this research project, attempts, for the first time, to integrate the seismological and geological data accumulated over the last several decades and to put defined constraints on its usage. Such constraints are based, for example, on the temporal changes in the completeness of the unified earthquake catalog, and on published determinations of the age of activity along specific faults.

The seismic zone map is based on the unified catalogue of earthquakes presented above, which covers the period since 1907, the catalogue of young faults in Israel (Bartov et al., 2000) and active faults (Bartov et al., 2002). This database includes faults that offset sedimentary rocks of Pliocene or younger age, volcanic rocks younger than 5 Ma and faults that have been defined as "young" based on geomorphologic considerations. The base maps for this database are the 1:200,000 geological map of Israel (Sneh et al., 1998) and the structural map of Israel (Fleischer and Gafsu, 1998; Fleischer and Gafsu, 2000). Other sources are mapped fault systems along the seismically active boundaries of the Israel-Sinai sub-plate, specifically in the Gulf of Eilat (Ben-Avraham et al., 1979; Ben-Avraham, 1985; Ben-Avraham and Tibor, 1993), the Gulf of Suez (Garfunkel and Bartov, 1977) and in the Roum-Yamune fault system (Bartov, 1994).

2.2 The Seismogenic Zones.

The seismogenic zones are shown on the map in Fig.4. Each zone encircles areas that show recent seismic activity and/or post-Pliocene geological activity. Based on the spatial distribution of epicenters and reported active faults, the following classification of seismic zones was defined:

A: Measurable seismicity clearly associated with active faults.

B: Measurable seismicity associated with mapped geological structures, which have not been defined as active in post Pliocene times.

C: Measurable seismicity with no apparent association with known geological structures.

D: Active faults and sporadic seismicity with no coherent relation between them.

E: Active faults with no recorded seismicity associated with them.

Some additional considerations in defining seismogenic zones are as follows:

1) The DST was subdivided in such a way that basins (Hula/Kineret, Dead Sea, Gulf of Eilat basins) and inter-basin segments (Arava, Jordan Valley) form distinct zones. The rationale is that basinal sections are characterized by continual, low to medium magnitude or swarm-type activity, while inter-basin sections have either been relatively quiescent over the instrumental period (e.g. the Arava) or ruptured in large earthquakes (the 1995 Gulf of Aqaba earthquake). An alternative approach could be placing zone boundaries halfway in basins, which are the

expression of fault step-over zones. This is based on the observation that the Gulf of Aqaba earthquake nucleated and was arrested within the Aragonese and Eilat basins, respectively. Seismic zones are defined as area sources, rather than line sources, even where the fault zone is well defined, both geologically and seismologically.

2) This is due to the finite width of fault zones (e.g. the Dead Sea Rift), their inclinations and the inherent hypocenter uncertainty.

3) Where the exact structural association between earthquake epicenters and specific fault systems is unclear, overlapping zones were introduced (e.g. Bet She'an/Gilbo'a-Jordan Valley-Carmel/Tirza, Baraq-Paran).

4) In the original model the Yammouneh source has been extended to the North to reach latitude 37oN and narrowed in the Southern part to avoid overlapping with the Sergayha branch.

5) Sources N-Lebanon and S-Lebanon correspond to the Northern and Southern regions in Lebanon with assumed activity rates similar to neighboring regions and consistent with the assumptions in the hazard assessment in Lebanon as evaluated by R. El Khoury.

6) Sirhan source stems from the Jordanian seismic source model.

7) Sergayha and Damascus sources are based on information from Syrian colleagues to account for the seismic activity associated with Sergayha fault (branching from the main transform near the Sea of Galilee) and with Damascus fault.

8) To the South, the Sinai triple junction accounts for seismicity in the northern Red Sea.

2.3 Formulation and b-value.

The seismicity of a seismogenic zone is quantified in terms of the frequency-magnitude relationship. That relationship is a key element in estimating the probability that a magnitude M earthquake will occur in a certain seismogenic zone within a predefined time interval. The formulae used in this study are:

$$\log[n(M)] = a - bM \qquad (8)$$

$$\beta = b \ln 10$$

$$N(\geq M) = \alpha \frac{\exp[-\beta(M - M\min)] - \exp[-\beta(M\max - M\min)]}{1 - \exp[-\beta(M\max - M\min)]} \qquad (9)$$

Where, n(M) is the annual frequency of earthquakes of magnitude M±dM (here, dM=0.1) and N(M) is the annual number of events with magnitude M or greater.

The completeness of the earthquake catalogue (see Table 1) applies to the territory within the area shown on the map in Fig. 3. This area comprises those parts of the Dead Sea transform system within the JSN and the ISN stations. Hence, assuming that Mmin=2.2 and Mmax=7.5 and following Wiechert (1980), we estimated the optimal values a, α and b that yield the least sum of squared residuals for log n(M) and log N(M).

Following the magnitude relationships above all magnitude values in the earthquake catalogue are converted to the unified magnitude that is analogous to the moment magnitude Mw (when $M_L \geq 5$) or Mm (when $M_L < 5$). Here the seismic moment is determined from short-period recordings.

The analysis for that part of the area with the most complete instrumental and historical data (Fig. 3) yields b=0.96.

2.4 Seismicity parameters of the seismogenic zones

2.4.1. The b-value

The amount of information available for each individual seismogenic zone may be found insufficient for accurate statistical assessments of the seismicity parameters. However, the b-value is indicative of the tectonic characteristics of a region and thus, we may assume that the seismogenic zones that constitute the Dead Sea Rift (DSR) or are branching off the Dead Sea Rift, will have the same value of b=0.96. This assumption is considered to better represent the tectonic characteristics of the seismogenic zones in the investigated region. The applicability of that assumption is further demonstrated in Figures 4, 5 and 7 that show the frequency-magnitude relationships for different seismogentic zones, where in each case the black line is the best fit for a fixed slope of b=0.96.

The seismo-tectonics of the Cyprus zone and possibly also in the Gulf of Suez are of different character. For both zones there are sufficient data to perform a separate analysis that yield b=1.07 and b=0.98 for the Suez and Cyprus, respectively. The cumulative frequencies vs. magnitude for those zones are shown in Fig. 8.

2.4.2. Maximum Magnitudes.

An important seismicity parameter is the maximum magnitude. Based on previous assessments (see e.g. Arieh and Rabinowitz, 1989, Shapira, 1983, 1984 Vered, 1978, Yuceman, 1992, Shapira and Shamir, 1994 and others) we assumed that the maximum magnitude along the DSR is 7.5 with the exception for the Yamouneh fault that may be associated with slightly higher magnitudes (Mmax=7.75). To the faults that are branches of the DSR we assigned maximum magnitudes of 5.5 and 6.0. These estimations are based mainly on the limited seismic history and partially on the length of the mapped fault. These faults, with the exception of the Carmel fault, are currently away from populated areas and for the present time, the uncertainty associated with defining Mmax will not pose a practical difficulty. In the case of the Carmel fault we assumed

Mmax=6.5 mainly due to the accumulated length of that fault system and due to its proximity to the population centers. We do not have any record of a strong earthquake (M>6) that has occurred in the past on that fault despite its proximity to the main cities of the Galilee, throughout the history.

Maximum magnitudes associated with the zones that are characterized as zones of background seismicity, follow the seismicity record (see also the references listed above). The estimated maximum magnitudes for the different seismogenic zones are shown in Tables 2, 3 and 4.

2.4.3. Seismicity levels ("return periods").

The black lines in Figs. 5-7 represent the best fit to the cumulative N(M) function where Mmin=2 and the b-value is fixed to b=0.96. However, in many cases we may suggest a parallel line (drawn in red on Figs. 5-7) that represents an upper bound from which we may deduct the upper value of "alfa" (i.e. the annual number of events) for M≥2.0. The "Maximum observed alfa" coefficients are tabulated in Tables 2, 3 and 4.

Table 2 shows the assumed length of each segment of the DSR. Table 3 presents that of the branching-off faults. Table 4 shows the area of each of the seismogenic zones that are characterized as areas with background seismicity without clearly associated fault segments.

The observed seismicity in the zones constituting the Dead Sea Rift demonstrate systematic rate of activity per unit length (N/km in Table 2). We observe an average activity rate of 0.26 events of M≥2.0 per kilometer. This average value is obtained while excluding the Arnona, Aragonese, Arava and the Yamuneh seismogenic zones. The Aragoneze zone is probably heavily "contaminated" with many aftershocks of the earthquake sequences that occurred during 1983-1996. Yamouneh segment in the north and the Arnona segment in the south are distant from the regional seismic stations and most properly our earthquake catalogue for these seismogenic zones is significantly incomplete. The frequency-magnitude relationship for the Arava valley is very different from those of the other segments of the DSR: while for most of the segments of the DSR the b value is within 0.96±0.05, the apparent b-value for the Arava is unacceptably high (close to 2). Furthermore, the seismic history shows no documented evidence of a major earthquake that originated in the Arava. The absent of major earthquakes in the Arava is also supported by the observed low seismicity over the instrumental period despite the fact that the Arava is well monitored by permanent and temporarily installed seismic stations.

Adopting the value of 0.26 events/year/km and considering the length of each zone along the DSR, we obtain an estimate of the annual number of events with M≥2.0. As for the Arava Valley, we used the observed upper bound of 25 events per year. The Arava is relatively distant from population centers and even if we are under-estimating its seismicity (and consequently, the seismic hazard), the impact on the population is currently insignificant. However, the seismicity of the Arava remains a problem to be further investigated.

The same evaluation process is repeated for the seismogenic zones that constitute faults system that branch from the main DSR. Here again, the rate of activity, N/km, is very similar and thus we may suggest an average value that will be applicable to those zones. The average value (excluding the Malhan fault) is 0.05 events (M≥2.0) per kilometer.

Table 4 presents the estimated seismicity rate per unit area (squared kilometer) in seismogenic zones that show background seismicity. The selected background seismicity rate for the Suez, Cyprus and the East Samaria zones are as observed. The seismogenic zones: East Mediterranean-1, East Mediterranean-2 and the Galilee show a similar value of 1.49 events (M≥2.0) per squared kilometer. The other low seismicity zones of background seismicity, namely: East Mediterranean-3, Central Israel, North Jordan, Palmyra region and Wadi Sirhan show an average rate of 0.47 events (M≥2.0) per squared kilometer. The corresponding "alfa" coefficients, re-scaled to the size of the area, are also shown in Table 4.

These seismicity estimates were jointly re-examined by scientists for all countries neighboring the Dead Sea Transform during a coordination workshop held in Barcelona (2006). The final alfa estimations are given in Table 9.

2.5 Comparison with palaeo-seismic and slip rate information.

The seismicity parameters are crosschecked against other information when available. Based on geological interpretations, the slip rate along the Dead Sea Rift is estimated to be in the order of 5-10 mm/year. Equations 10 and 11 relate average slip rates to seismicity parameters.

$$\bar{M}o = \mu L W \bar{d} \qquad (10)$$

$$\bar{M}o = \sum_{m=5}^{M\max} N(m) Mo = \sum_{m=5}^{M\max} 10^{a-bm} 10^{1.5m+16} \qquad (11)$$

Table 5 presents the average slip rate inferred from the given (suggested) rate of cumulative activity (see Eq. 9). Table 5 also shows the postulated alfa value in the case of d=5 mm/year. Evidently there is a huge discrepancy between the two estimations, except for the Aragoneze deep where the 1995, Mw=7.1 earthquake took place. Present seismic activity suggests a slip rate of the order of 1-2 mm/year along the DSR (in agreement with the few geodetic GPS and In-SAR surveys recently conducted along the DSR, see e.g. Baer et al. 2000). It is assumed that the slip rate along the faults that are branches of the DSR is about 10-20 times slower than that of the DS rift (Y. Rotstein – Private communication). Here again, the present day seismic activity suggests a much slower annual slip.

The slip rate analysis indicates that the estimated seismicity parameters and the associated earthquake hazard assessment are NOT conservative. On the other end, these are upper bounds to the known seismicity of the analysed regions.

It should also be important to compare the evaluated seismicity level with the few available paleo-seismic information. Amit et al. (1995) suggest an average repeat time of ~2000 years for M>6 earthquakes in the southern Arava valley. Ken-Tor et al. (1998), Ken-Tor et al. (2001) suggest an average return period of 300 years for earthquakes stronger than M=5.5 in the Dead Sea basin.

Tables 6 and 7 show estimated return periods for magnitudes 5, 6 and 7 in each seismogenic zone. We may state that the estimations based on seismicity data are not in conflict with what is currently known from paleo-seismic studies. The most complete seismic history to the part of the Dead Sea Rift between southern Lebanon and the Dead Sea basin. In that part of the rift we expect a "return period" of about 75 years and 960 years for earthquake greater that M=6.0 and 7.0, respectively. These estimates match the documented history of earthquake catastrophes in the Holly-Land.

3. Horizontal Peak Ground Acceleration Attenuation Relationship

3.1 Concepts

The attenuation relationship is essential for performing the probabilistic seismic hazard analysis. The seismic activity along the Dead Sea Fault system is moderate. Consequently, despite of the relatively dense array of strong motion instruments operating in the region (see Fig. 8), there are insufficient acceleration data to enable develop a regional attenuation function and we adhere to empirical equations that were developed elsewhere. One of the most used attenuation function, for rock site conditions was that of Joyner and Boore (1981) shown also in Fig. 10. This relationship was widely used in the Middle East to prepare seismic hazard maps. The commonly used arguments for choosing this equation is the similarity found in the estimated Q – value for the California region and the EMR territory.

The necessity to reconsider the applicability of the Joyner and Boore (1981) attenuation low and consequently re-analyze the seismic hazard in the region stemmed from strong motion recordings of the 22-th November 1995 Gulf of Aqaba earthquake (Mw=7.2). This event is the strongest ever recorded in the region and it triggered strong motion accelerometers installed at distance of more than 400 km. Table 7 lists the earthquakes that have triggered regionally installed strong motion instruments. Ten stations of the strong motion instruments installed in Israel, Jordan and in Saudi Arabia, recorded this event. Other smaller earthquakes were also recorder. The distribution of the measured peak ground accelerations (PGA) with respect to distance and event magnitude is shown in Fig. 9.

The discrepancy between the predicted PGA values by Joyner and Boore (1981) and the observed PGA values was, at first, attributed to the local site conditions (site amplification factor) presented inherently into on-surface, free-field recorded observations. Assuming none of the sites, with registered strong motion records, behaved nonlinearly, the effect of the local site conditions is eliminated through de-convolving the observed accelerogram with the empirical transfer function of the recording site. The transfer function of each site has been empirically determined by the use of Nakamura's and HVSR techniques, utilizing free-field measurements for about a month, in association with geological information and geophysical refraction studies (see Zaslavsky et al., 2003). For most of the sites, the received soil/site amplification factor is in the order of 1.5.

Exclusion of the influence of local geological conditions does not yield perceptible changes in the PGA values. Accordingly, we were forced to make use of an already derived attenuation relationship elsewhere. More recently developed relationships have been considered (see Fig. 11). State-of-the-art developments are based on more quantitative, qualitative and reliable information as well as encompass more factors having influence on the phenomenon of the ground motion attenuation. Most of the selected expressions have been created within the last decade.

We finally chose the attenuation function of Boore et al. (1997) (hereafter noted as BJF). This attenuation law is a notable exception in the way it deals with the local site conditions. Most of the nowadays relationships approach the soil classification in rather simplifying manner e.g., rock/shallow soils, deep stiff soils and soft soils. The BJF relationship incorporates a site factor in terms of the average shear wave velocity, measured over the upper 30 m (100 ft). This as well as the equation term referring to the fault mechanism type is built-in features making BJF relationship attractively to our study. The relationship between the predicted PGA values by BJF and the observed PGA values are shown in Fig. 12.

The BJF attenuation function for strike slip faults and for Vs=620 m/s ("Generic Rock"), in Equation (12), has been implemented into the Probabilistic Earthquake Hazard Analysis for the Levant region.

$$\ln A = -0.055 + 0.525(M_W - 6) - 0.778 \ln r \ , \ r^2 = R^2 + 31.02 \qquad (12)$$

The standard deviation of predicting ln A is 0.52. R is the distance (km) to the fault rupture.

4. A probabilistic Seismic Hazard Map for Building Codes.

4.1 Definition

In accordance with the current Israeli code 413, and under the understanding that the first codes to be implemented in Jordan and by the Palestinians will also be based on probabilistic PGA estimations, we quantify the seismic hazard in terms of Horizontal Peak Ground Accelerations (PGA) which have a probability of 10% of being exceeded at least once within an exposure time of 50 years. PGA values are computed for rock site conditions.

The map in Fig. 13 is the main product of this study and provides the basic seismological information to be incorporated by the engineers in preparing their national building code.

4.2 Method

The most used approach for probabilistic assessments of PGA is the method formulated by Cornell (1968). This approach is followed by most a-seismic building codes (see McGuire et al., 1993).

The probability that the value Z will be exceeded within t years is given by the equation:

$$P_t(Z) = \sum_{j=1}^{K} \int_{m=M_{min}}^{M_{max}} P_t(m) \int_{r=R_0}^{R_{max}} P(r)(P(A \geq Z)| m,r) dmdr \qquad (13)$$

Where m denotes magnitude, r is the distance to the energy source and j is a seismogenic zone. $P_t(m)$ is the probability of occurrence of a magnitude m earthquake in zone j within t years. $P_t(m)$ is determined from equations (8) and (14). Equation (14) is based on the assumption that the random temporal occurrence of the earthquakes in zone j obeys Poisson distribution laws.

$$P_t(m) = 1 - \exp[-t/n(m)] \qquad (14)$$

It should be noted that we have no evidence that a characteristic earthquakes for the study region is justified, neither do we have data to determine the return period of possible characteristic earthquakes.

P(r) is the probability that the earthquake of magnitude m in zone j, will occur at a distance r from the analyzed site/geographical point. This probability is derived from the assumption that earthquake epicentres will be uniformly distributed within the area defining the seismogenic zone. There are currently insufficient data to accurately enough quantitatively characterize all linear sources (active faults) in the region.

$P(A \geq Z)$ is the probability that given the magnitude of the earthquake and the distance to the source, the ground motions A at the site will exceed the level Z. $P(A \geq Z)$ is computed under the assumption that the uncertainty is estimating the expected ground acceleration is log normally distributed with a know standard deviation (Eq. 12).

4.3 A probabilistic regional PGA code map for use in building codes.

A probabilistic ground shaking hazard map integrates the parametric contributions of the source-path-site continuum and portrays the spatial and temporal variations of a ground shaking parameter. Each value of ground shaking depicted at a point on a probabilistic map (such as the peak amplitude of ground acceleration, the value of spectral acceleration at a specific period, or the modified Mercalli intensity) is calculated by summing the contributions of all the earthquake sources. The value at each location represents a specific exposure time (e.g., 50 years), a specific probability of exceedance (e.g., 2-percent or 10-percent), and a specific site geology (e.g., bedrock, stiff soil, or soft soil). More than one map is required to characterize the ground-shaking hazard completely. Probabilistic ground shaking maps are used in model building codes, disaster scenarios, risk assessments, loss estimation, and seismic zonation.

A probabilistic map is the best way to integrate the parametric contributions of the source-path-site continuum, a model of the community's earthquake hazard environment, into a map format. Probabilistic ground shaking hazard maps can be used in model building codes, sitting and design criteria, disaster scenarios, risk assessments, loss estimation, and in seismic zonation.

The computations were performed by the computer program EZ-FRISK (Edition 2.1, 1995) developed by Risk Engineering Inc.

It should be noted that the integration (Eq. 13) is performed from **Mmin=4.0**.

The map in Fig. 13 presents the PGA values to be included in the building codes that utilize PGA and the seismic input parameter for building design.

4.4 Seismic Hazard Mapping of the Dead Sea Rift Region

In the Barcelona meeting a seismic source model for hazard computation through the whole Dead Sea Rift region was developed based on the discussion of key issues and national seismic hazard assessment strategies and the presentation of national data/maps and current practices. This harmonized source model for the Levant region was developed based on data and expert judgment from the different countries in the region after having exchanged information on the practices on hazard assessment in each case: the Lebanon case was presented by Ramy El Khoury; the Jordanian case was presented by Adnan Khasawneh; the Israeli case was presented by Avi Shapira; the Palestinian case was presented by Jalal Al Dabbeek; the Syrian case was presented by Mohammad Daoud; the Saudi Arabian case was presented by Mohammad S. Al Haddad. In addition, the participants compared PGA values along border lines

The procedure involved several testing and discussion to smooth out possible differences at border areas. The final model consists of 30 sources shown in Figure 14. Sources are enumerated in Table 9. Sources 1 to 24 stem from the original model developed for the Israeli building code 413 in which Yammouneh source has been extended to the North to reach latitude 37^{o}N and narrowed in the Southern part to avoid overlapping with the Sergayha branch assuming the same seismic behavior as the original source in the Israeli model. Sources N-Lebanon and S-Lebanon correspond to the Northern and Southern regions in Lebanon with assumed activity rates similar to neighboring regions and consistent with the assumptions in the hazard assessment in Lebanon as evaluated by R. El Khoury. Sirhan source stems from the Jordanian seismic source model, with the same geometry and the same seismic parameters. Sergayha and Damascus sources were developed in collaboration with M. Daoud to account for the seismic activity associated with Sergayha fault (branching from the main transform near the Sea of Galilee) and with Damascus fault. Seismic parameters have been associated to these sources from the estimates of rates of seismic activity. To the South, the source Sinai triple junction accounts for seismicity in the Red Sea. The associated seismic parameters for each of the sources are given in Table 9 according to the following:

$$\log N(M) = a - bM \quad , \beta = b \ln 10$$

$$N(\geq M) = \frac{\alpha e^{-\beta(M - M_{min})} - e^{-\beta(M_{max} - M_{min})}}{1 - e^{-\beta(M_{max} - M_{min})}}$$

where, N(M) is the annual frequency of earthquakes of magnitude M±dM and N(M) is the annual number of events with magnitude M or greater.

