PHYSICAL METHODS AND APPROACHES IN ENVIRONMENTAL STUDIES

Use of geophysical methods for the solution of environmental problems in Israel

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Received 18 July 2004, accepted 28 October 2004

Abstract

Integration of different geophysical methods is necessary for the study of seismic hazard problems including seismotectonic zoning. Defining such zones with different long-term seismicity within Israel may result in huge savings in the budget for anti-seismic programs. More detailed integrated geophysics is required for the solution of another group of geo-ecological problems related to detection of landslides and collapse structures, karst and other sinkholes (e.g., along Dead Sea onshore), unknown underground constructions, etc. Mapping of gas-hydrate layers on the base of seismic prospecting and well logging data is particularly important from both natural resources and ecological hazard points of view. Methane-hydrates as potential energy resources are at least twice as great as all the resources of coal, oil and conventional gas in the world. At the same time, non-controlled change of temperature and/or pressure may cause decomposition of gas-hydrate deposits, followed by destruction of offshore constructions. Some methods of electric prospecting are important for the solution of problems related to inspection of saline or other pollutions of underground waters and grounds, revealing sites of corrosion and leakage from reservoirs

and pipelines. Different geophysical approaches are required for the study of physical-biological effects, e.g.: direct detection of radioactive emanations and/or revealing of fault zones as fluid flow channels, comparative analysis of the geophysical maps and areas of endemic diseases, monitoring of geophysical fields for prognosis of chronic disease intensification and human reaction weakening.

1 Introduction

Geo-ecological investigations are necessary for the identification of and protection from dangerous natural geological phenomena and those of anthropogenic origin. Such investigations are particularly important for Israel with its high population density and intensive development of infrastructure. Such investigations usually involve integration of different geophysical methods and other tools of Earth sciences, such as geology and geochemistry, hydrogeology and engineering geology.

Geophysical methods study physical fields of the Earth and physical properties of media. Geophysical data allow one to characterize deep and near-surface features of vast regions with high mobility and economic efficiency. Geophysical methods reveal hidden geological structures and bodies at the root of dangerous processes. From this point of view faults of different kind are the most important targets, as earthquake focuses are commonly located on fault planes, and some faults may serve as channels for the transport of charged particles or other pollutants within the fluid flow. In addition, geophysical data aid elucidation of mineral prospection ([1, 2]).

In recent years geo-ecological application of geophysical methods has been greatly expanded. Now near-surface geophysics is intensively applied for solution of environmental protection problems throughout the world (e.g., [3–6]). Similar studies have been performed in Israel (e.g., [7–17]). In parallel, geo-ecological research includes use of seismological methods (e.g., [18–21]), and monitoring of the earthquake precursors, such as the radon flux and the magnetic field of the Earth (e.g., [22, 23]).

2 Methodological aspects of geophysical studies

2.1 General characteristics

It is important that both artificial and natural physical fields are the subject for geophysical studies, and measurements of natural geophysical fields do not destroy natural environment (Table 1).

Field studied	Natural	Artificial
Elastic waves	Seismology	Seismic prospecting
Electromagnetic waves	Magneto-telluric method	Frequency sounding
Electric	Self potential	Electric profiling
Magnetic	Magnetic prospecting	Artificial additional magnetization
Gravity	Gravity prospecting	-
Thermal	Thermal prospecting	-
Radioactivity	Gamma-spectrometry survey	Nuclear magnetic resonance

Table 1: Characteristic geophysical methods.

Methods using natural phenomena are faster to do and less expensive than methods using artificial energy sources. For example, environment-friendly thermal prospecting for hydrocarbons costs less than one-tenth of 1% that of a seismic survey [24]. These methods are especially useful for surveying underground cavities, sites of fluid leaks from reservoirs and pipeline corrosion. However, their successful application has been limited, as techniques for rapid quantitative interpretation of related anomalies were unavailable. Relevant techniques of inverse problem solution for self-potential (SP) and thermal anomalies have been developed in recent years (e.g., [10]). Essential similarity in analytic expressions between such anomalies and magnetic anomalies permits application of the rapid methods of characteristic points and tangents elaborated for magnetic prospecting [25], for the SP and/or thermal prospecting. Figs. 1 and 2 represent examples of quantitative interpretation of SP and thermal anomalies using characteristic points and tangents methods, respectively.

Interpretation of the SP anomaly using characteristic points method (Fig. 1) was performed over a pit measuring 1 m x 1 m x 1 m, which was dug in a sand soil at a landfill near Ashdod [11]. We filled the pit with one ton of crude oil on 25.03.1998. Then, we measured the SP field on 01.04.1998 and 29.07.1998. Measured anomalies showed the amplitude decrease, whereas there was the area increase with time. Quantitative interpretation of SP anomalies showed that the calculated center depth of the source body increased from 45 cm (01.04.1998) to 77 cm (29.07.98). It allowed us to evaluate the rate of spreading of the pollution (about 8 cm per month). It is possible also to evaluate the direction of pollution advance
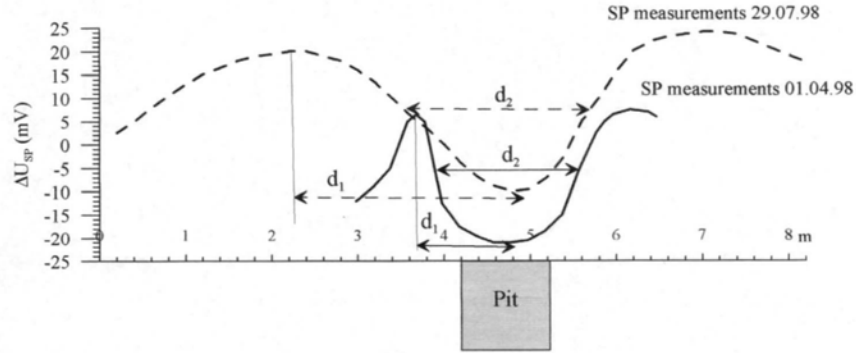
Figure 1: Interpretation of the self-potential anomaly for the evaluation of oil pollution using differences of x-coordinates of maximum and minimum of the anomaly (d_1), and right and left points of its semi-amplitude (d_2).