Supplementary to this work, we also computed the PGA values using the attenuation equation of Ambraseys et al. 1996. The results are shown in the maps in Figs. 15 and 16.

5. Engineering Characteristics of Buildings in the study region.

Many of the buildings in the territories of the Palestinian National Authority as well as in Jordan and great parts of Israel are much influenced by traditional practice and are also very similar with respect to the building materials. The problem of integrating concepts of existing building codes with the local practice is addressed by studying the applicability of different codes, evaluating the vulnerability of existing structure and their expected seismic performance and investigating the dynamic characteristics of buildings in the region.

5.1. Common Palestinian Buildings and Variations in Building Codes

It is well understood that the code provisions for design and construction of buildings using equivalent static load method is different depending on the specific situation of each country. This includes different parameters each of which has an effect on the value of the base shear coefficient (BSC). This situation applies for Palestine as different many codes are applied. To show the influence of applying different codes, a four and ten stories buildings with the same construction methods, were analyzed. All parameters were made constant except, those related to the structural systems considered which included the ductile moment resisting frame (DMRF), the moment resisting frame (MRF), the braced frame (BF), the shear wall (SW), and the bearing wall (BW). To calculate the BSC, twenty different codes were applied, for example, from the region: Egypt, Jordan and Israel, from Europe: Greece and Yugoslavia, from Latin America: Chile and Colombia, in addition to Japan, New Zeeland and UBC 85, 88 and 97. The results obtained had huge variations in the results despite that many parameters were fixed. Thus it was concluded that there is need for a seismic code for the region.

5.2. Vulnerability and Expected Seismic Performance of Common Palestinian Buildings.

There are different factors affecting the overall vulnerability of a structure in addition to its construction type. These factors are generally applicable to all types of structures. To emphasize the necessary data required for assigning the vulnerability classes of Palestinian buildings, most major Palestinian cities were investigated by collecting information based on the following parameters: site conditions, regularity and configuration of buildings (structural and architectural elements), adjacency (seismic joint), strengthening, earthquake resistant design (ERD), and importance of buildings.

The results of the previously mentioned investigations were arranged in standard tables for all cities included in the study, for each of which, a representative zone or more were selected for investigation.

Based on collected data and analysis, which was done according to European Macro-seismic Scale (EMS- 98), about one third of Palestinian common buildings have seismic vulnerability class A and 40 percent have seismic vulnerability class B.

The problems related to earthquakes in the Palestinian cities can be summarized, but not limited to, the following:

- High vulnerability to earthquake damages and losses, as a direct result of high percentage of weak buildings that do not comply with seismic resistance requirements.
- Lack of national programs and public policies on preparedness, mitigation and emergency response.
- Weak institutional capacity in disaster management and rescue operation.
- Lack of awareness by citizens and weak capacity of professionals, engineers and decision makers.

5.3 Dynamic Characteristics of Common Palestinian Buildings.

During the year 2003, engineers from engineering community (private sector) which are from Jerusalem, Nablus, Hebron, Bethlehem, Jenin, Tulkerm, Qulqilyah and Ramallah, and researchers from ESSEC have been engaged in a number of studies which aimed to characterize some of the parameters of dynamic response of common building in Palestinian territories.

To quantify the seismo-engineering parameters of buildings required for developing appropriate building codes, the Palestinian staff determined analytical models for different categories of RC buildings in West Bank. Comparative studies of the natural period values for each category were computed by using provisions of UBC97 and finite element model using SAP2000.

In the analysis, the determination of natural periods of buildings FOR CRACKED AND UNCRACKED SECTIONS has been done by using the plain and space frame models. Also, the studies included the effect of the following parameters on the values of natural periods of buildings:

- Masses of common buildings.
- Stiffness perimeter of concrete common wall system.
- Variation of column and beam (structural elements of the frames) stiffness.
- Openings of perimeter concrete walls.

5.4. Dynamic characteristics of common buildings in Jordan.

Researchers from Building Research Center developed analytical model models that represent different categories of RC buildings in Jordan. Computer models were built using SAP2000IN. Different soil conditions and seismic zones were considered. The models were dynamically analyzed. Results obtained were scrutinized and compared with those obtained through static force procedures of local and international codes (UBC 1997). The study is expected to result in approximate values for the fundamental period of vibrations (T) and the design base shear V for typical buildings in Jordan.

6. Site response investigations – the first step for estimating spectral accelerations.

6.1 Methods used to determine site amplification

The amplification of ground motions from earthquakes due to local geology is a great importance in earthquake hazard and risk evaluations. Various empirical techniques using earthquake data for site response estimations have been recently summarized and discussed, see Field and Jacob (1995); Satoh et al. (2001) among many others. The site response functions are best determined from recorded ground motion during an actual strong event by comparison with recordings at a nearby reference site located on rock (Jarpe et al., 1988; Darragh and Shakal, 1991; Satoh, et al., 1995; Hartzell, 1998; Reinoso and Ordaz, 1999 among many others). In most cases, mainly in regions where the seismic activity is relatively low as in the region of the Dead Sea Transform Fault system, this type of analysis is usually impractical. Many investigators evaluated site response functions from moderate to weak earthquakes motion (for example Tucker and King, 1984; McGarr et al., 1991; Field et al., 1992; Liu et al., 1992; Carver and Hartzell, 1996; Hartzell et al., 1996; Steidl et al., 1996; Zaslavsky and Shapira, 2000, Zaslavsky et al., 2000; Zaslavsky et al., 2002a, Zaslavsky et al., 2002b). However this approach requires a relatively high number of earthquake records. As an alternative, estimation of the local site response to seismic waves are based on ambient vibrations as proposed by Kanai and Tanaka (1968). Nakamura (1989,

2000) hypothesized that site response could be estimated by dividing horizontal component noise spectra by vertical component noise spectra. Results obtained by implementing the Nakamura technique (Ohmachi et al., 1991; Lermo and Chavez-Garcia, 1993; Zaslavsky et al., 1995; Seekins et al., 1996; Gitterman et al., 1996; Konno and Ohmachi 1998; Mucciarelli and Monachesi, 1998; Chavez-Garcia and Cuenca, 1998; Toshinava et. al., 1997; Shapira et al., 2001, Zaslavsky et al., 2002a, 2002b, Zaslavsky et al., 2003) support such use of microtremor measurements to estimate the site response for surface deposits.

In our investigations we focus on following approaches:

6.1.1. Analysis of the Fourier spectrum of microtremors.

The idea of evaluating site characteristics from microtremor records originated from the pioneer work of Kanai and Tanaka (1961). They pointed out that the predominant frequency in the horizontal spectra of microtremors is related to shallow, local geological conditions. Since then it has been reported that this technique has proved to be effective in estimating fundamental frequencies (Tanaka et al., 1968; Katz, 1976; Katz and Bellon, 1978; Ohta et al., 1978; Kagami et al., 1982; Zaslavsky, 1984, 1987). However, in most cases, due to the influence of artificial sources from dense population, heavy traffic and industrial activities, resonance frequency cannot be directly identified in the microtremor spectra (Zaslavsky et al., 2001).

6.1.2. Noise Spectral Ratio with Respect to Reference Site.

Kagami et al., (1982) proposed that the ratio of the horizontal components of the velocity spectra at the investigated site to those of a reference site can be used as a measure of the site response function:

$$R_k(\omega) = \frac{|H_S(\omega)|}{|H_r(\omega)|} \tag{15}$$

where H_s and H_r denote spectral amplitudes of the horizontal components of motion at the investigated site and those of the reference site, respectively. This approach is appropriate when the source and path effects of the recorded motions of the two sites are identical. In practice, however, these conditions can very seldom be met, especially when measuring microtremors.

6.1.3. Horizontal-to-Vertical Noise Spectral Ratio.

Nakamura (1989, 2000) proposed the hypothesis that the site response function under low strain can be determined as the spectral ratio of the horizontal versus the vertical component of motion observed at the same site. He hypothesized that the vertical component of microtremors is relatively unaffected by the softer near-surface layers. Hence, the site response is the spectral ratio between the horizontal component of microseisms (H_h) and vertical component of microseisms (H_v) recorded at the same location:

$$R_n(\omega) = \frac{|H_h(\omega)|}{|H_v(\omega)|} \qquad (16)$$

In other words, the vertical component of the microtremors on the surface retains the characteristics of horizontal microtremors at the bedrock (reference site).

6.1.4. Horizontal-to-Vertical S-Wave Spectral Ratio (Receiver Function)

This technique is based on Nakamura's hypothesis for S-wave (Lermo and Chavez-Garcia F.J., 1993)):

$$R_s(\omega) = \frac{|S_{sh}(\omega)|}{|S_{vs}(\omega)|} \qquad (17)$$

where S_{sh} and S_{sv}, respectively, denote horizontal and vertical amplitude spectra computed at the same investigated site, from S-waves.

Receiver function was introduced by Langston (1979) to determine the velocity structure of the crust and upper mantle from teleseismically recorded P-waves. Langston made the assumption that the vertical component of motion is not influenced by local structure, whereas the horizontal components, owing to the geological layering, contain the P to S conversion.

6.2 Assessments of site effects in urban areas across Israel.

6.2.1 The towns Lod and Ramla.

Throughout the history, Lod and Ramla were affected by strong earthquakes.

The last destructive earthquake of occurred on July 11, 1927 caused the destruction of a great part of these towns reaching the seismic intensity of VIII on the MSK scale. Such a high intensity from a relatively distant earthquake was probably the results of the local site effects. Ambient vibration measurements (Nakamura technique) involved over 360 individual measurements (grid of 250m x 250m), were carried out (Zaslavsky et al., 2001). The map in Fig. 17 shows the distribution of the fundamental frequency. The investigated area exhibit peaks at dominant frequency between 0.6 to 2.5 Hz. with amplification factor from 3.5 up to 7 (Figure 18). The shear-wave structures for different sediments were deduced by trial-and-error fitting of the calculated functions to the empirical transfer functions.

6.2.2 Kefar Sava city.

Geological conditions in the Kefar Sava area are similar to those in Ramla-Lod, therefore high level of amplification was expected. The necessity of carrying out measurements in Kefar Sava is emphasized by the fact that Kfar Sava is a relatively new city and thus seismic intensity information from historical destructive earthquakes to indicate zones of higher earthquake hazard is not available. In a study by Zaslavsky et al (2003b), the site effect on seismic ground motion was estimated by applying two experimental methods: H/V spectral ratio from ambient vibration at 340 sites (Nakamura technique) and H/V spectral ratio from seismic events at 3 sites (receiver function). The satisfactory agreement between the receiver functions and the ambient vibration H/V spectral ratios facilitated extrapolation of ambient vibration measurements to estimate site response. In Figures 19 and 20 we present maps that reflect the fundamental characteristics of site effects in the study are: predominant frequency and maximum relative amplifications. Dense gird of measurements enabled mapping of local geological structures that were not identified on structural map.

6.2.3 Kiryat Shemona town.

This city is situated at the transition between two major segments of the Levant Transform. The most recent large earthquakes in the region occurred in 1759 and in 1837. These earthquakes had a maximum MMS intensity of 10 and caused severe loss of life and damage in northern Palestine and in Lebanon. The ambient noise survey was carried out at 285 sites (Zaslavsky et al., 2002c). The site response is obtained in terms of H/V spectral ratio and in terms of ratio of the horizontal components spectra at the investigated site and those at the reference site. In some cases the shape of spectral ratios and level of spectral amplifications obtained from two methods are similar. However, in many cases, the soft-to-hard spectral ratios do not reproduce the frequency at which the maximum amplification occurs.

In Figures 21 and 22, we plotted distributions of the fundamental frequency and of maximum amplification level. As shown in these figures site amplifications range from 2.0 to 7.0 within the frequency band 2.0-13.0 Hz in the city and from 2.0 to 5 in the frequency band 0.7-13 Hz outside of the city. These results suggest that there is significant shear-wave velocity change and considerable variation of sediments thickness. We strongly recommend that prediction of different seismic shaking characteristics during large earthquakes should be based on the experimental site response functions obtained over a relatively dense gird of measurement points.

6.2.4 Towns of Arad and Dimona.

These towns are situated near the Dead Sea rift. The most recent large earthquake in the region occurred on July 11, 1927. This earthquake caused the destruction of several cities and towns reaching the seismic intensity of VIII on the MSK scale, with a death toll of 285 people and 940 wounded. The earthquake on February 11, 2004, M=5.2, was widely felt and caused some panic. In order to estimate site response functions empirically 275 and 110 sites were instrumented in the towns of Dimona and Arad, respectively (Zaslavsky et al., 2004). The H/V spectral ratio from ambient vibration technique was used to estimate site response. Additionally, weak ground motion amplifications were determined using H/V spectral ratio for S-waves generated by explosions at three sites. Similar response functions were obtained from two source facilitated extrapolation of ambient vibration measurements for site response estimation. Distributions of resonance frequency and corresponding maximum amplification factor are depicted in the maps. The site response functions exhibit peaks of amplification factors ranging from 2 to 7 in the frequency range of 1 to 9 Hz for Dimona; and a factor of 2 to 4 in the frequency range of 2 to 7 Hz for Arad. Figures 23 and 24 show zone divisions in the towns of Dimona and Arad, respectively.

6.2.5 Towns of Afula and Bet Shean.

These towns are situated near the Dead Sea rift. The most recent large earthquake in the region occurred in 1759 and 1837. These earthquakes had a maximum MMS intensity of 10 and caused severe loss of life and damage in northern Palestine and in Lebanon. In addition, the town of Bet Shean suffered major destruction from a nearby earthquake in January 749, which caused essentially a destruction of the flourishing city at that time. The horizontal-to-vertical spectral ratios of ambient noise were used to approximate the fundamental resonance frequencies of the subsurface and their associated amplitudes. About 210 and 300 sites were instrumented in the towns of Bet Shean and Afula, respectively (Zaslavsky et al., 2005). The soil sites exhibit H/V peak amplitudes ranging from 2 to 7 in the frequency range 0.9 Hz to 13 Hz for Bet Shean. H/V spectral ratios in the Afula area reveal two resonance peaks corresponding shallow and deep reflectors. The first resonance frequency varies from 0.35 Hz up to 12 Hz with amplitudes of 2-8 units. The second resonance peak shows amplitude of units 2-8 in the frequency range 1 Hz to 10 Hz. These results imply significant variations in the shear-wave velocities across the area and considerable variations of sediments thickness. Figures 25 and 26 show zone divisions in the towns of Bet Shean and Afula, respectively.

6.2.6 Continuation of measurements in the Hashfela area.

For microzoning goals about 550 ambient noise measurements across the study area of 128 km^2 including the towns of Petah Tikva, Hod-Hasharon and Rosh HaAyin, partially Ramat Hasharon and Qiryat Ono and adjoining settlements Elishma, Neve Yaraq, Givat Ha-Shlosha, Kefar Sirkin, Nahshonim, Givat Shemuel, Ganey Tikva and others, have been done on different grid scales. Majority of measuring sites were spatially distributed each 500 meters (Zaslavsky et al., 2006).

High variations in the observations led us to increase the density to a grid spacing of 250 m and in some sites even 150 m.

Analysis of measurement results over the study area showed that Fourier spectra of horizontal and vertical components and H/V spectral ratios are categorized by shape considering two resonance peaks; and correlation with the geological features exists.

Measurement results indicate site amplifications ranging from 2.5 up to 7-8 decreasing from the west to the east within the frequency band 0.4-13 Hz. In the first approximation the resonance frequency has general trend to increase toward the east. Owing to a higher resolution, the frequency map not only identifies and traces the structural blocks and faults detected in the structural map of the top Judea Gr. but also reveals the new tectonic features. In the western part of the study area, at the Coastal Plain, sharp shift of the first resonance frequency from 0.3 Hz up to 1.2-1.3 Hz indicate change of the fundamental reflector from the Judea Gr. to calcareous sandstone of the Kurkar Gr. Figure 27 shows he distribution of the fundamental frequency. Figure 28 shows the distribution of the amplitude associated with fundamental frequency.

6.3 Site response zoning of the coastal planes of Israel.

About 4 million inhabitants in Israel, almost two third of total population of the country, live in the strip of seacoast (between the towns of Ashqelon and Haifa) and in the Hashefela region. Owing to the proximity to seismically active faults as well as the population density here, this region may be considered a high seismic risk zone. In order to characterize the seismic response of the seacoast and HaShefela areas, the ambient noise survey (Nakamura method) was carried out at 550 sites (Zaslavsky et al., 2002d; Zaslavsky et al., 2002e; Zaslavsky et al., 2003c). Figures 29 and 30 summarized the distribution of fundamental resonance frequencies of the soil layers and their associated maximum amplification factors. We should say that only when the fundamental frequency and amplification maps were constructed, was the strong correlation between features of geological structure and measurement results revealed. In particular, we found out that the impedance contrast between soft sediments and hard bedrock, responsible for site effect at Coastal Plain and Hashefela regions is formed by different reflectors. The observed resonance frequencies and their amplifications were correlated with analytical functions that correspond to the 1-D subsurface model. A detailed comparison of the analytical and empirical values constitutes a low-cost, efficient and fast procedure in order to establish the spatial dependence of both suitability and reliability of the method, improvement of models assumed and delimitation of those areas for which in-depth surveys are needed for proper assessment of soil response.

6.4 Initiating and updating building codes in the study area.

The MERC program emphasizes research that will translate into impacts on the economy and the environment. The potential outputs of the project presented here comply with this idea as it has a substantial potential development impact. This message was conveyed by the collaborating institutions to their authorities. Consequently, the importance of the project and its practical impacts where highly appreciated by high-level authorities.

In Israel, the evaluated hazard map is used to update the current building codes (during 2002, the Standards Institution of Israel has adopted the updated hazard map). The Palestinian Authority has not yet adopted a building code. However, the notable involvement of the engineering community across the Palestinian cities in the project, has expedite the process of enforcing a-seismic building practice alongside with increasing awareness of the planner.

The impact on the Jordanian authorities is in the process of being developed together with the increasing involvement of the Jordanian engineering community. Actually, the process of providing the Jordanian engineers with a seismic building code has already started.

6.5 Contribution to Earthquake Preparedness plans.

The project has increased the awareness of earthquake threat and the project results are being used by the local municipalities and by the engineering community. In Israel, the advancements in determining local site effects have enabled the development of software to simulate earthquake scenarios to be used in Earthquake Risk Management operations.

6.6 Facilitating empirical determinations of site effects and the dynamic characteristics of buildings.

A portable GII-SDA system was provided to NRA and to ESSEC to enable site response and building response investigations. The last project's workshop in Aqaba (Jordan) was dedicated to train the technical staff of NRA and ESSEC in operating and maintaining this system. In addition, newly developed software for data analysis (the SEISPECT program) was developed by GII, provided to the participating institutions and exercised through the Aqaba meeting. The systems are operational for future site response investigations and for measuring the dynamic characteristics of existing building by NRA and ESSEC.

6.7 Enhancing seismicity monitoring and recording of strong ground motions.

Monitoring of seismic events requires cooperation of all the countries in the region. By the installation of new 5 strong motion accelerometers in Jordan and 5 in the territories of the Palestinian Authority, the capabilities and chances to record strong ground motions of engineering are enhanced significantly. Future cooperation will be needed to analyze the data and maintain the systems. The strong motion accelerographs (ETNA manufactured by Kinnemetrics, California) were delivered to ESSE and to NRA and are in operation. In parallel, the project has provided NRA, Jordan with the hardware and software for a new PC based seismic data acquisition system (GII-SDA). This purchase has improved the routine operation of the Jordanian Seismic Network. Following the NRA's requirements for upgrading it national seismic network, GII has provided that acquires data from the national seismic network. GII has added new software for reformatting of the data to facilitate routine data processing by different s/w including the SEISAN. The system is in operation and provides seismic data.

IMPACT, RELEVANCE and TECHNOLOGICAL TRANSFER.

1. General Comments.

The most populated areas of Israel, Jordan and the West Bank/Gaza are vulnerable to strong earthquakes. Such earthquakes are a threat to the safety, social integrity and economic well fare of the people in that region. To reduce earthquake damage, building codes should be continuously updated to reflect the improvement in our understanding of the effect of earthquakes on buildings.

This research project will have a lasting benefit because of the potential for saving lives and protecting the built environment.

This project was made possible only through regional cooperation in the fields of seismology and engineering. However, since September 2002 we have experienced intensive hostilities in the region. This unfortunate situation had a sever impact on the project: Scheduled meetings, workshops and other activities were cancelled. However, despite political difficulties and due to the well-recognized importance of our work, we managed to make some useful progress.

One of the solutions to maintain cooperation was through the development of a project web-site where detailed information, elaborated reports, lists of publications and products are presented. The site's address is: WWW.RELEMR-MERC.ORG.

It should also be emphasized that the US Geological Survey and the UNESCO initiative **RELEMR** (Reduce Earthquake Losses in the East Mediterranean Region) has played a major role in facilitating meetings and workshops between the participants, also enabling scientists and engineers from other countries in the region, to participate in the discussions and share their knowledge and experience.

We made significant progress through working over the internet and during RELEMR meetings in Spain, Cyprus, Turkey and Jordan. Eventually it became evident that without mutual visits and field operations, we can not make a significant progress. At this stage we asked the US-AID/MERC to extend the project without additional funding. Extension for additional 18 months enhanced the chances to conduct the necessary work and in January 2004 we managed to organize, under the auspice of the Jordan Royal Society and RELEMR, a 2 weeks workshop in Aqaba, Jordan.

The investigators through publications, presentations and a website have disseminated the results of the project to the appropriate audiences.

ACTIVITIES AND PRODUCTS

1. **Meetings and Training**

- RELEMR Workshop, Istanbul, Turkey, October 1998
- 27-28 July 1998: discussions and preparation at GII of the full proposal with Mr Abdel Qader Amrat (Jordan) and Dr. J. Dabbeek (Al Najah University).
- 15 December 1999: Eng Amrat and Dr. Jallal Dabbeek –meeting at GII after being granted the US AID MERC grant.
- RELEMR Workshop, Nicosia, Cyprus, May 1999.
- Amman first meeting 26 January 2000 at NRA.
- First Amman MERC workshop 27-30 March 2000- Jordan (Avi Shapira (GII), Yuli Zaslavsky (GII), Nitzan Rabinowitz (GII), Yoseph Leonov (GII), Abdel Qader Amrat (NRA), Darwish Jaser (NRA), Jallal Dabbeek (ESSEC), Radwan El Kelani (ESSEC), Awni Batayneh (NRA), Ahmad Al-Masri (NRA), Eid Al-Tarazi (HU), Abdel Hakeem El-Jawhari (ESSEC), Khaled Kahhaleh (RSS), Walter Hays (ASCE), Ma'in Hiyari (NRA), Mohammed Naser (NRA), Wajdi Al Ramimi (NRA), Omar Mayas (NRA), Waleed Olimat (NRA).
- Seismic Calibration in the Eastern Mediterranean Region, Istanbul, Turkey, May-June 2000.
- Second Nablus workshop July 2000- Workshop and training course on the ETNA strong motion accelerometer organized by ESSEC.
- Earthquake Hazard and Risk Assessment Methodology, Istanbul, Turkey, October 2001.
- Earthquake Hazard Assessment Practice and Velocity Models and Reference Events in the Mediterranean Region, Santa Susanne, Spain, May 2001.
- Reference Events on/near the Dead Sea Rift, Paris, France, October 2002.
- Seismic Analysis and EQ Hazard Assessment in the Mediterranean Region, Nicosia, Cyprus, September 2003.
- Third MERC meeting, Aqaba, Jordan –January 2004
- Fourth MERC meeting within the RELMER meeting, Ankara, Turkey, January 2005.
- Fifth MERC meeting within the RELMER meeting, Chania, Greece, September 2005.
- Sixth MERC meeting within the RELMER meeting, Valetta, Malta, April 2006.
- Seventh MERC meeting within the RELMER meeting, Barcelona, Spain, December 2006.

2. **Productivity**

Here are the main products of the project (see also the web site):

- Compilation of the geological and geophysical information in Israel and in Jordan by the Geological Survey of Israel, The Geophysical Institute of Israel and the Geology Directorate of the Natural Resources Authority in Jordan.

- Interferometric synthetic aperture radar (InSAR), the only source of information for surface deformation in the Gulf region, was used to calculate pre-, co- and post-seismic deformation interferograms. This data, integrated with source mechanism and moment distribution based on inversion of teleseismic broad band waveforms, served to constrain a 3D numerical elastic model of the mainshock rupture. The model was used to calculate synthetic interferograms and to improve the estimation static source parameters by an iterative process of minimizing the differences between the observed and the synthetic interferograms. Finally, the static stress changes induced by the main shock were calculated, showing a very good agreement with the hypocenters of major aftershocks and suggesting a mild stress increase on the fault segment to the north of the main shock rupture plane.
- Compilation of a UNIFIED earthquake catalogue for the period 0 – 1999 (including unification of the magnitude scale).
- A seismogenic zone scheme for the region (see Fig. 4).
- Assessment of the frequency magnitude relationship for each of the seismogenic zones.
- Intra-national discussions with the engineering communities in the Palestinian territories (ESSE), Jordan (NRA & Association of the Eng.) and Israel (GII & the Inst. of Standards of Israel).
- Complete analysis of strong ground motions relevant for the project.
- ***Developing a regional seismic hazard map to be implemented in building codes.*** The hazard parameter is PGA, estimated for a probability of occurrence of 10% in an exposure time of 50 years, for rock site conditions.
- Upgrading software for data acquisition (***GII-SDA***).
- Developing new software (program ***SEISPECT***) for data processing of the data acquired by the project (seismograms and accelerograms).
- The acquired ARCVIEW ***GIS software*** is used to display earthquake catalogue data and to serve as a platform for visualizing earthquake scenarios.
- Examination of buildings with respect to their adherence to different building codes.
- Mapping site effects of the most populated parts of Israel and provide first approximation spectral accelerations amplification levels. The later is used to examine and demonstrate the applicability of the SEEH procedure (Boore, 1983; Shapira and van Eck, 1993).
- Quantification of the impact of different codes on the structural design.
- Development of scaling laws of dynamic source parameters of local and regional earthquakes and attenuation of seismic energy across the region.
- Installation of the new strong motion accelerometers (ETNA) in Jordan and in the territories of the Palestinian National Authority.
- Upgrading the current seismic monitoring of the JSN (installation of the SDA system in

NRA, Amman).

- Providing each of the NRA and ESSEC seismological units with a portable system for site response and building response investigations.
- Developing the project's web-site www.relemr-merc.org.

The Aqaba meeting in January 2004, performed under the auspice of RELEMR was indeed a "break through". It provided the necessary tools for performing site investigations and empirical determinations of dynamic characteristics of buildings. Seismic microzoning studies were completed during the report period for the cities of Aqaba, Tafila, Karak and Amman in Jordan and for the cities Kiryat Shemona, Dimmona and Arad, Israel, in addition to local studies for sites in Eilat, Lod and Ramla (Israel).

Farther modifications were made to the software package, SEISPECT, which is used for those investigations.

An earthquake of magnitude 5.1 occurred in the Dead Sea basin on February 11, 2004. It was followed by an Mw=4.7 earthquake on July 7, 2004. These events were widely felt all over the Levant and triggered a number of strong motion instruments. The acceleration recordings provided a good opportunity to compare predicted seismic hazard functions with observations. It was very encouraging to observe a high level of agreement between observed and predicted amplitude spectra and consequently, a relatively good agreement between the observed and the predicted acceleration response spectra at different sites.

In order to assess the dynamic characteristics of different categories of reinforced concrete buildings in Jordan, representative analytical models were developed by the Royal Scientific Society of Jordan using SAP2000N. The parameters investigated included the level of seismic hazard (different seismic zones were considered), soil conditions as well as the building height (number of stories). The models were analyzed dynamically using the response spectrum of the Uniform Building Code (UBC 1997). Results of the dynamic analyses were compared with those obtained through the application of the static force procedure of local and international codes. Based on the fact that low-rise stone-concrete buildings (buildings that utilize stone masonry walls backed by plain concrete as exterior walls) are the most dominant in the Jordanian residential building stock, an effort was made to assess their seismic vulnerability. The majority of the Jordanian residential buildings were designed and constructed without any due consideration of providing an adequate level of lateral load resistance. The resulting deficiencies and weak links in stone-concrete buildings were analyzed. A comprehensive questionnaire targeting both designers and builders was devised to assess the seismic vulnerability of this type of construction and build what maybe described as an "expert opinion" regarding the seismic response of typical residential buildings. Furthermore, recommendations to overcome the observed structural deficiencies and to improve the construction practice were given. However, in order to implement these recommendations into the construction practice, experimental investigations are required to assess their viability and applicability. Further research and investigation is deemed necessary to assess the seismic response of the common Jordanian structural systems and to develop a suitable methodology for the assessment of their seismic vulnerabilities. Future research needs are also discussed.

The Jordanian scientists completed a set of probabilistic hazard maps for rock conditions, in terms of Peak Ground Acceleration, PGA, and of Spectral Acceleration, SA, (at 0.1, 0.2, 0.3, 0.5, 1.0, and 2.0 s period) for a probability of exceedence of 10% in 50 years using the attenuation relationships of Ambraseys et al. (1996).

To determine the effective natural period and stiffness of common buildings, the Earth Sciences and Earthquake Engineering Centre of En Najah University, Nablus, performed several structural analysis by using 2D and 3D models for ten buildings (also using the structural analysis programme SAPS2000). Also, the natural period of selected buildings has been measured experimentally by using the micro tremors (ambient vibration measurements).

Comparing the results of the natural periods obtained applying the UBC97 and IBC2003 with those analytically and experimentally calculated, the following was concluded:

The natural period of building computed using the UBC97 method is a general value, (no specific structural system or mass are specified). A more exact value can be determined using dynamic analysis.

The natural period of local framed building determined using dynamic analysis is larger by about 25% - 30% of that computed by using the UBC97 method, because of the large mass. Also, the natural period of perimeter walls building determined using dynamic analysis is less by about 12%-30% than that computed by using UBC97 method.

The natural period determined using space frame analysis is less than that determined using plane frames analysis because of the increase of stiffness of the slab.

In frame buildings, the natural period of interior frames is larger than that of exterior frames because of larger mass (both have the same stiffness). And in the perimeter wall buildings, the natural period of the interior frame is larger than that of exterior frame because of the larger mass and much less stiffness than the exterior frame.

The natural period of buildings is decreased by about 10% as the mass of building is decreased by 20% in frame and perimeter wall buildings.

The workshop in Barcelona (December, 2006) can be considered as the highlight of this project. The fundamental seismic hazard map for building codes in Jordan, Israel and the Palestinian territories was completed in an earlier stage of this MERC project a few years ago. As additional knowledge was accumulated and more work was done towards the drafting and implementing building codes (see previous project reports) it became essential to merge new information and re-examine previous evaluations. Consequently, the main goal of the Barcelona (2006) meeting was to compare different versions of seismic hazard maps proposed for building codes in Jordan and Israel into one regional map, which also complies with recent hazard assessments in Lebanon, Syria and neighboring parts of Egypt and Saudi Arabia. Taking into account the above mentioned research and studies (presented in various recent workshops) we devoted large part of the time and efforts for updating of the catalogues and software (prior to the meeting) and reproduced seismic hazard maps for the whole region. In addition, the Barcelona meeting served as a concluding meeting for a series of meetings and studies that were done at each participating institute. Those studies were presented and discussed. Since the values of seismic hazard assessment near the borders, as presented in the maps of each country along with mutual consultation, were very similar it was relatively easy task to create a uniform hazard map and obtained an harmonized version in those regions. We were fortunate to have a group of scientists from non-participating countries (i.e. Saudi Arabia, Lebanon, and Syria). Those researchers were willing to share with us their knowledge and experience, and their seismological catalogue as well. The net result, which was not originally planned, was that the original map was expanded to include more regions in those countries, beyond The Palestinian Authority, Israel and Jordan.

3. Scientific impact of cooperation

The meetings in Ankara, Turkey, in Chania, Crete, and in Valetta, Malta, facilitated again by the RELEMR initiative, provided the opportunities for the project participants to meet and discuss the results. Both meetings emphasized on earthquake engineering. The RELEMR meeting in Ankara provided training on analysis of strong motion recordings.

During the meeting in Chania and Malta, project participants from Jordan, The Palestinian National Authority, Israel and the USA discussed the topic of vulnerability of buildings to earthquakes and presented the different approaches used in their countries for assessing building vulnerability. This workshop was followed by part I workshops on the HAZUS (Hazard US) software developed by/for the US Federal Emergency Management Agency for assessing the impact of earthquakes, and a workshop (parts I& II) on the stochastic method for the prediction on seismic ground motions, presented by Dr. D. Boore of the US Geological Survey.

The ESSEC wisely used the materials and systems provided by the project to be implemented in training courses on:

Measuring micro tremors by the 12 channel amplifier, using the Seismic Data Acquisition (SDA), and the Seismic Interpretation Software (SIP), and the software for spectral analysis of seismological data (SEISPECT), and measurement by 24 channel seismograph.

The training included theoretical and practical parts: the theoretical part included an introduction to the software, data processing using existing data and data analysis and interpretation. While the practical part included field training on setting up the equipment and installing and operating the field software for the seismic data acquisition (SDA).

The participants in these training courses were students from the faculty of Engineering at An-

Najah National University as well for junior researchers and engineers from private and governmental sectors. The courses focused on the benefits of the micro tremors as a rapid and inexpensive technique for assessing site effect by determining the predominant periods of the sites during earthquakes.

The last meeting in Barcelona (Dec. 2006) aimed at merging the hazard maps used in the Building Codes of Jordan and Israel. Due to participation of other scientists from countries that do not participate in the project the geographical boundaries of the map are beyond the borders of Jordan, Israel and Palestinian Authority.

4. Description of project impact

We are proud to report that the outcome of the projects activities has been implemented in both Israel and Jordan.

In Israel, the Standards Institution of Israel has adopted (2004) the seismic hazard map in the Israeli Building Standard 413. In 2005 a number of hazard maps (Peak Ground Accelerations for different levels of probability of occurrence) were prepared for an updated code for the safe construction of bridges.

In Jordan, the Jordanian government took over a responsibility to develop the Jordanian Buildings Code .The Jordan code loads and forces shared the country into four seismic zones A, B, C, D the most active risk in zone A along the Dead Sea rift valley. The scientific work described above is part of these efforts.

During 2005, the ESSEC and its staff from engineering community made the required preparations and conducted three workshops in the Palestinian main cities. The main goal of the workshops was to highlight the importance of hazard maps, building code requirements and seismic vulnerability of common buildings which was accomplished through the project Earthquake Hazard Assessment for Building Codes. The target groups, in those workshops, were engineers and planners from consulting firms, contractors, NGOs, PNA Institutions and International organizations working in the area. The invitations and announcement for participating in the workshops were performed through advertisement in the local newspapers and invitation letters to different governmental and non-governmental institutions.

The merged seismic hazard map (one of the main topics) will serve as the seismic hazard map in the Building Code of each country and will be a useful source of information for engineers and urban planners.

5. Strengthening of data exchange and cooperative research of Middle East institutions

Technical assistance was provided by GII for the repair and upgrading the seismic systems and the associated software.

The recent workshops on building vulnerability, HAZUS and Synthetic accelerations have significantly improved the capabilities of the Middle East institutions to better evaluate earthquake hazards for improved building codes.

The hands on workshops provided better understanding and familiarity with processing software and evaluation procedures.

The project has strengthened the data exchange between the participants. It is strongly manifested every time a felt earthquake occurs in the area.

All the workshops and especially the last one in Barcelona (Dec. 2006) have proved us that data exchange and cooperative research is a feasible target. The final outcome (the regional hazard map) is composed based on the knowledge and experience of participating and non-participating countries.

GII maintained the project's web site which provides means for continuous interaction and communication between the participants over the Internet. Furthermore, it appears that many people, which are not part of the project, from various countries in the Middle East, enter the web page and take advantage the reports and publications there.

The only practical way to conduct meetings between Middle East participants is to continue doing it under the umbrella of the RELEMR meetings. However we found out that these meetings are also useful in other ways: 1) it is a very good opportunity for the participants to expose the work and studies that were done; 2) the scientific discussion serves as a critical review of the studies.

6. Future work

There is strong evidence to suggest that the impact of the project will be sustainable beyond the end of MERC funding especially when the political situation improves. In summary, the project outcome is expected to be integrated into the codes of the region and will be relevant to the development of the region for years to come.

This specific project terminated on March 31, 2007. Since we view this project as a first major step among many in the domain of cooperative seismology and construction engineering in the Middle East we plan to further pursue the goal of preparing the seismological and engineering information needed for improved building codes. Realizing that the main goal of this project namely; implementation of modernized building codes in the region, has been achieved and realizing that most of the available funds have been used, we shall try to emphasis on future joint meetings (apparently, possible only under the umbrella of RELEMR) and farther elaborate on the following topics:

1) Site effects and their implementation in building codes.
2) Synthetic accelerograms and Shake maps.
3) Earthquake vulnerability of buildings in the region.
4) Assessment of earthquake losses.

5) GII will continue to maintain the project's web site which provides means for continuous interaction and communication between the participants over the Internet.
6) Produce colored map for public distribution of loci of epicenters in the project area.
7) Risk maps (i.e. for main or selected cities).

PROJECT MANAGEMENT AND COOPERATION

1. **Managerial Issues**

The project was fairly well integrated into the RELEMR activities, especially at the later stages of the project and provides a platform to conduct meetings between the project collaborators. Apparently, the only practical way to conduct meetings between Middle East participants was to continue doing it under the umbrella of the RELEMR meetings.

Much of the cooperation is performed over the internet. GII's programmer maintained the project's web-site which is constantly being updated.

2. **Special Concerns**

Everybody was very much concerned about the political situation in the region. We were thankful for receiving the prolongation for another 18 months, which helped us in fulfilling our final goal. The collaborative aspect of the project, as was originally planned, was based on a series of meetings and workshops to be held at the premises of the collaborating institutions. The unfortunate political situation did not allow such meetings to easily occur on a frequent basis. We made significant progress through working over the internet (see www.relemr-merc.org) and during RELEMR meetings.

3. **Cooperation, Travel, Training & publications**

Cooperating investigators traveled to the RELEMR meetings in various sites and countries. The RELEMR meetings facilitated the execution of the project.

Publications and Reports associated with the project are presented on the project's web site: www.relemr-merc.org

4. **Future cooperation & work**

There is strong evidence to suggest that the impact of the project will be sustainable beyond the end of MERC funding especially when the political situation improves. In summary, the project outcome is expected to be integrated into the codes of the region and will be relevant to the development of the region for years to come.

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Table 1: Estimation of the seismicity level along the Dead Sea Rift.

		Observed			Suggested	M>4		M>5		M>6	
Zone	**km**	**N(M>2)**	**Mmax**	**N/km**	**Alfa**	**events/y**	**years**	**events/y**	**years**	**events/y**	**years**
Arnona	100	25	7.5	0.25	20.00	0.241	4	0.026	38	0.003	358
Aragoneze	56	62	7.5	1.11	11.20	0.135	7	0.015	68	0.002	640
Elat	56	23	7.5	0.41	11.20	0.135	7	0.015	68	0.002	640
Arava	164	11	7.5	0.07	11.00	0.132	8	0.014	69	0.002	651
Dead sea	100	14	7.5	0.14	20.00	0.241	4	0.026	38	0.003	358
Jordan v.	100	15	7.5	0.15	20.00	0.241	4	0.026	38	0.003	358
Hula	60	9	7.5	0.15	12.00	0.144	7	0.016	63	0.002	597
Roum	80	10	7.5	0.13	16.00	0.192	5	0.021	48	0.002	448
Yamuneh	280	9	7.75	0.03	56.00	0.674	1	0.074	14	0.008	126

Table 2: Estimation of the seismicity level along fault systems that are branching-off the Dead Sea Rift.

		Observed			**Suggested**	**M>5**		**M>4**	
Zone	**km**	**N(M>2)**	**Mmax**	**N/km**	**alfa**	**N**	**Years**	**N**	**Year**
Carmel	140	9	6.5	0.06	9.00	0.011	87	0.108	9
East Sinai	56	4	6	0.07	2.80	0.003	304	0.033	30
Thamad	108	3.5	6	0.03	5.40	0.006	158	0.064	16
Barak	64	3	5.5	0.05	3.20	0.003	354	0.037	27
Malhan	28	0.33	5.5	0.01	1.40	0.001	809	0.016	62
Arif	52	1.2	5.5	0.02	2.60	0.002	435	0.030	33
Paran	120	1.1	6	0.01	6.00	0.007	142	0.071	14
	280	11.7		0.04					

Table 3: Estimation of the seismicity level in areas of background seismicity.

		Observed			Suggested	M>5		M>4	
Zone	KmSqr	N(M>2)	Mmax	N/Km^2	Alfa	N	Years	N	Years
Suez	31774	**65**	**7**	2.05	65.00	0.085	12	0.78	1.28
Cyprus	40863	**110**	**8**	2.69	110.00	0.307	3	2.18	0.46
Bet She'an	1065	**9**	**6.5**	8.45	9.00	0.011	87	0.11	9.27
E. Med.	73799	**38**	**6.5**	0.51	36.90	0.047	21	0.44	2.26
Central Isr.	4093	**2**	**5.5**	0.49	2.05	0.002	553	0.02	42.12
N. Jordan	19404	**5.2**	**5.5**	0.27	9.70	0.009	117	0.11	8.88
Palmira	22164	**11**	**6**	0.50	11.08	0.013	77	0.13	7.59
W. Sirhan	28507	**17**	**6**	0.60	14.25	0.017	60	0.17	5.90
Galil	1930	**1.1**	**5.5**	0.57	0.96	0.001	1173	0.01	89.33

Table 4: Level of Seismicity in the fault zones and slip rates of the main faults

			Obs.	Corresp.	Suggest.	Corresp.	Alfa if
Zone	**length km**	**Mmax**	**Alfa**	**slip rate**	**Alfa**	**slip rate**	**5 mm/y**
Arnona	100	7.5	25	1.3	20	1.1	90
Aragoneze	56	7.5	62	6.0	11	2.0	50
Eilat	56	7.5	23	2.3	11	2.0	50
Arava	164	7.5	10	0.4	11	0.4	145
Dead sea	100	7.5	14	0.8	20	1.0	90
Jordan v	100	7.5	15	0.8	20	1.0	90
Hula	60	7.5	9	0.9	12	1.9	52
Roum	80	7.5	10	0.7	16	1.4	60
					Suggest.	Corresp.	Alfa if
Zone	**length km**	**Mmax**			**Alfa**	**slip rate**	**0.3 mm/y**
Carmel	140	6.5			9	0.12	20
East Sinai	56	6			2.8	0.04	20
Thamad	108	6			5.4	0.04	39
Barak	64	5.5			3.2	0.02	41
Paran	120	6			6	0.04	41

Table 5: Estimated return periods of earthquakes in the fault regions.

Zone	M≥5 years	M≥6 years	M≥7 years
Arnona	30	300	4000
Aragonese	50	460	6000
Elat	50	460	6000
Arava	30	280	3800
Dead sea	30	300	4000
Jordan v.	25	230	3000
Hula	35	340	4500
Roum	30	300	4000
Yamuneh	10	90	1000
Carmel	32	300	
East Sinai	300		
Thamad	160		
Barak	350		
Malhan	800		
Arif	450		
Paran	280		

Table 6: Estimated return periods of earthquakes in region of background seismicity.

Zone	M≥5 years	M≥6 years	M≥7 years
Suez	10	100	3900
Cyprus	3	60	500
E. Samaria	160	2000	
E. Med.-1	25	300	
E. Med.-2	40	500	
E. Med.-3	45	500	
Central Isr.	600		
N. Jordan	120		
Palmira	80		
W. Sirhan	60		
Galilee	400		

Table 7: Completeness of earthquake information in the DS rift system

Period	Threshold Magnitude	Area	Comments
Since 100 AD	6.5	The whole region	Destructive earthquakes
Since 1000	6.0	The whole region	Damaging earthquakes
Since 1800	5.5	The whole region	Felt and reported
Since 1900	5.0	The whole region	Felt, reported and recorded
Since 1940	4.0	Within the DS rift	Felt, reported and recorded
Since 1964	3.0	Within the DS rift	Detected by the WWSSN
Since 1983	2.5	Within JSN & ISN	Detected by the ISN
Since 1986	2.0	Within JSN & ISN	Detected by the ISN & JSN

Table 8: Earthquakes that triggered strong motion stations.

Sequence No.	yearmodyhrmn	M (local)	Latitude	Longitude	H (km)	Region
1	197904231301	5	31.24	35.46	10	Arad
2	198408240602	5.3	32.66	35.18	18	Galilee
3	198704272041	4.2	31.26	35.49	9	Arad
4	198710231632	4.1	31.19	35.34	7	Arad
5	198901031710	3.9	32.48	35.46	12	Samaria
6	198901061059	3.7	32.46	35.48	21	Samaria
7	199109280043	3.9	31.08	35.5	13	Moav
8	199308020912	4.1	31.48	35.49	18	Arad
9	199511220415	6.2	28.76	34.68	14	Gulf of Aqaba
10	199511231807	5.4	28.85	34.91	10	Gulf of Aqaba
11	199512260619	5	28.89	34.61	13	Gulf of Aqaba
12	199610091310	6.1	34.4	32.29	7	East Mediterranean
13	199703260422	5.5	33.86	35.39	5	Beirut
14	199705290706	3.7	33.35	35.62	8	Golan
15	199708041129	4	33.26	35.73	10	Golan
16	199910281539	4.6	30.4	34.98	9	Parran

Table 9: Sources and seismic parameters. Mmin: Minimum magnitude, Mmax: Maximum magnitude, beta = b ln10, alfa: No. of events/year (M ≥ Mmin).

No	Source	Mmin	Mmax	beta	alfa
1	Aragonese	4	7.5	2.21	0.1925
2	Wadi-Araba/Arava	4	7.5	2.21	0.3007
3	Arif	4	5.5	2.21	0.0302
4	Arnona-Dakar	4	7.5	2.21	0.5654
5	Barak	4	5.5	2.21	0.0371
6	BeitShean-Gilboa	4	6.5	2.21	0.0599
7	Carmel	4	6.5	2.21	0.1199
8	Central-Israel	4	5.5	2.21	0.0232
9	Cyprus	4	8.0	2.25	2.7769
10	Dead-Sea	4	7.5	2.21	0.2887
11	Aqaba/Eilat	4	7.5	2.21	0.1925
12	Galilee	4	5.5	2.21	0.0348
13	Hula-Kineret	4	7.5	2.21	0.2526
14	Jordan-Valley	4	7.5	2.21	0.3729
15	Malhan	4	5.5	2.21	0.0162
16	Mediterranean-1	4	6.5	2.21	0.3956
17	Mediterranean-2	4	6.5	2.21	0.2277
18	Mediterranean-3	4	6.5	2.21	0.2158
19	Paran	4	6.0	2.21	0.0238
20	Roum	4	7.5	2.21	0.2887
21	Yammouneh	4	8.0	2.21	0.9144
22	Suez	4	7.0	2.46	2.0425
23	East-Sinai	4	6.0	2.21	0.0333
24	Thamad	4	6.0	2.21	0.0642
25	N-Lebanon	4	5.5	2.21	0.0903
26	S-Lebanon	4	6.5	2.21	0.0364
27	Sirhan	4	7.0	1.63	0.0500
28	Damascus	4	5.0	2.21	0.0641
29	Sergayha	4	7.5	2.21	0.0820
30	Sinai-T.J.	4	7.5	2.21	2.2726

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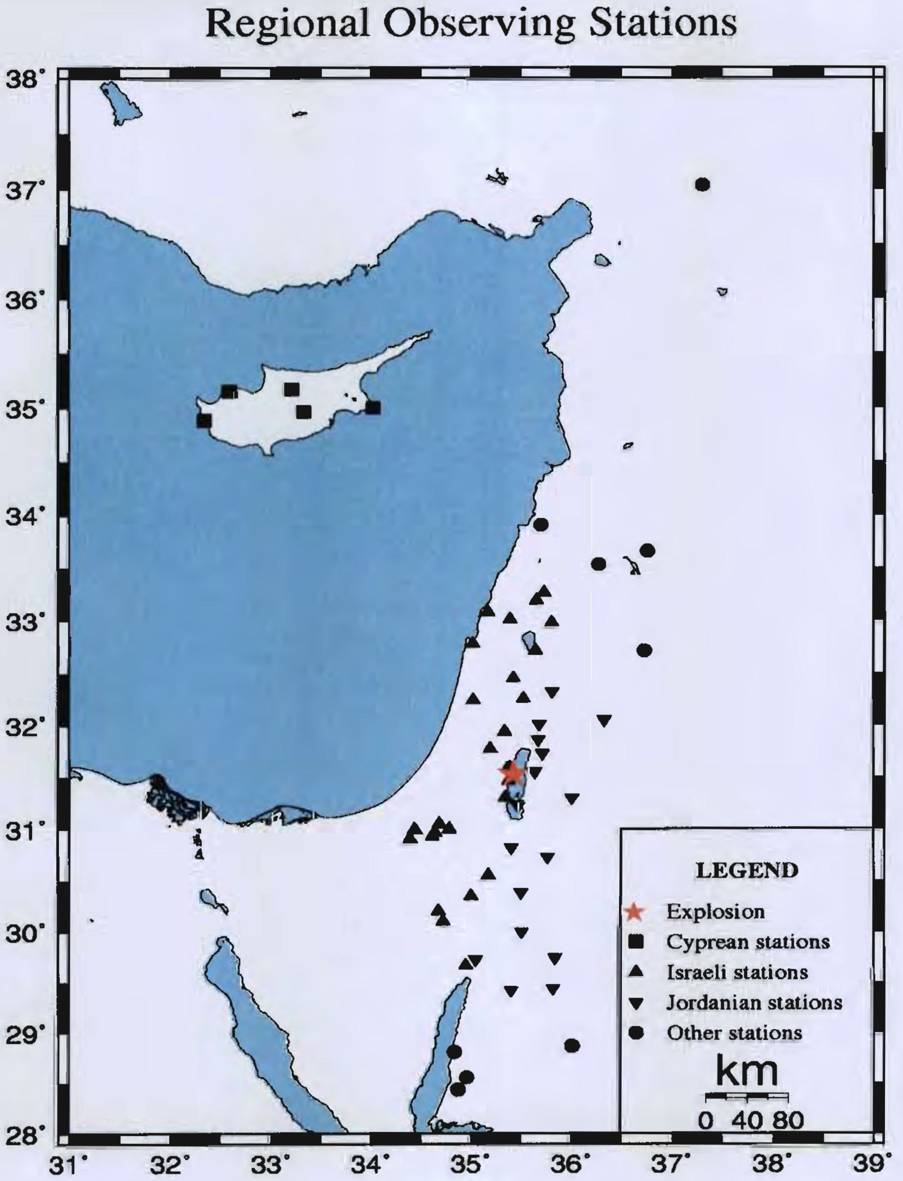


Fig. 1: Collaborating seismic networks which operate in the study region (Jan. 2000). The red star is the location of an underwater calibration explosion used for developing a local seismic travel time model.

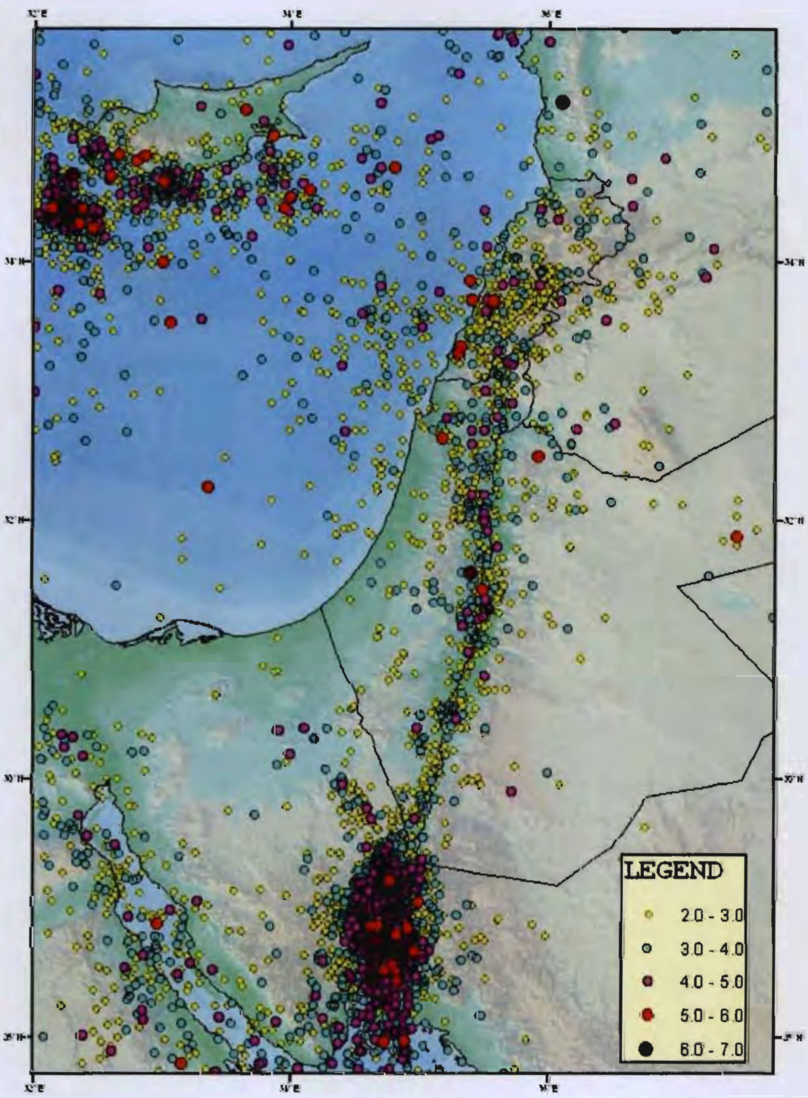
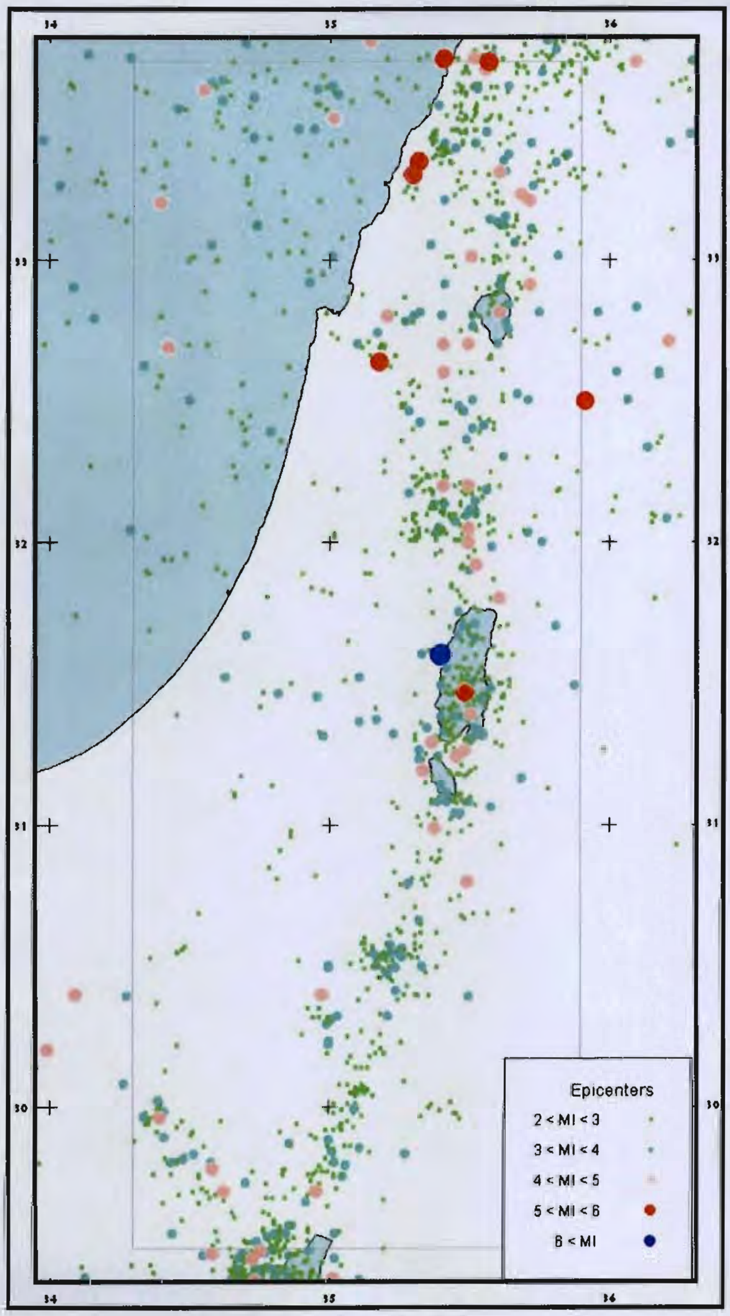


Fig. 2: Regional Seismicity during 1900-2007.



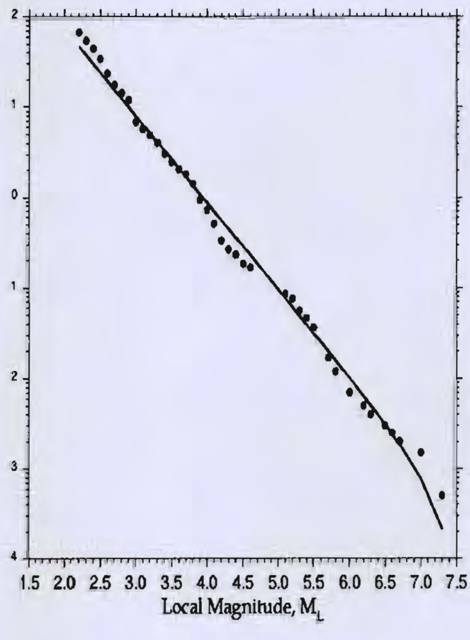


Fig. 3. (a) A map showing the area where the earthquake catalog is considered to be most complete (b) The cumulative Frequency-Magnitude relationship for this area with b=0.96.

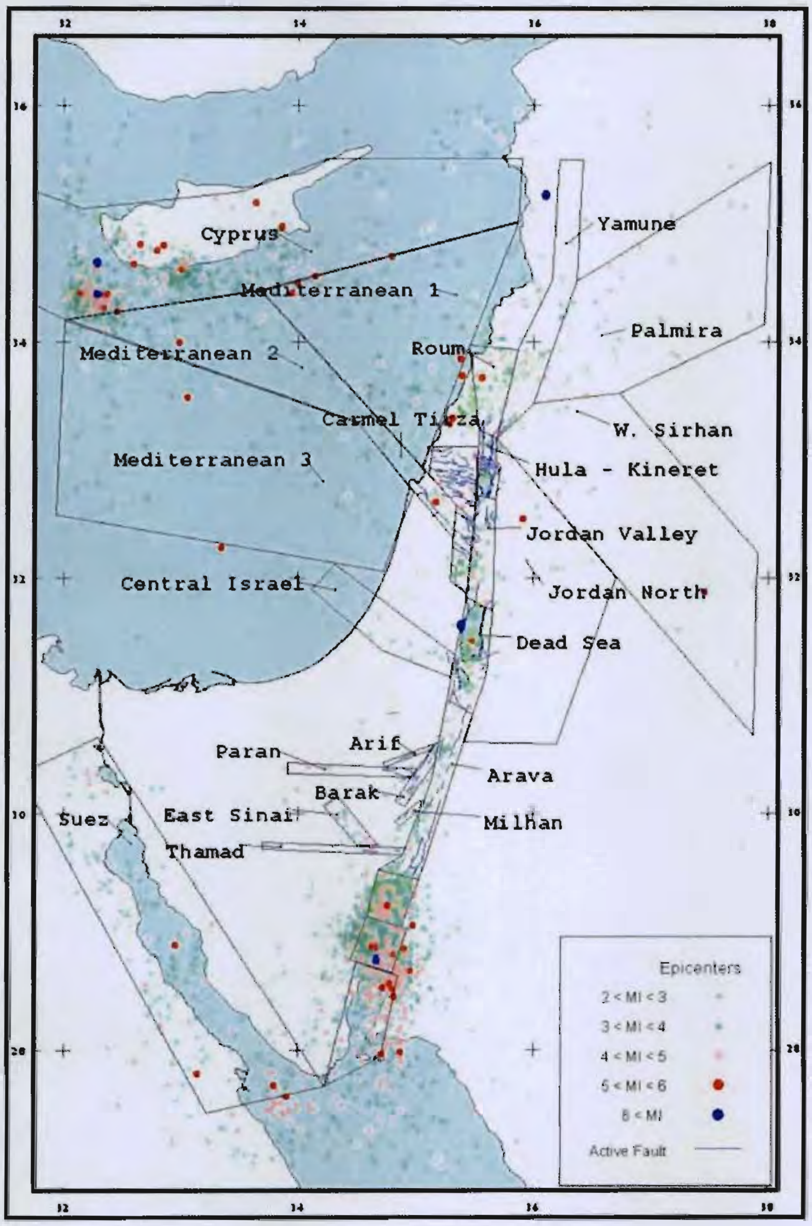


Fig. 4. Suggested seismogenic zones.

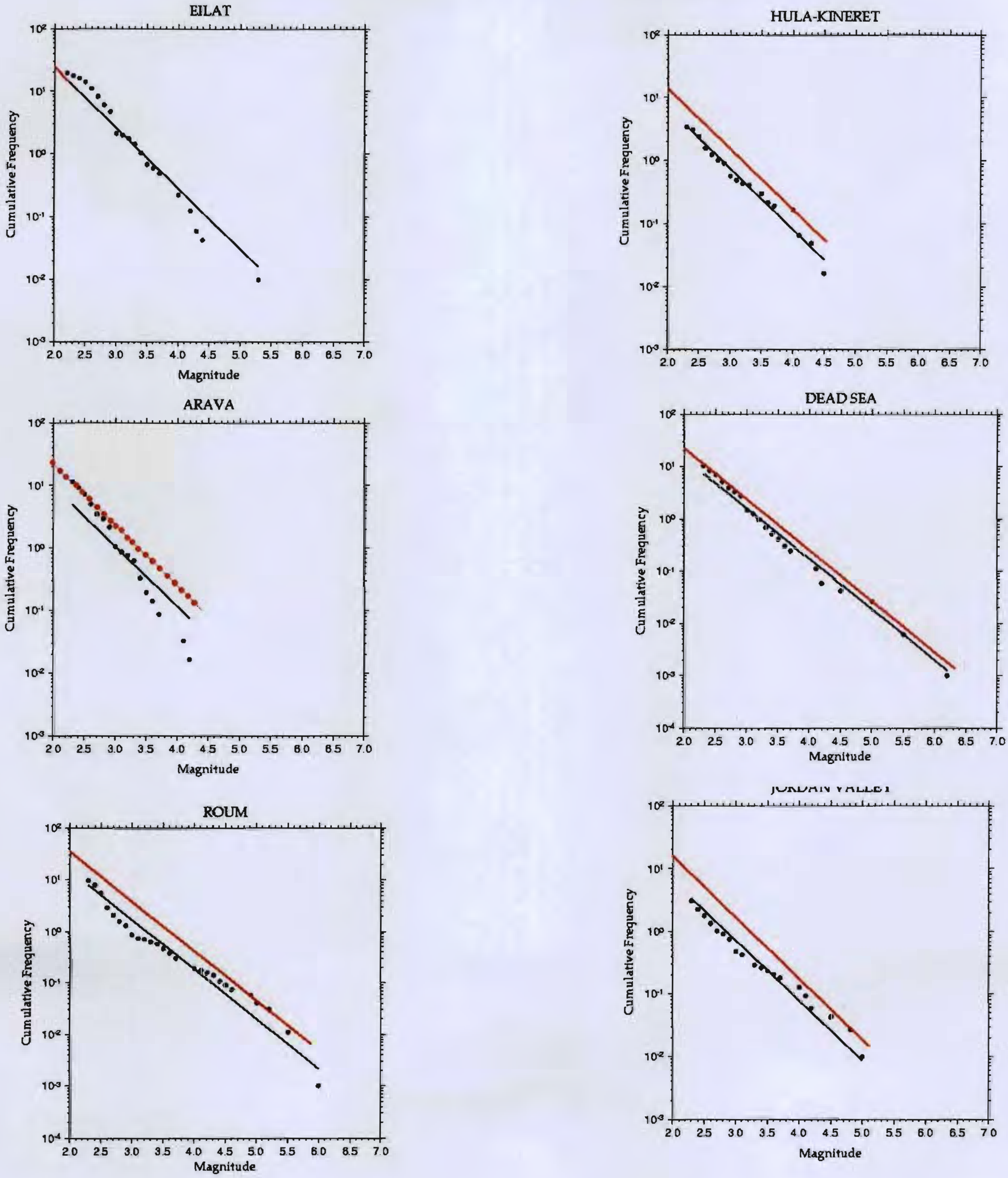


Fig. 5: Frequency-Magnitude relationships for segments of the Dead Sea Transform. b=0.96 is fixed. The red-line is the assumed upper bound.

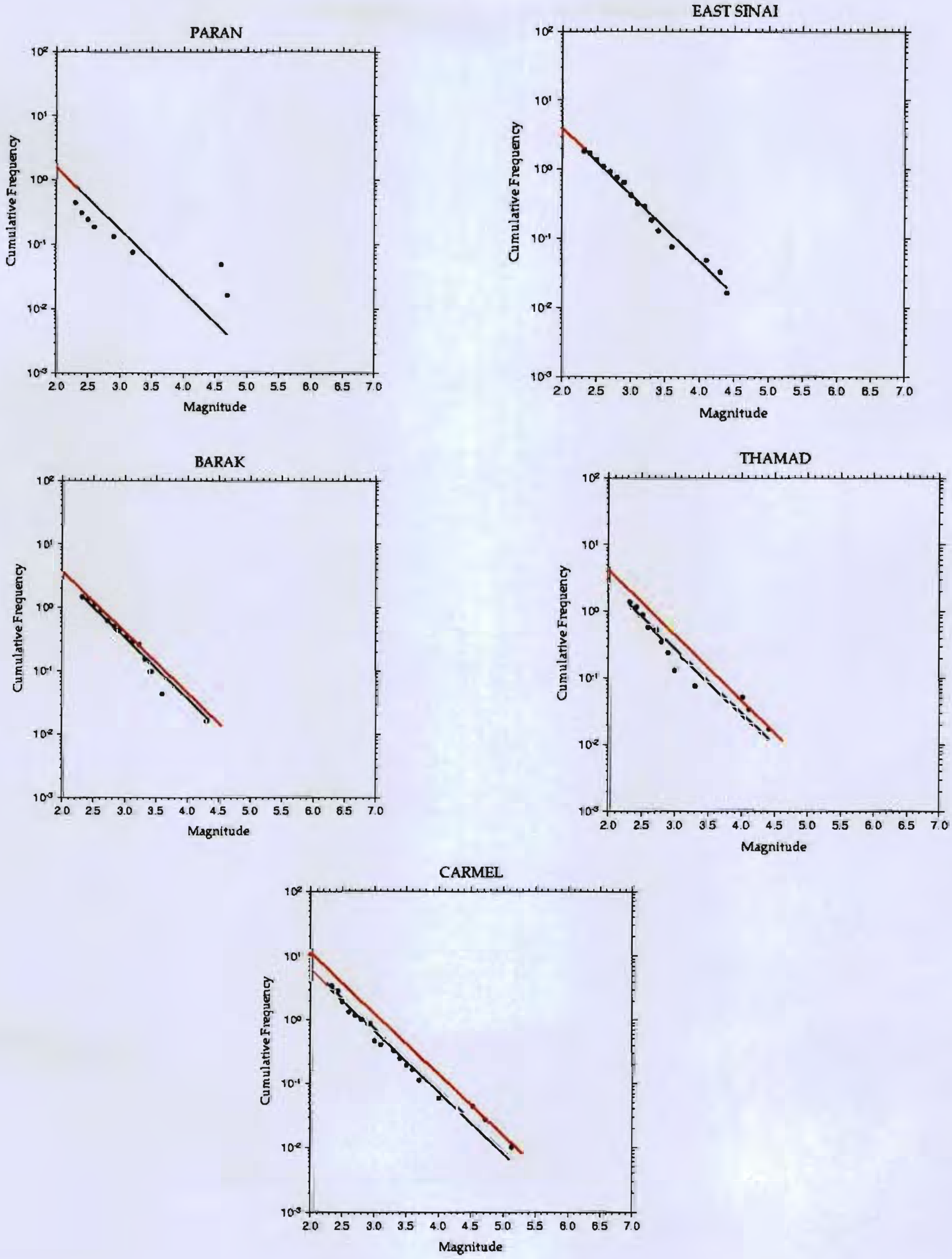


Fig. 6. Frequency-Magnitude relationships for faults branching from the Dead Sea Transform. b=0.96 is fixed. The red-line is the assumed upper bound.

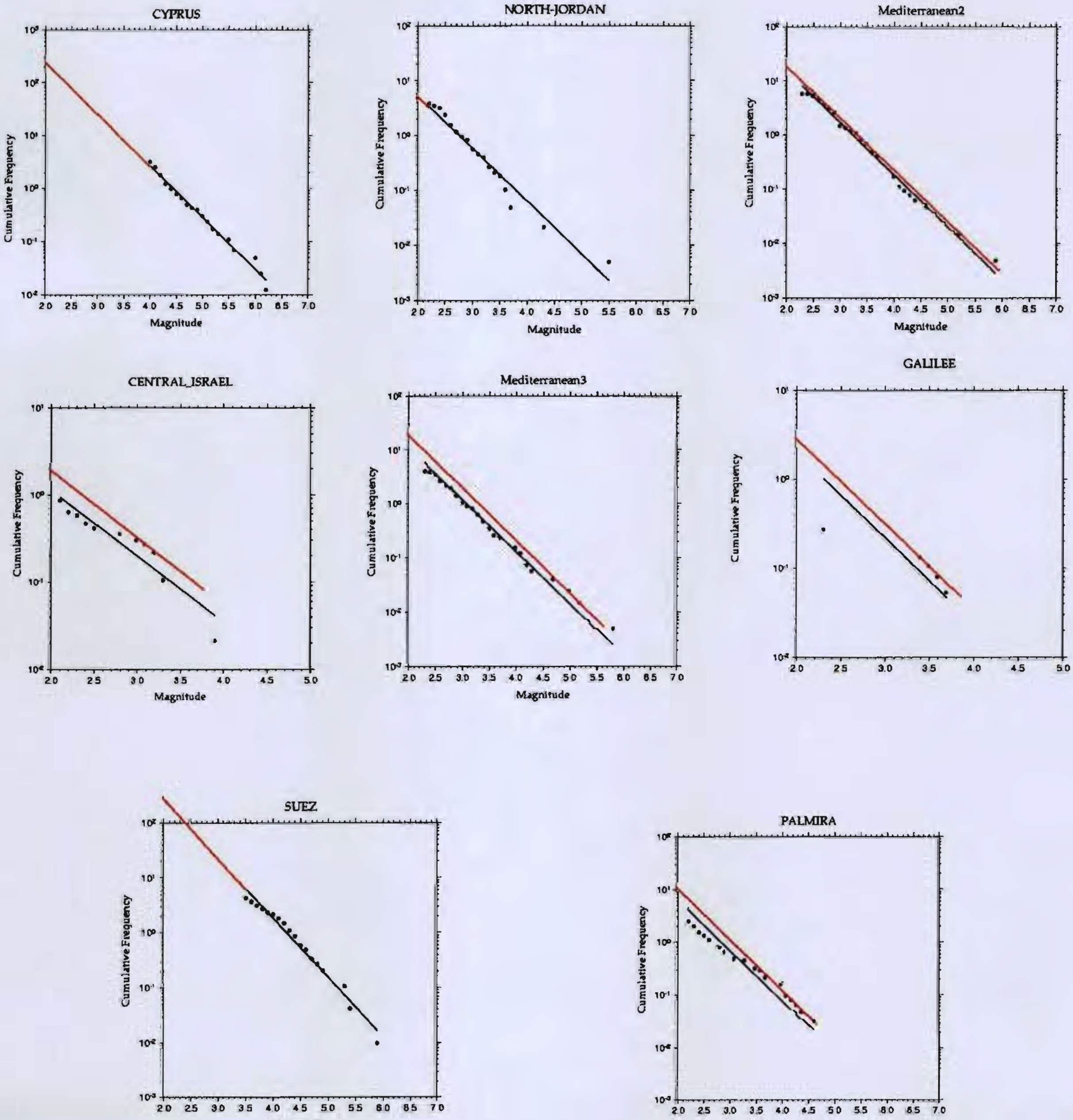


Fig. 7. Frequency-Magnitude relationships for seismically active regions (background seismicity). b=0.96 is fixed. The red-line is the assumed upper bound.

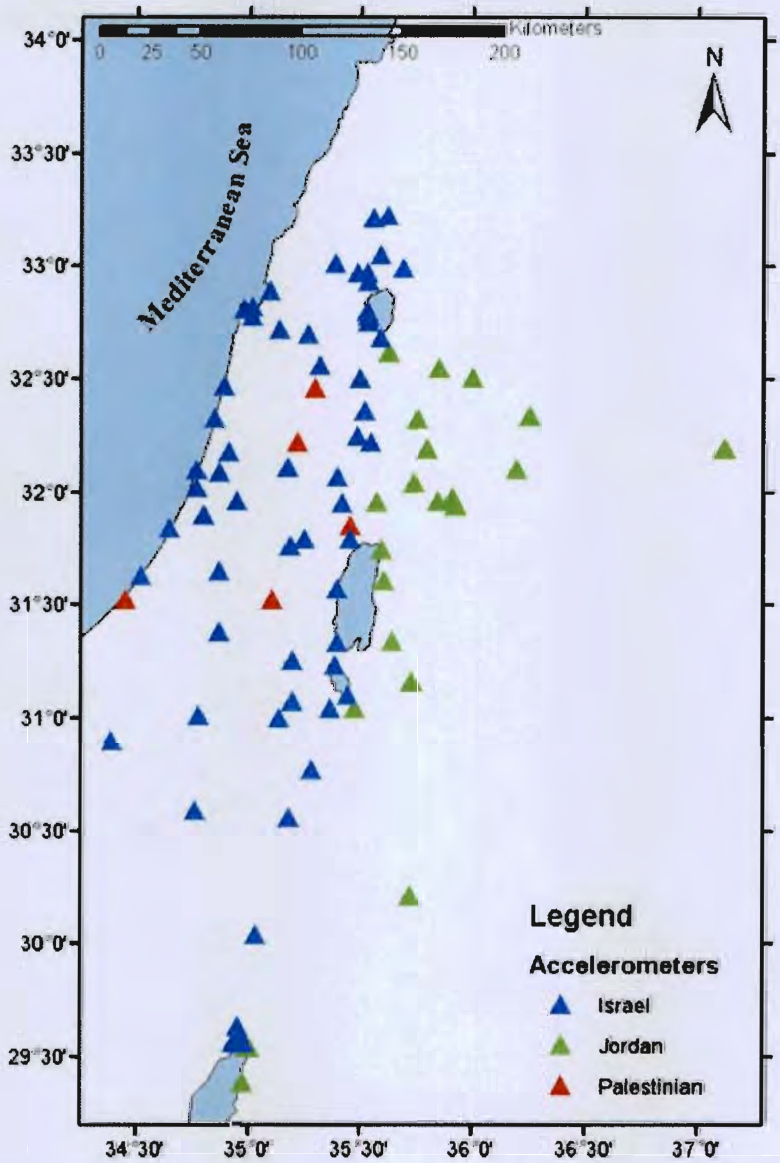


Fig. 8. Strong motion (accelerograph) stations participating in the study. The Palestinian stations and 5 Jordanian stations were purchased by the project.

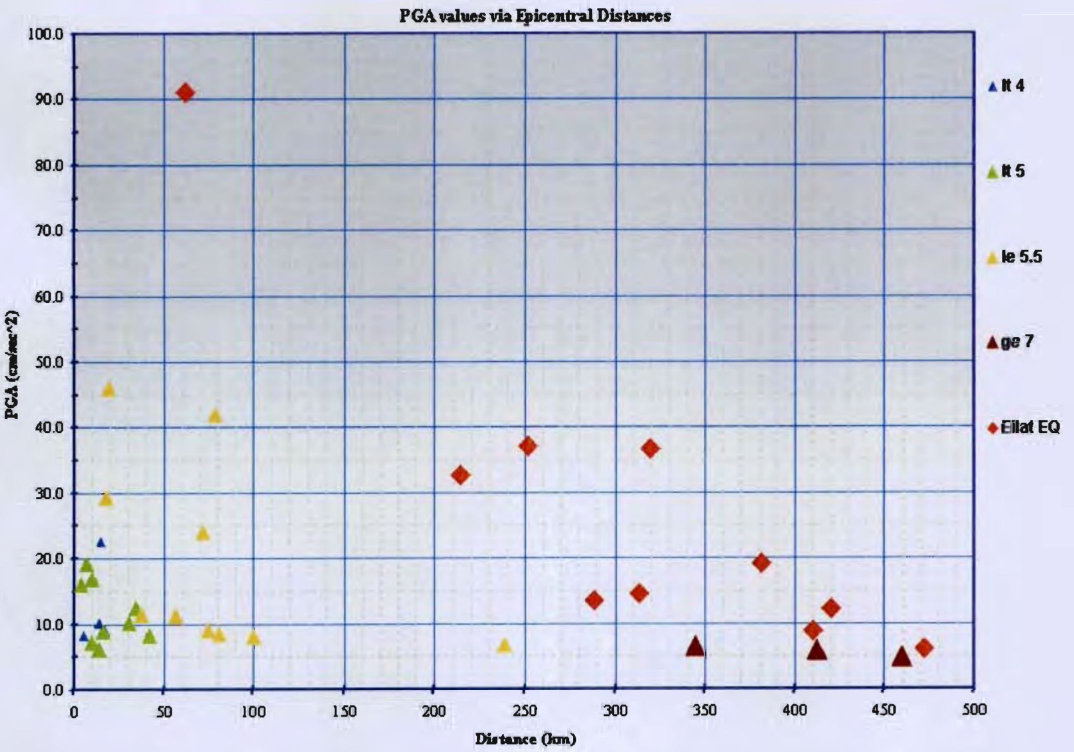


Fig. 9. Distance distribution of PGA readings used in this study.

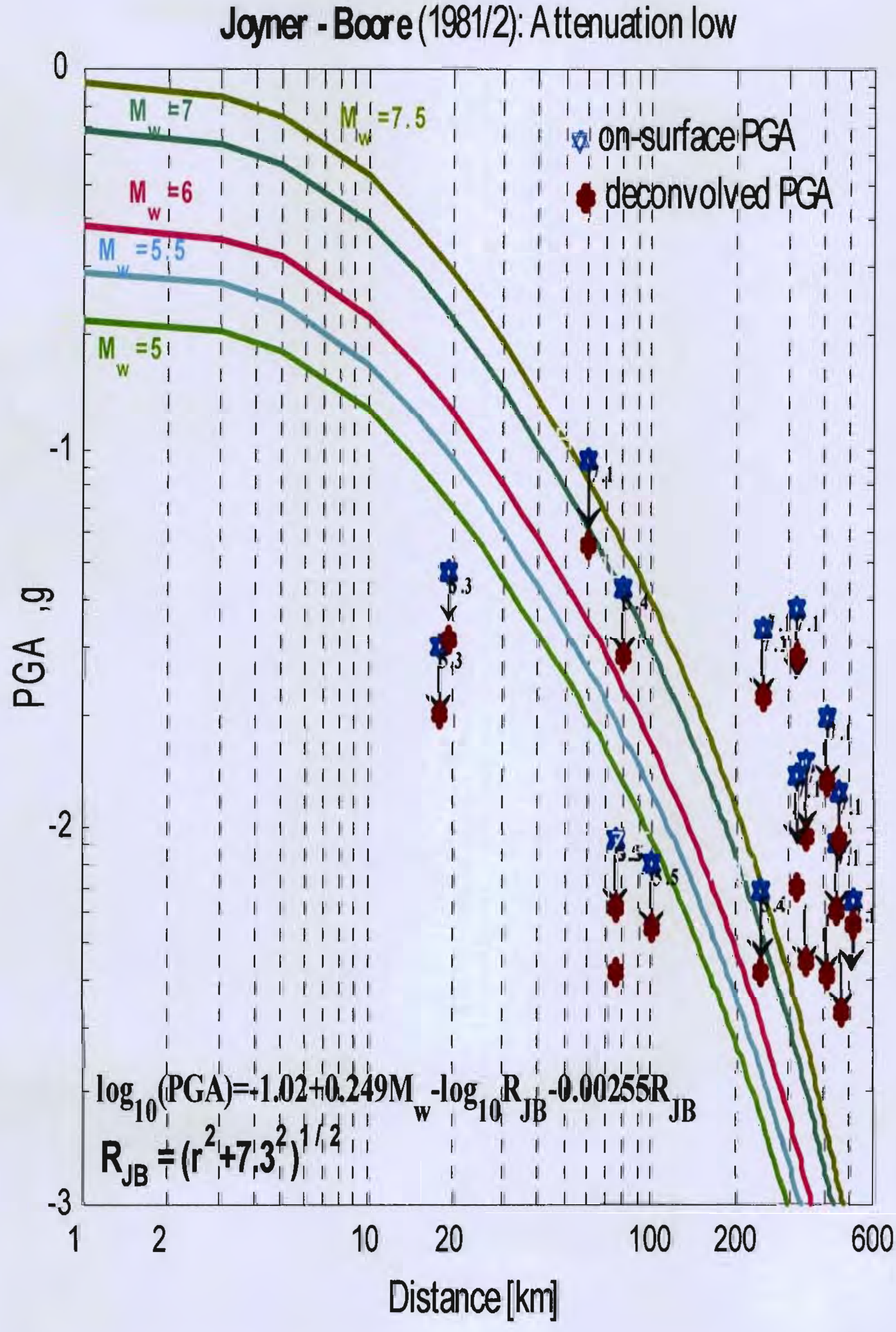


Fig. 10. The Joyner and Boore attenuation function and PGA observations (a) in Blue – original readings (b) in Brown – after de-convolution with the site response function.

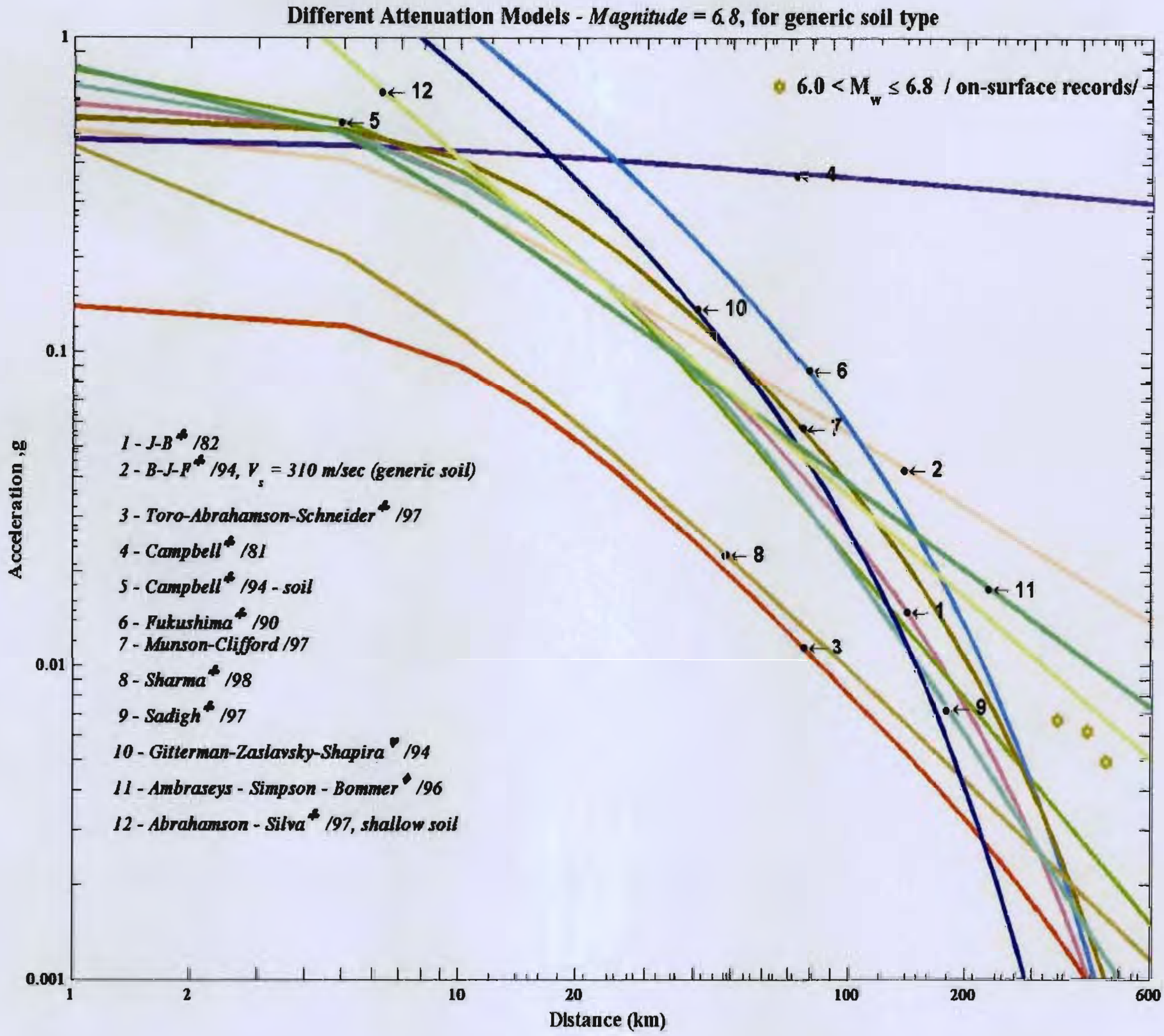


Fig. 11. The Attenuation functions considered for adoption in building codes for Israel, Jordan and the Palestine N.A.

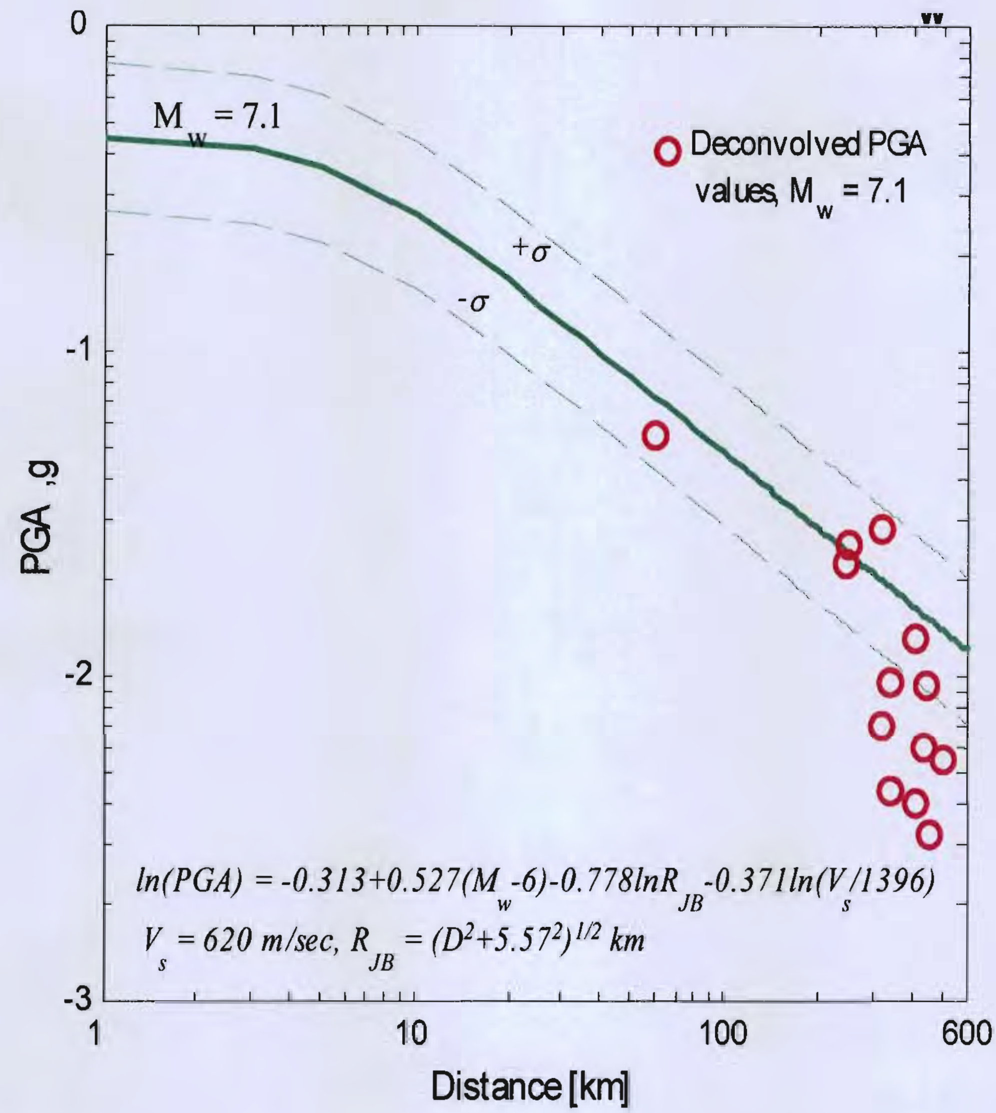


Fig. 12. The selected attenuation function (BJF) and regional PGA observations (de-convolved with the site response functions).

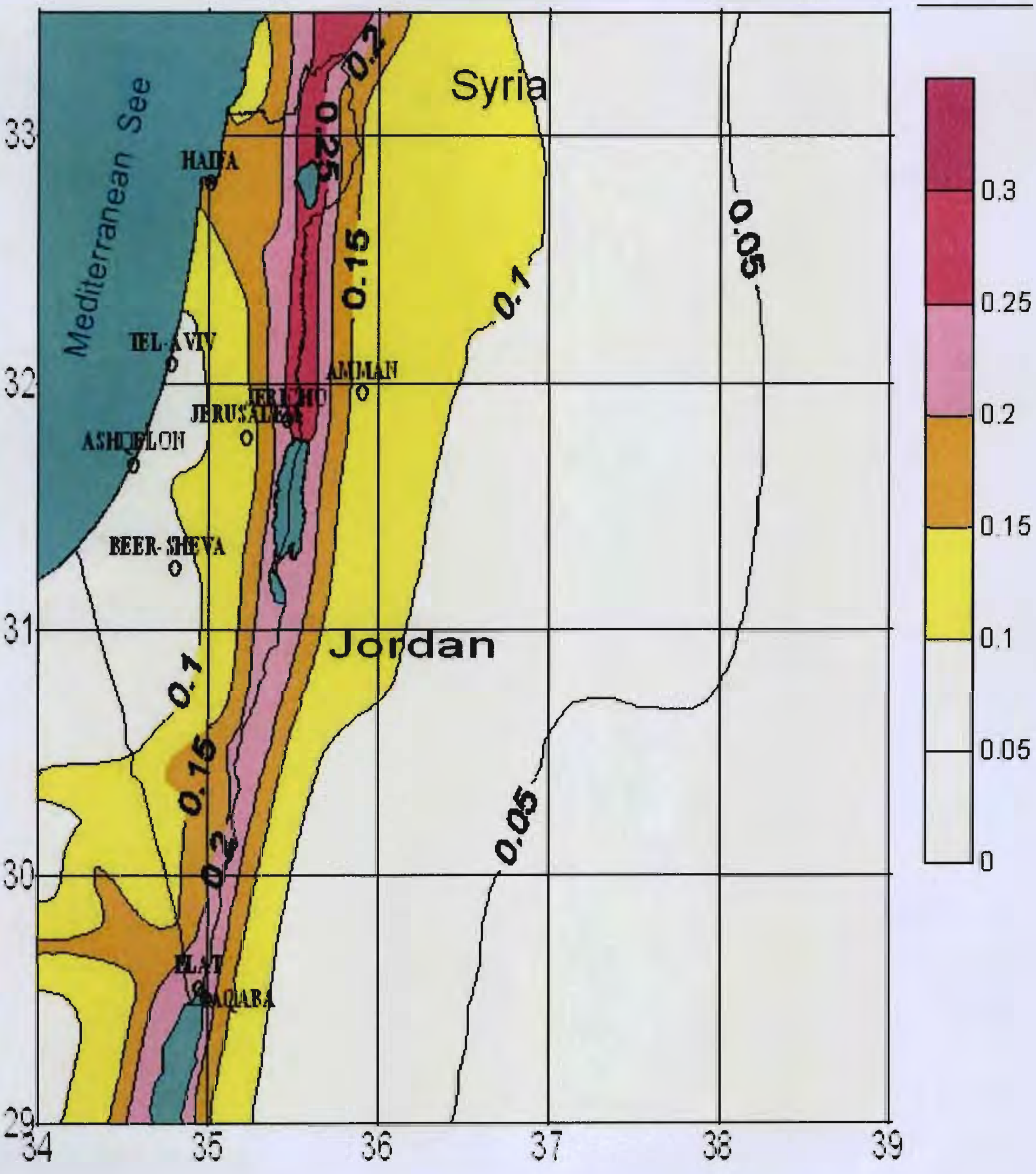


Fig. 13. The seismological hazard map suggested for application in building codes. PGA values (fractions of g) correspond to the probability of occurrence of 10% in an exposure time of 50 years.

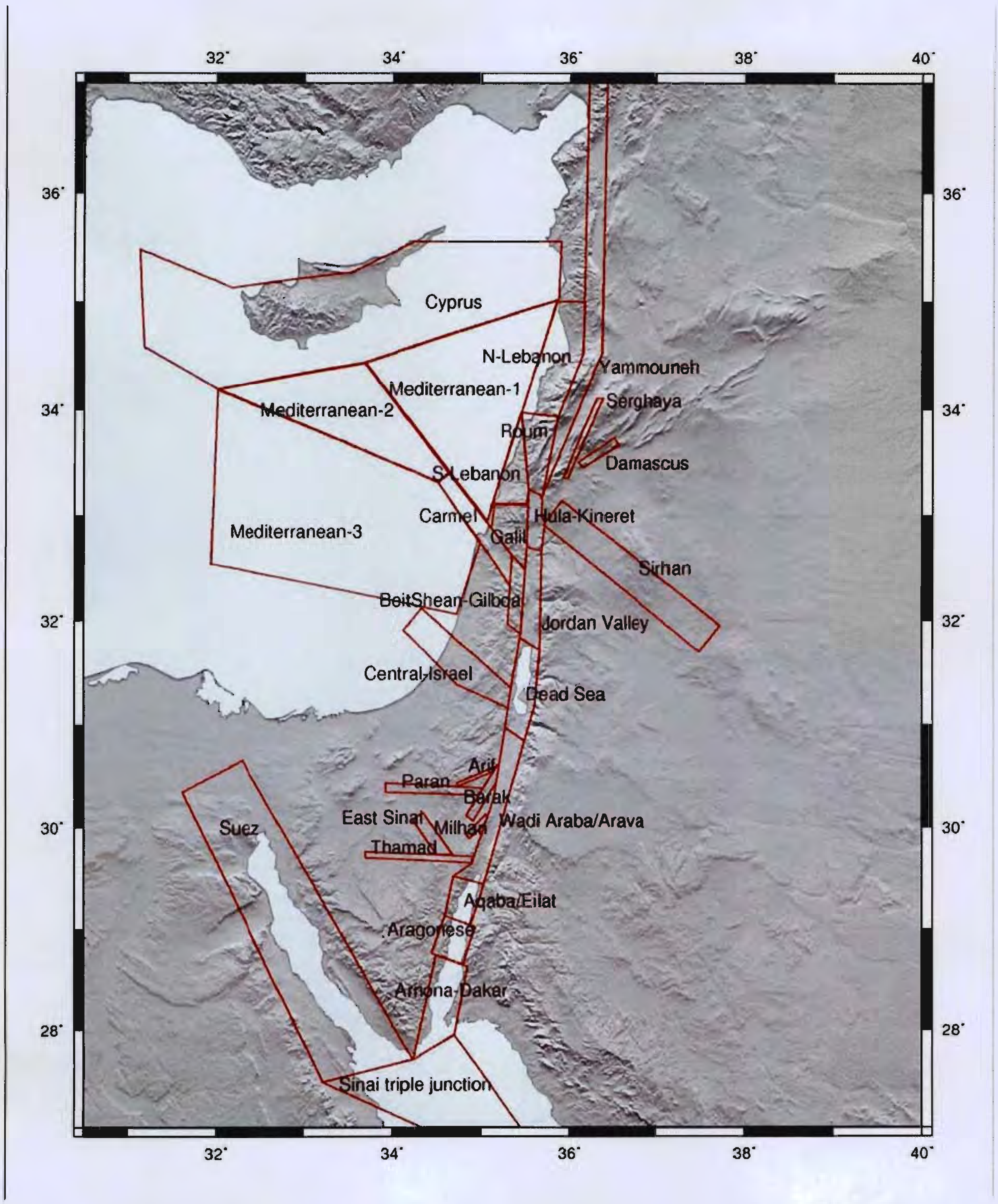


Fig. 14. Seismic source model for the Levant region.

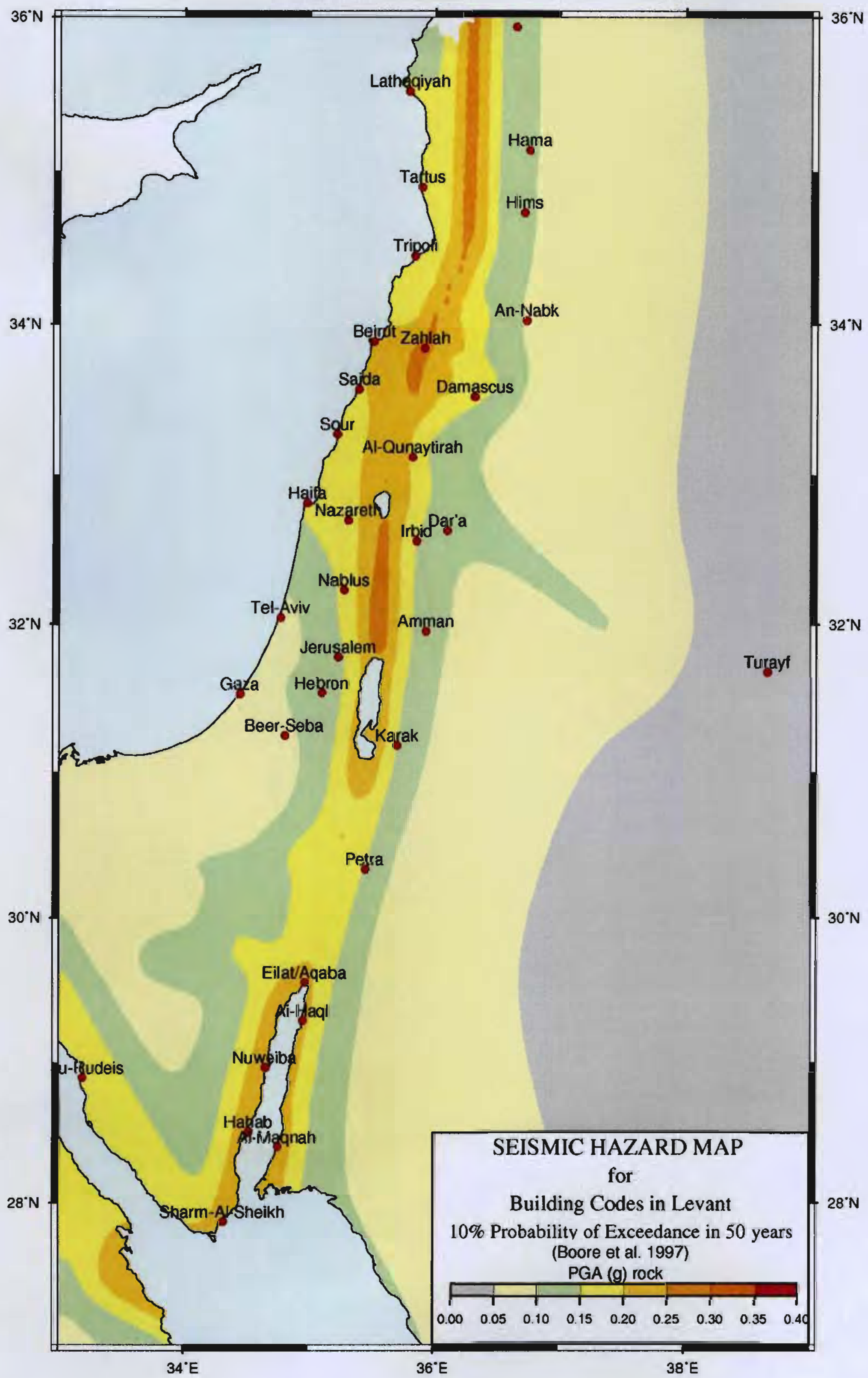


Fig. 15. Seismic hazard map for the Levant region using Boore et al. (1997) peak ground acceleration attenuation relationship. PGA is assessed for a 10% probability of exceedance in an exposure time of 50 years and for Generic rock.

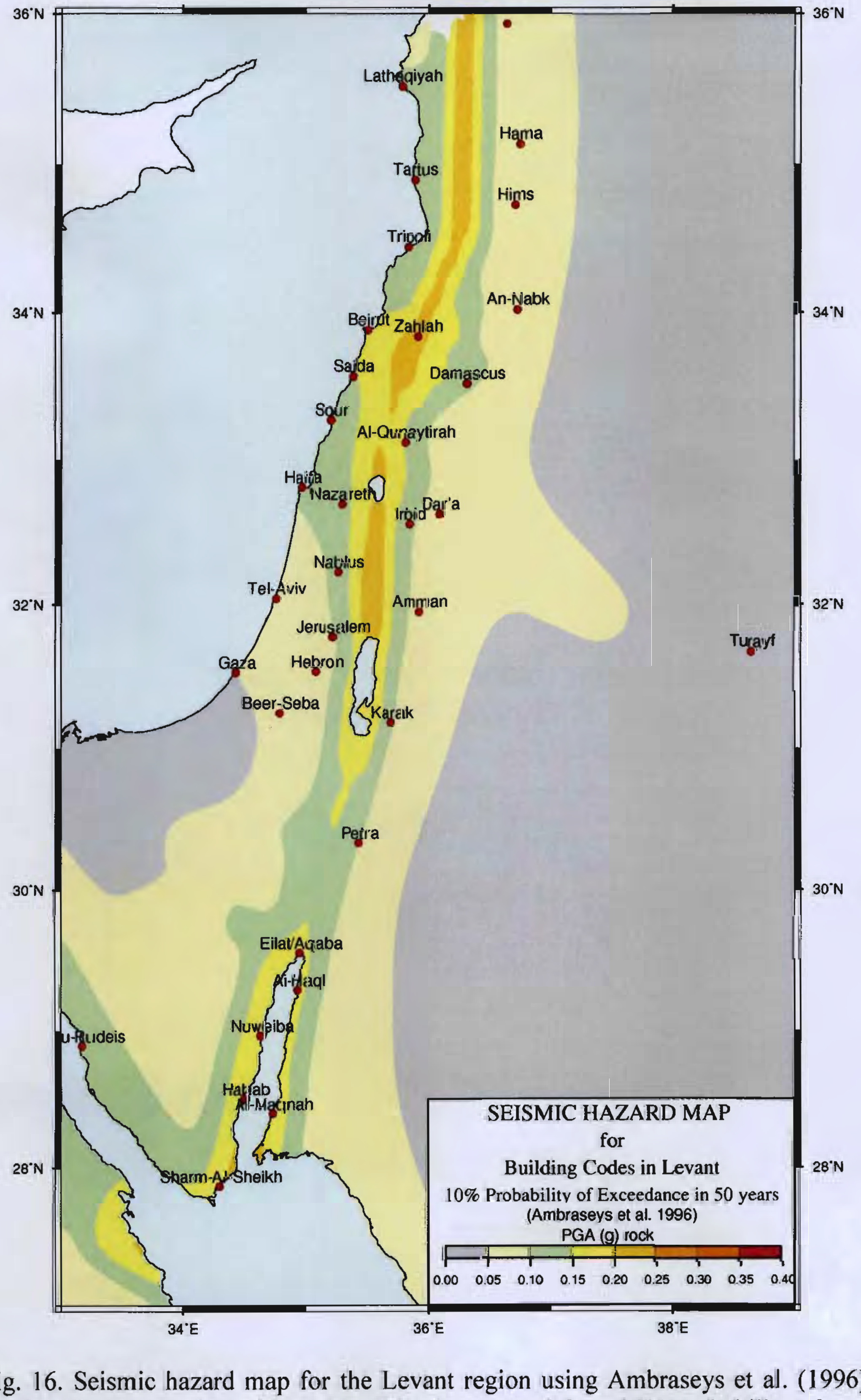


Fig. 16. Seismic hazard map for the Levant region using Ambraseys et al. (1996) peak ground acceleration attenuation relationship. PGA is assessed for a 10% probability of exceedance in an exposure time of 50 years and for rock.

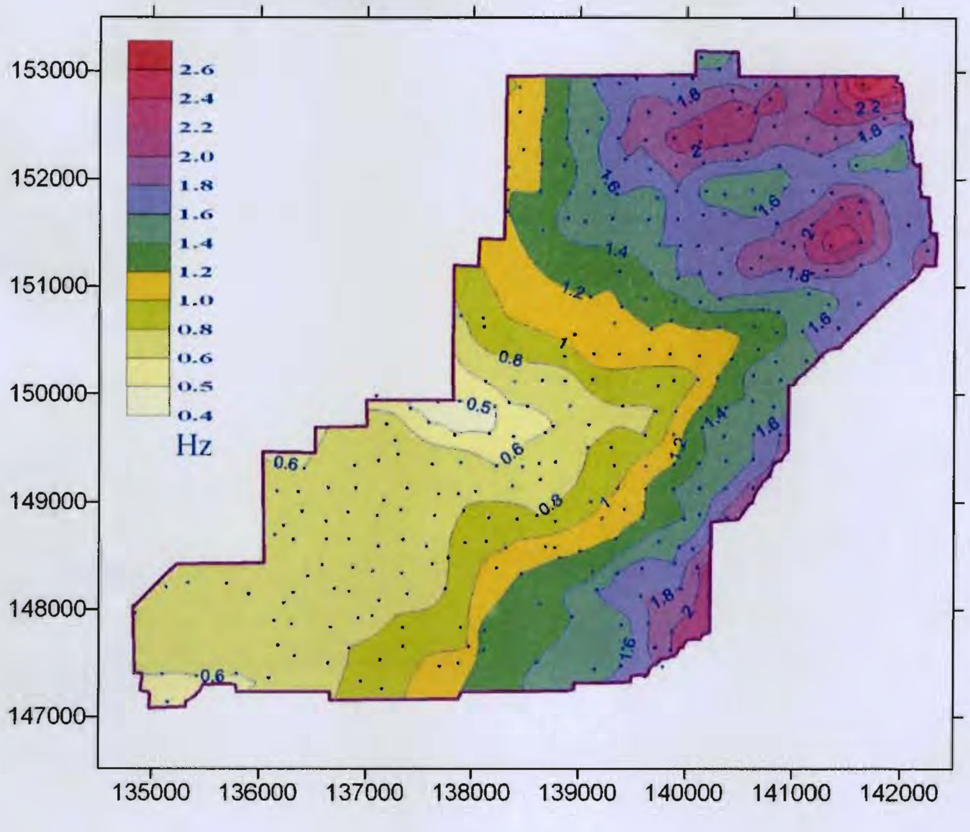


Fig. 17. Distribution of estimated resonance frequencies across the towns Lod and Ramla.

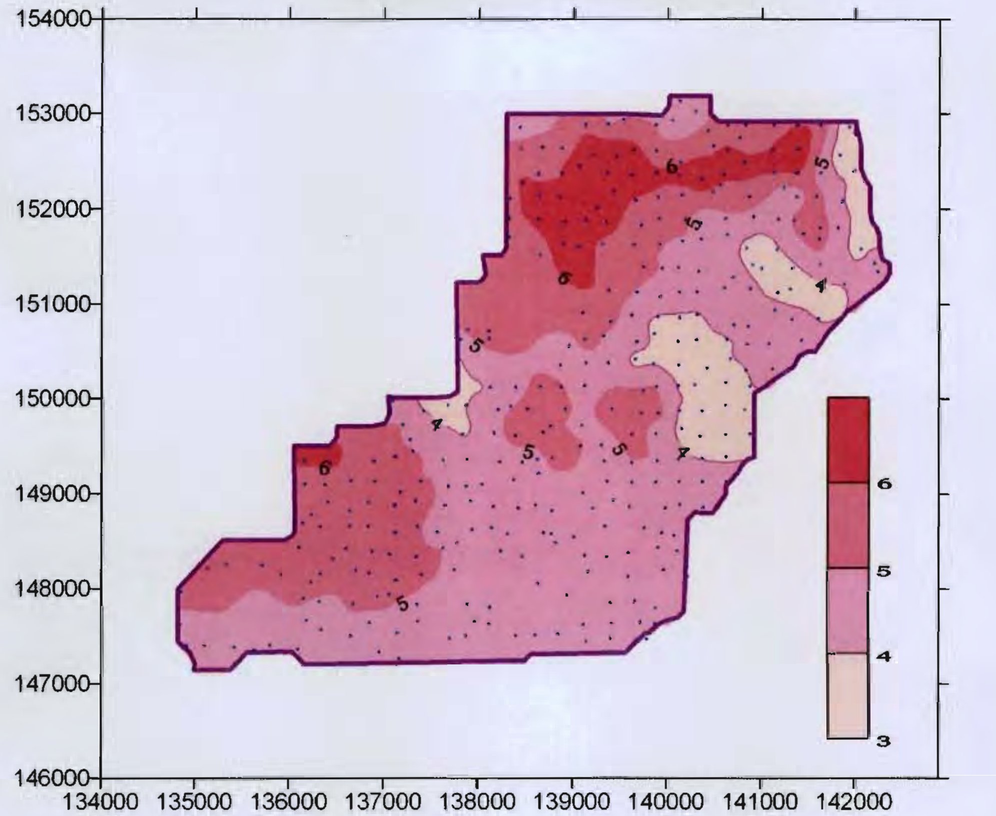


Fig. 18. Distribution of estimated maximum site amplification factor in the towns Lod and Ramla.

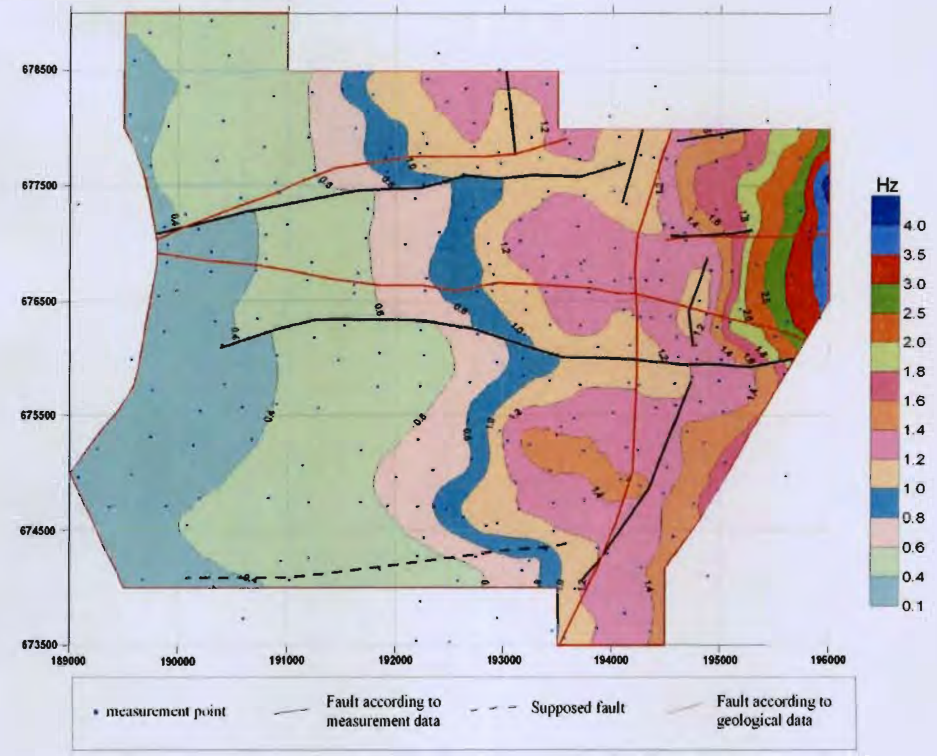


Fig. 19. Distribution of estimated resonance frequencies in the area of Kefar-Sava.

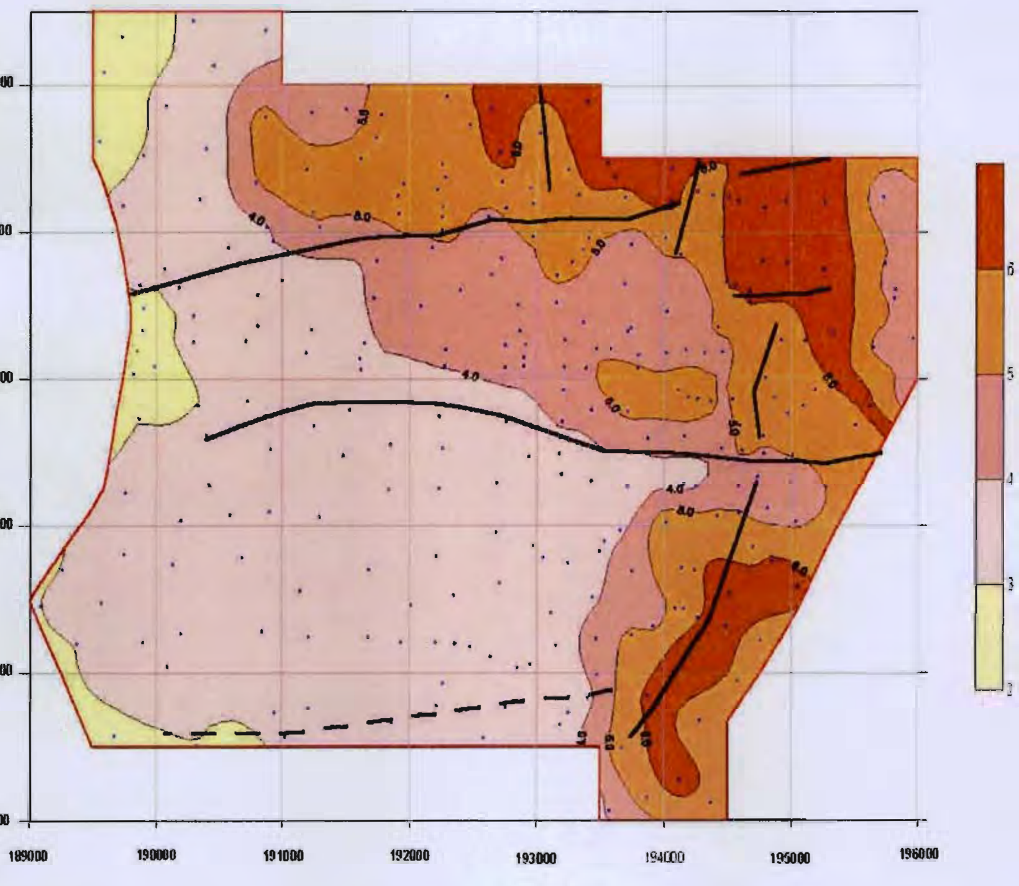


Fig. 20. Distribution of estimated maximum site amplification factors in the area of Kefar-Sava.

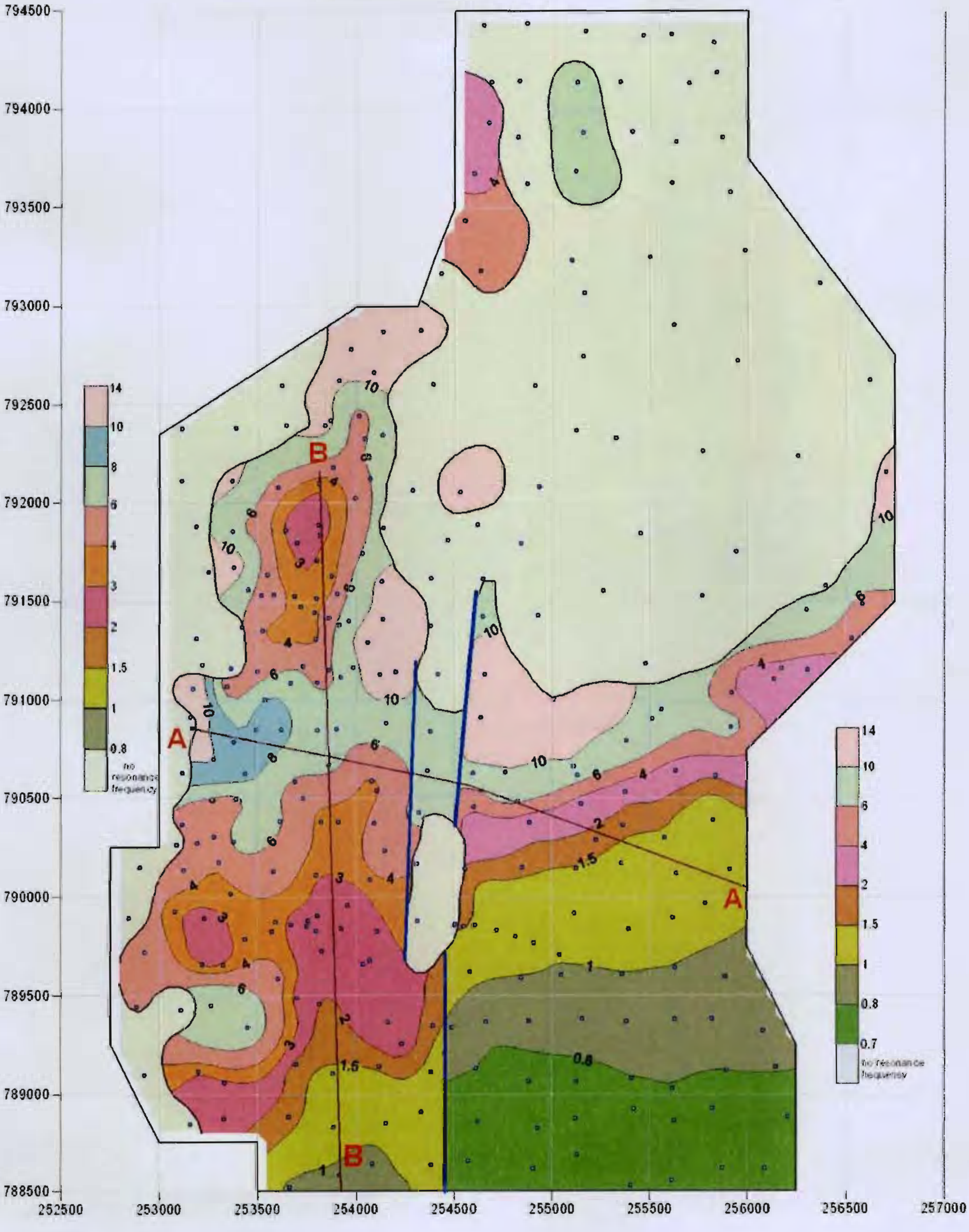


Fig. 21. Distribution of estimated resonance frequencies across Qyriat-Shmona.

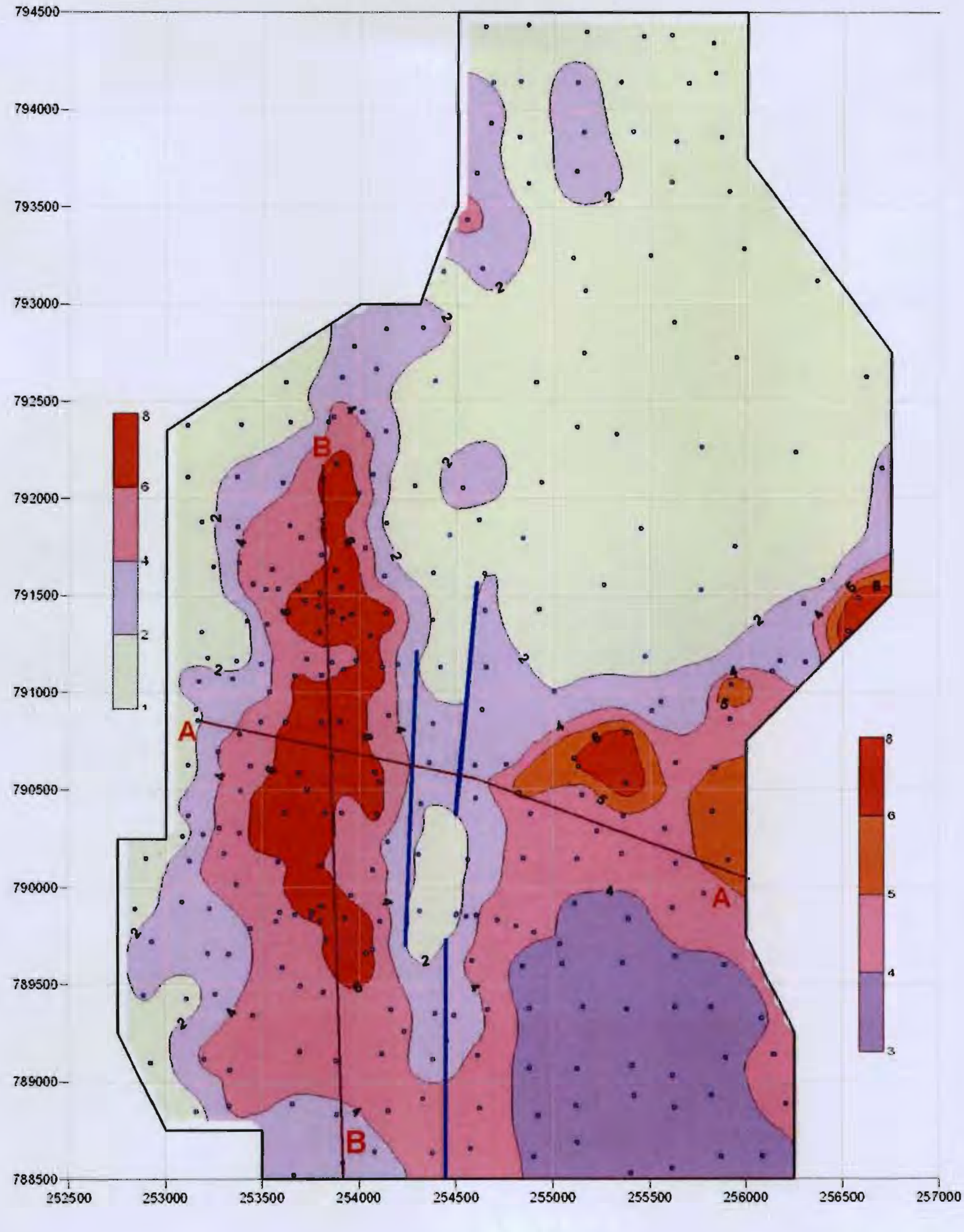


Fig. 22. Distribution of estimated maximum site amplification factors in Qyriat-Shmona.

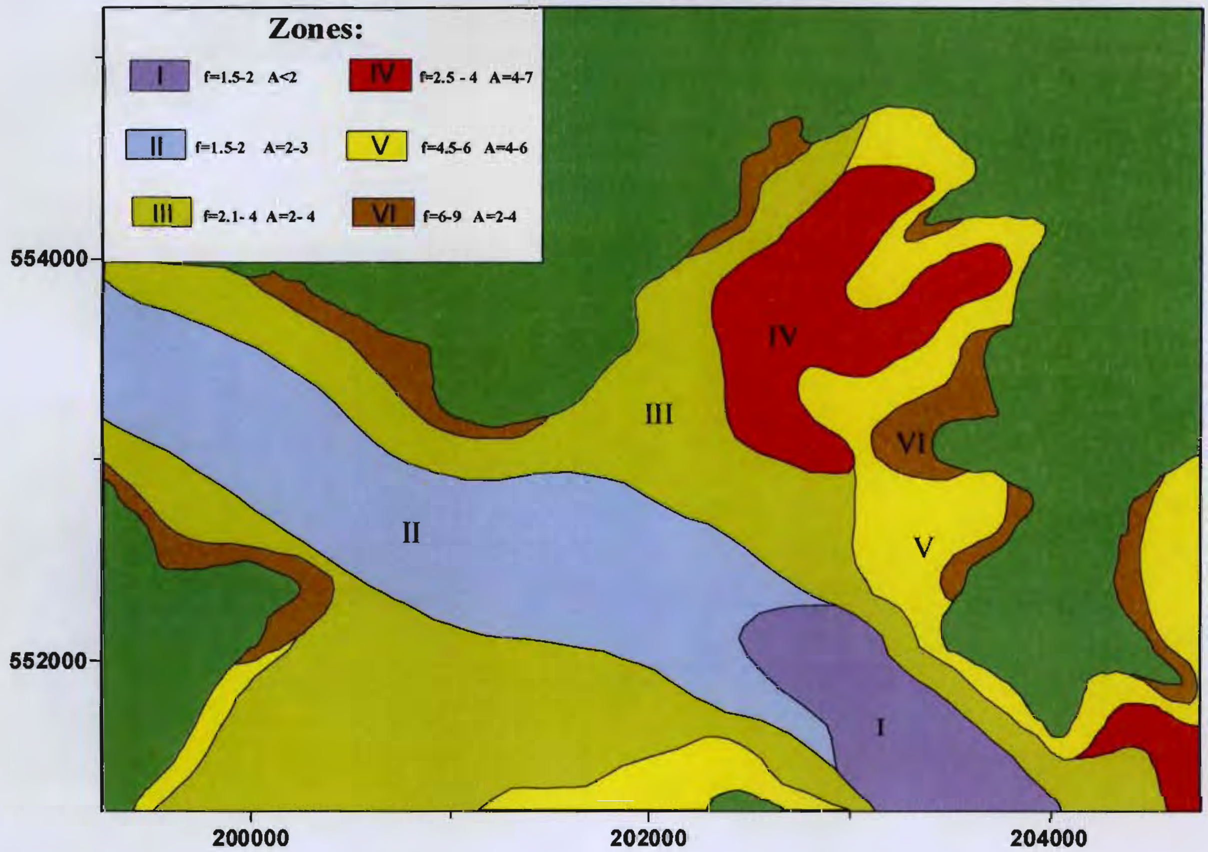


Fig. 23. Map showing zone division in the town of Dimona.

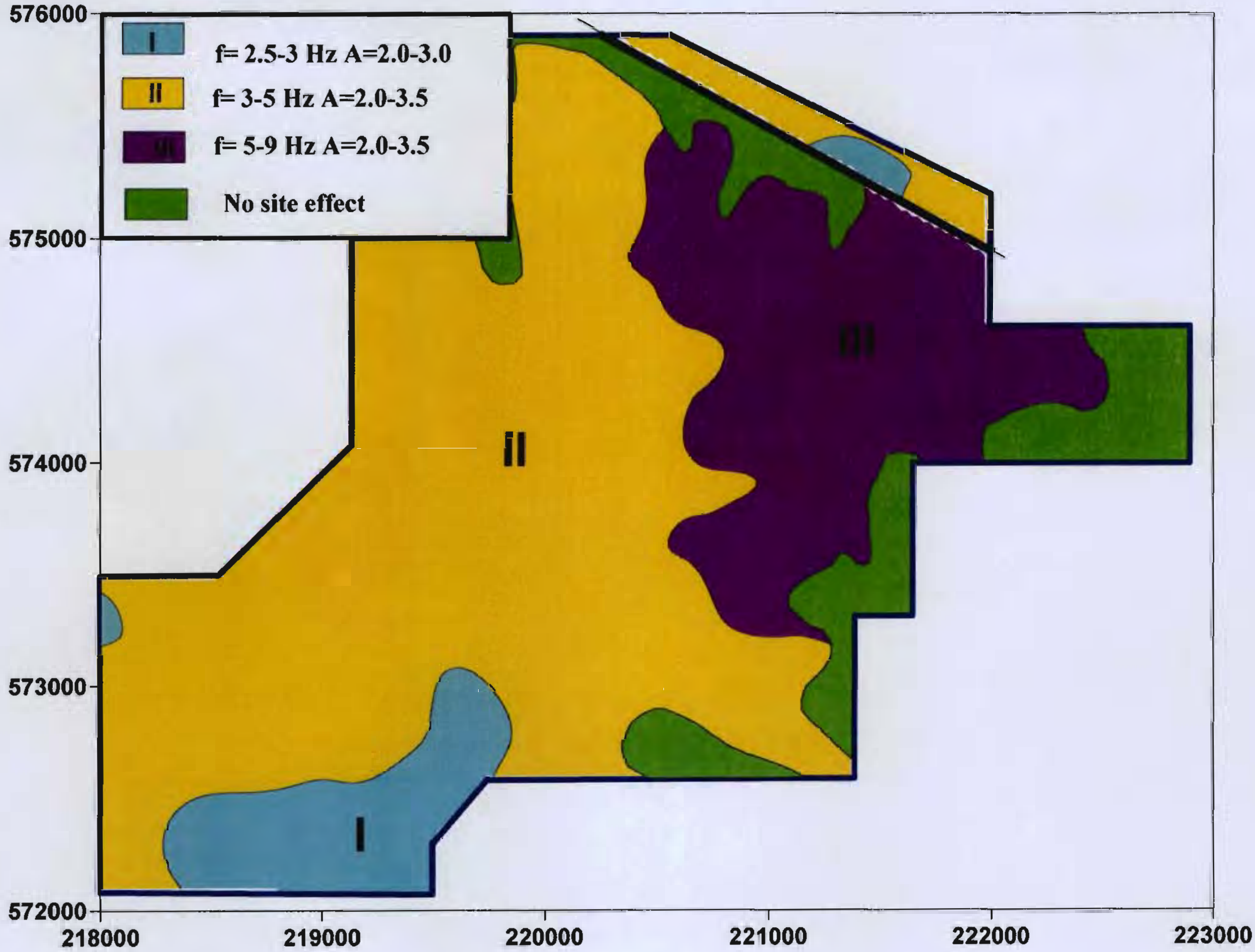


Fig. 24. Map showing zone division in the town of Arad.

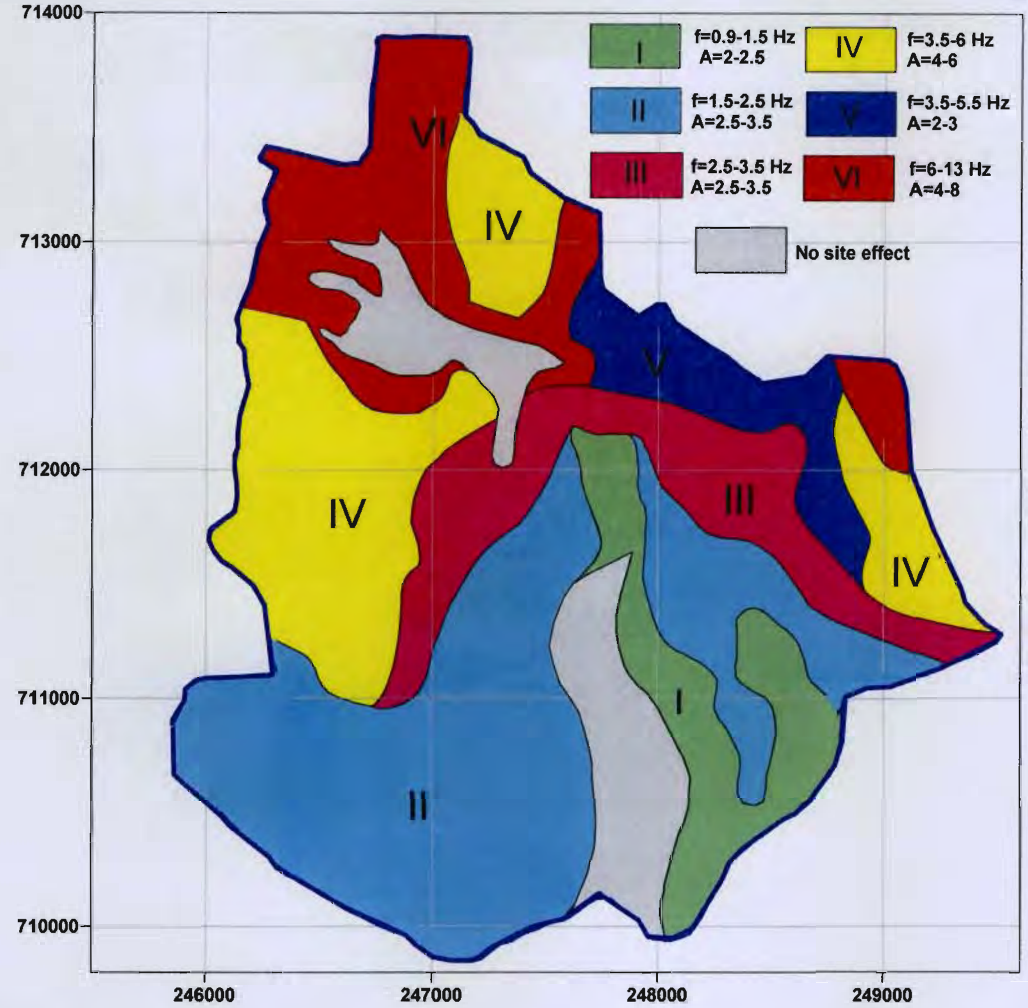


Fig. 25. Map showing zone division in Bet Shean.

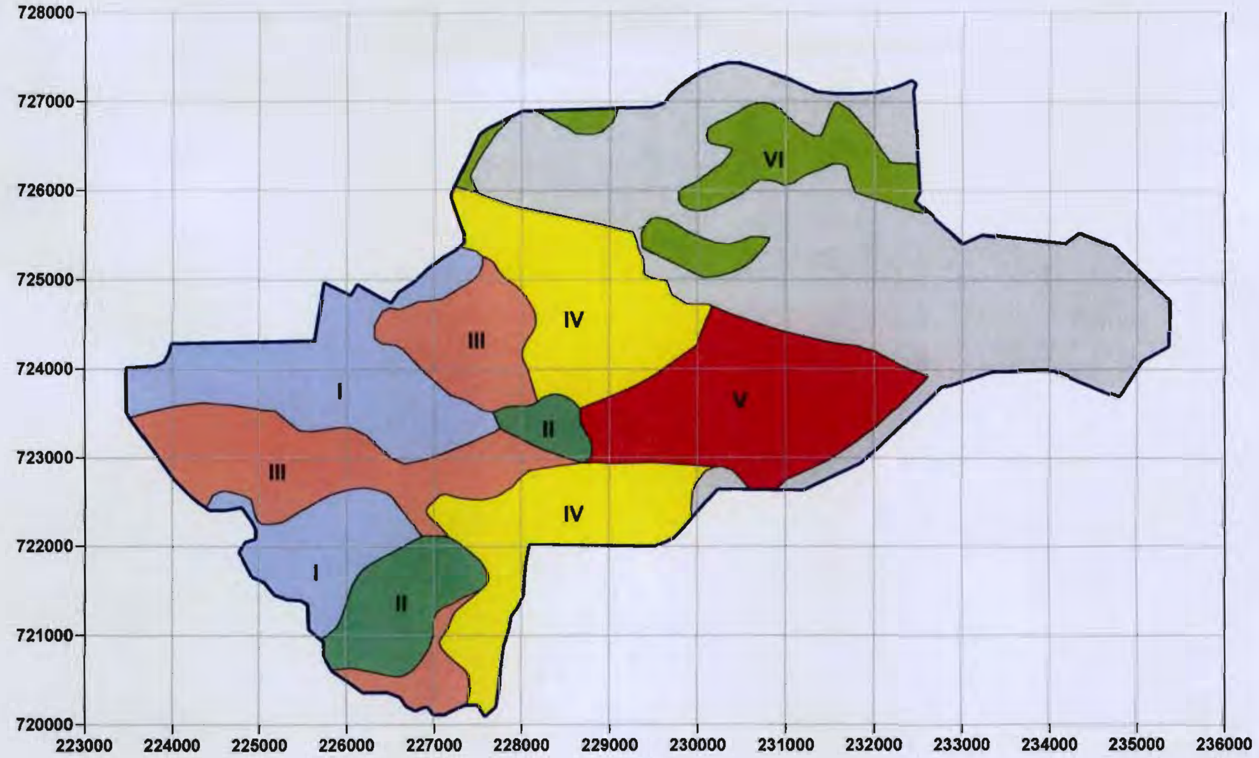


Fig. 26. Map showing zone division in Afula.

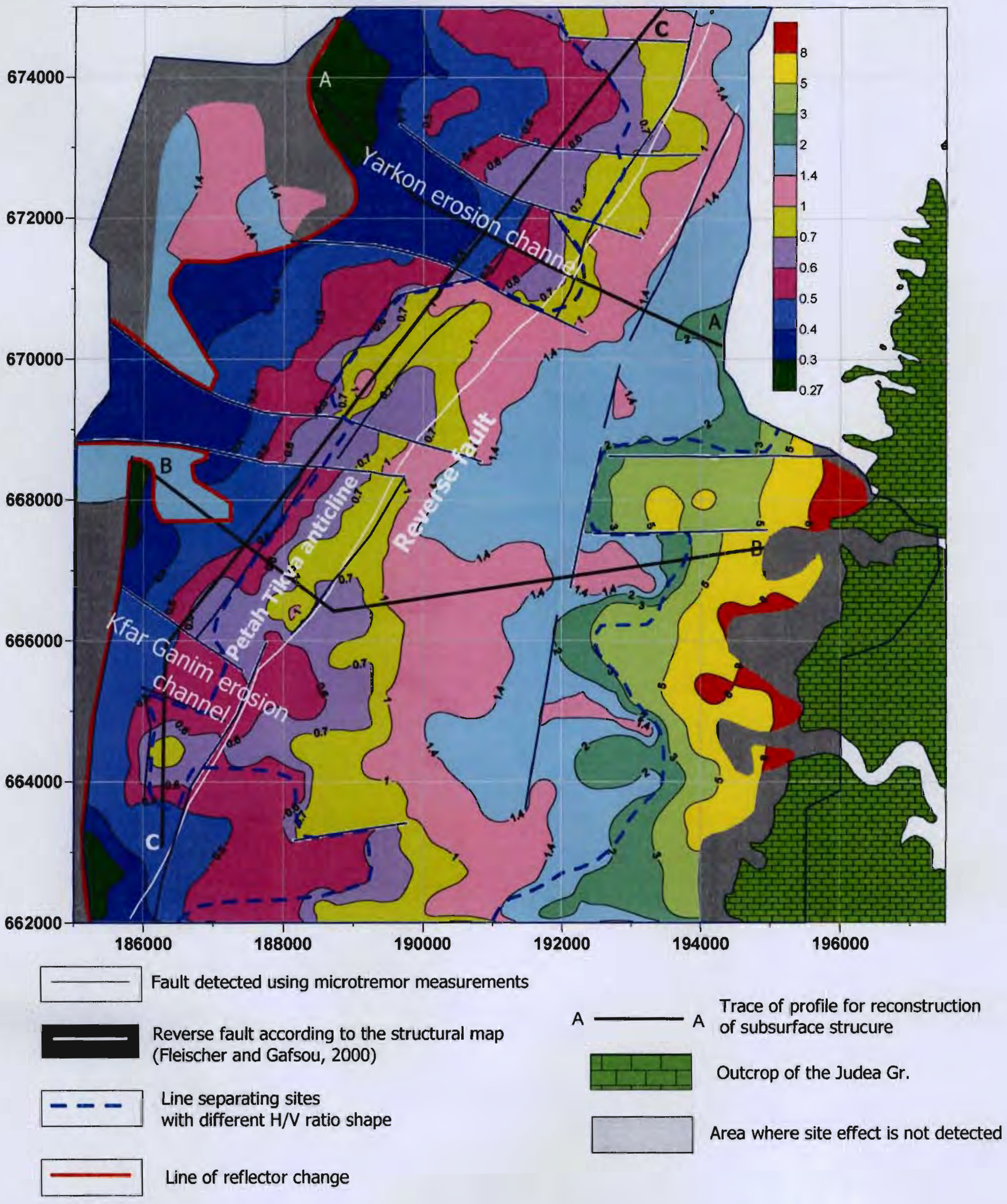


Fig. 27. Distribution of the fundamental frequency.

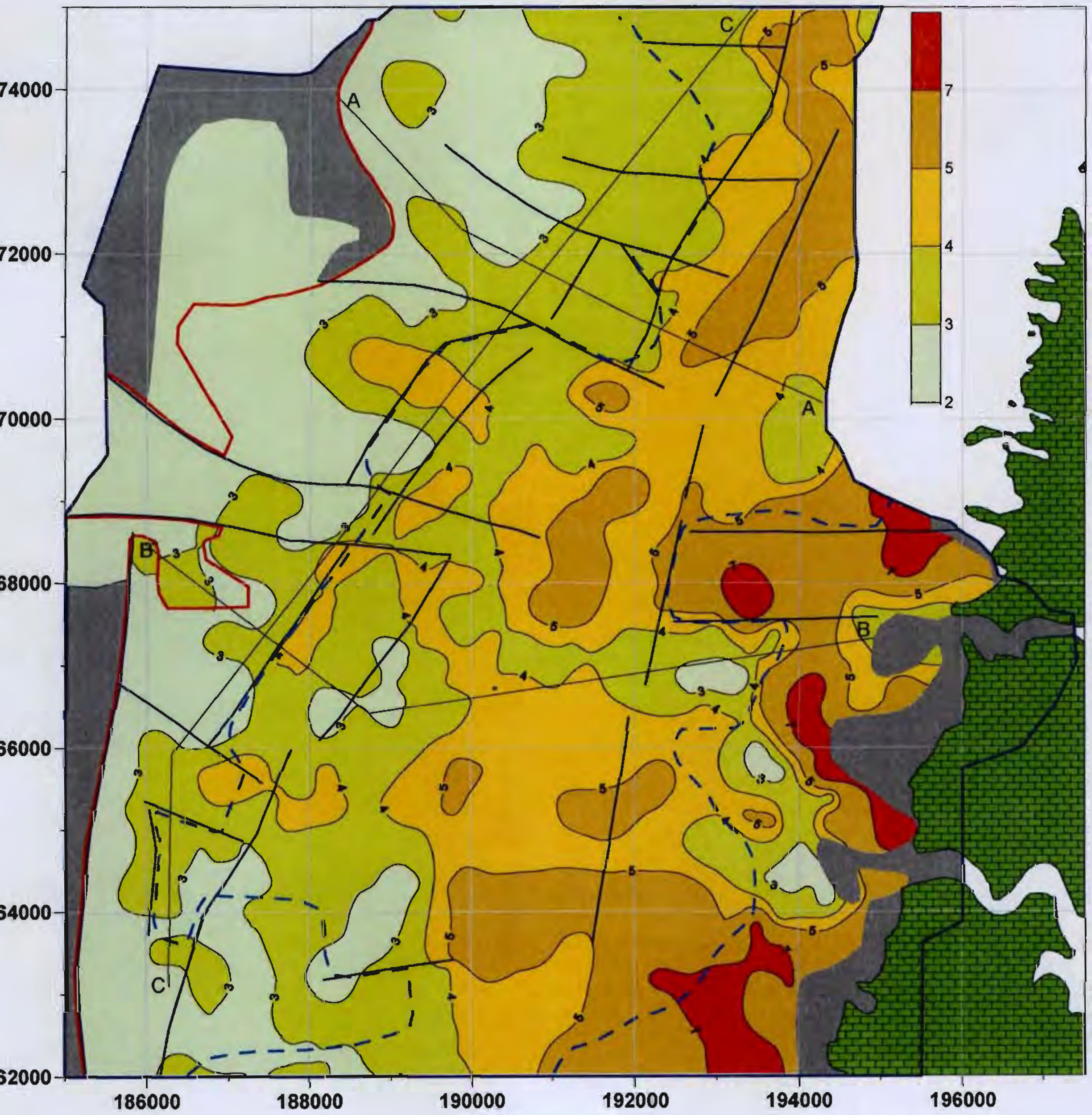


Fig. 28. Distribution of the amplitude associated with fundamental frequency.

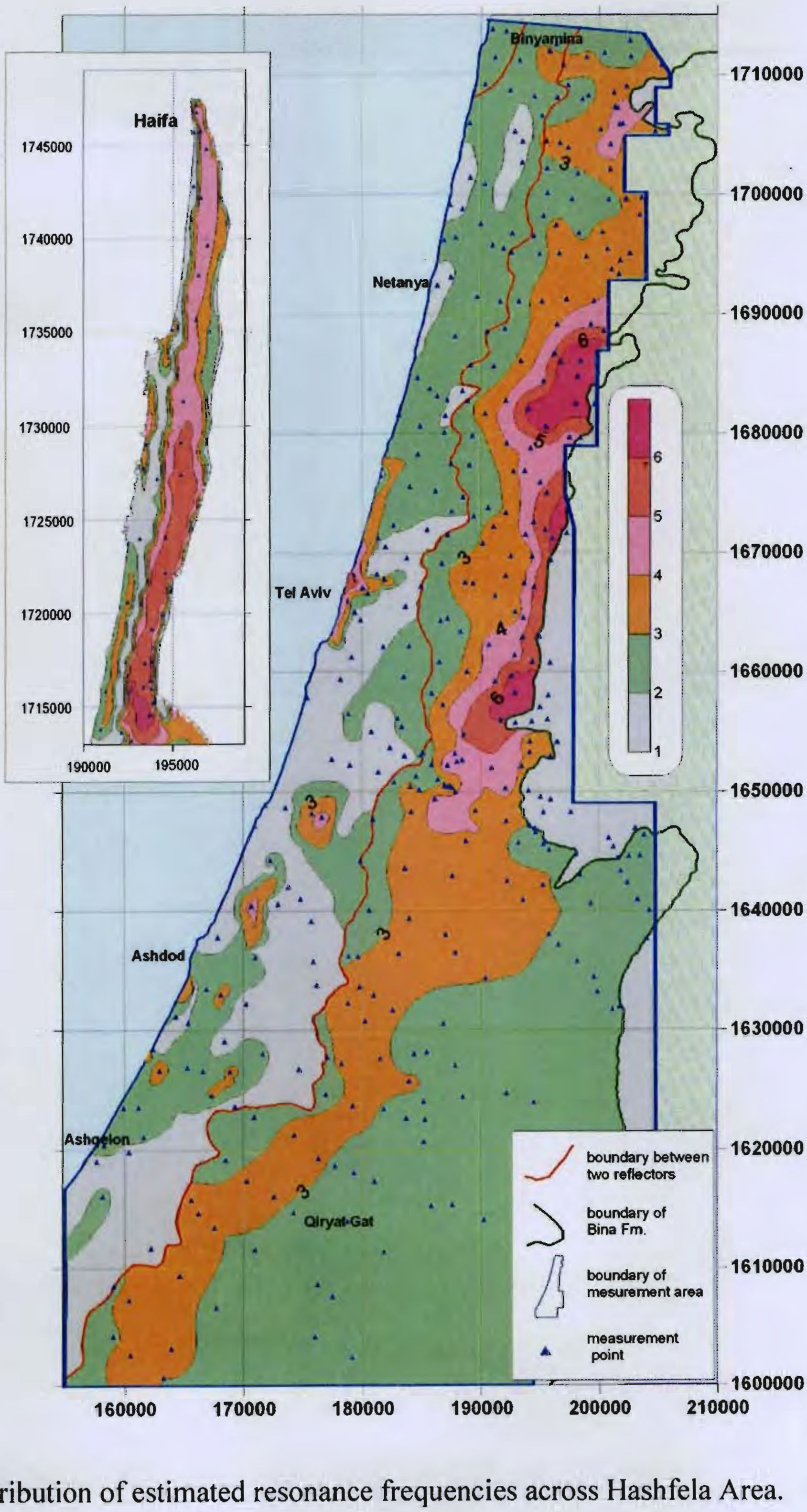


Fig. 29. Distribution of estimated resonance frequencies across Hashfela Area.

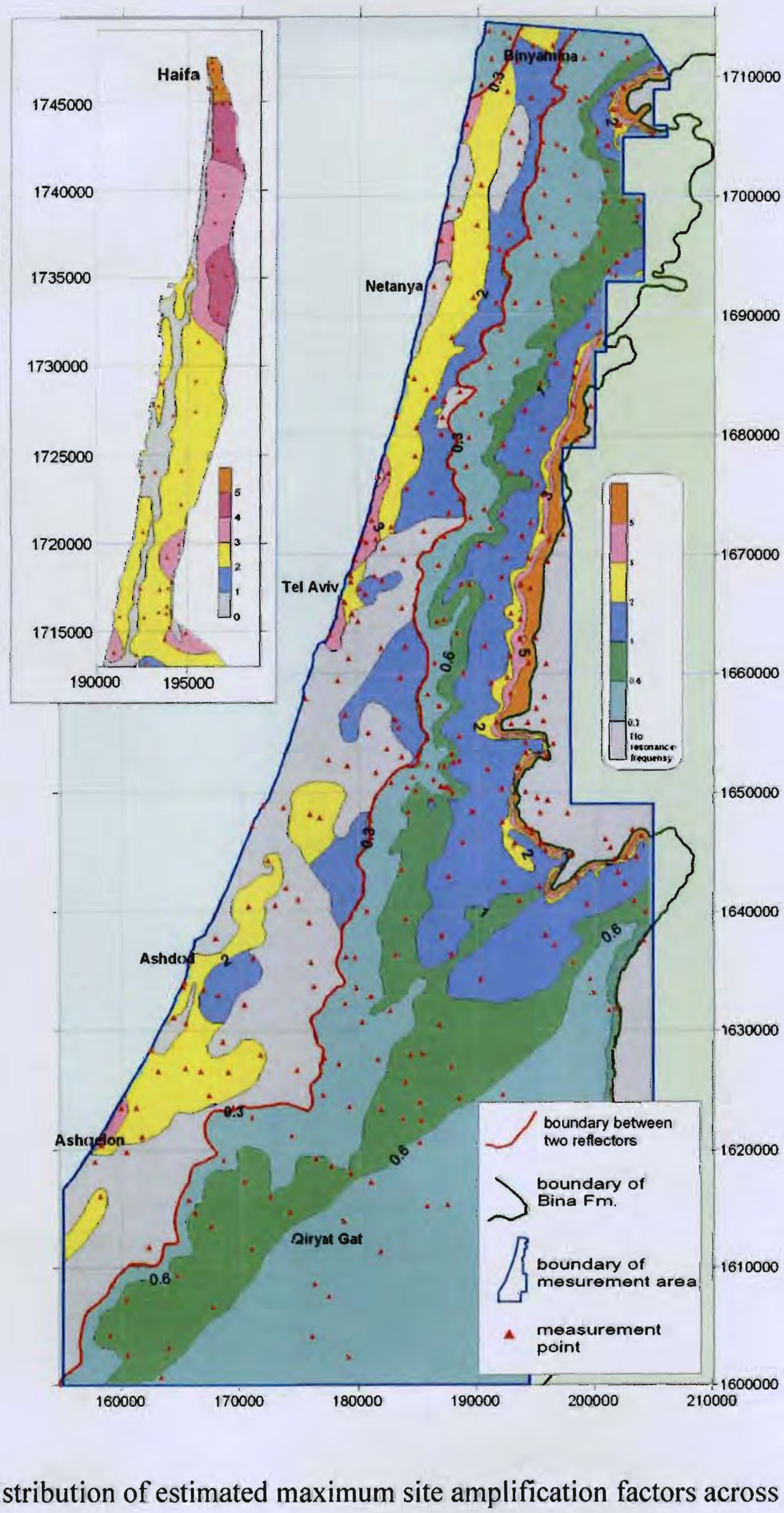


Fig. 30. Distribution of estimated maximum site amplification factors across Hashfela Area.