based on calculated data of the shift of coordinates of source epicenter and the change of direction of its polarization vector.

An example of interpretation of the thermal anomaly using the tangent method (Fig. 2) is given for a hidden fault in the Middle Kura depression [26]. Fig. 2 shows that the inverse problem solution is corroborated by independent geological-geophysical data.

Application of such techniques is a part of a consistent interpretation system developed by the author and his students for geophysical fields recorded in complicated environments, such as oblique magnetization (polarization), variable media and inclined surface of observation. These complicated environments are characteristic for a wide zone of temperate and tropical latitudes of the Earth, including mountainous and many other regions of Africa, America, Asia, Australia, and Mediterranean countries of Europe. This system was described in the book [10], which was positively reviewed by the member of the U. S. Environment Protection Agency as well [27].

The system includes several successive stages of the processing and interpretation of geophysical data wiz: 1) elimination of natural noise (primarily rugged topography effect), 2) petrophysical characterization of targets and host media, 3) techniques of detection of sought-for geological features using quantitative (informational) criteria, 4) estimation of the anomalous body parameters using rapid methods for solving an inverse problem of geophysics, and 5) 3D physical-geological modeling with application of an effec-
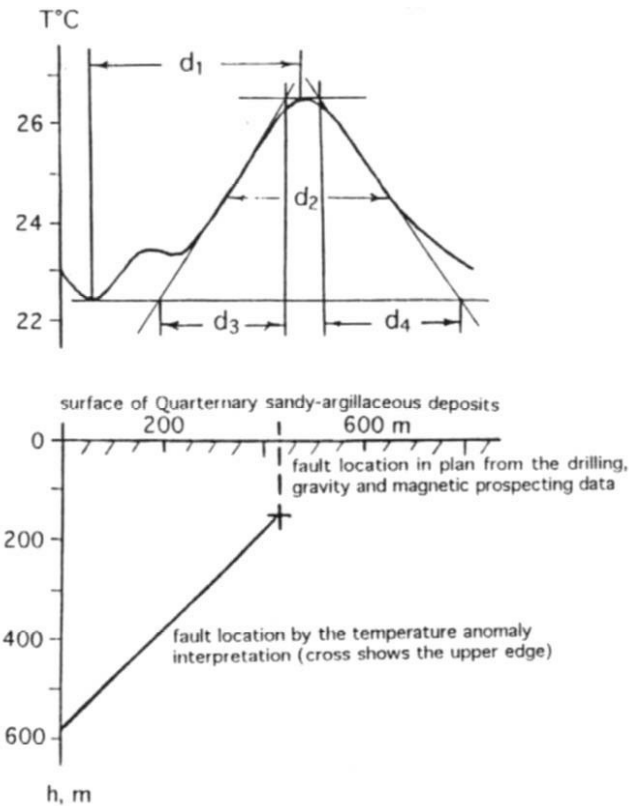
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Figure 2: Interpretation of the temperature anomaly for hidden fault characterization using the tangent method.

tive algorithm for the solution of a direct problem in gravity and magnetic prospecting. Original techniques required for complicated environments were developed for each stage. So, the author developed terrain correction methods that were based on analysis of correlation between observed physical fields and elevations of observation points (e.g., [28, 29]). These methods not only allow one to eliminate topographical effects, but also promptly reveal the presence of hidden near-surface bodies (faults, cavities, etc.) and to characterize the physical properties of the upper part of the medium studied. Moreover, the possibility was shown how to analyze topography data using methods that were developed for the processing and interpretation of geophysical fields, and to retrieve additional geological information from topographic data [28]. Thus, it is possible to integrate both conventional

geophysical fields and elevation field for geo-ecological studies.

Israel is characterized by inclined magnetization (about 45^0), mostly rugged topography, variable geological structure and petrophysical characteristics. Thus, this system is required for the interpretation of geophysical data during geo-ecological studies. Methods developed by the author for the detection of hidden faults and their intersection nodes are particularly important, as these targets are central objects in several directions of geo-ecology.

2.2 Uncovering intersection nodes

Deep fault zones (DFZ) and especially their nodes of intersection (NI) control both many types of earthquakes (e.g., [30, 31]) and mineral resources (e.g., [1, 10]). Spatial distribution of DFZs and NIs of different types is very important for the solution of many geological, engineering-geological and environmental problems. The DFZs generate linear components of geophysical (including terrain relief) anomalies. It is difficult to reveal the DFZ in geophysical fields, if observed fields are complicated by the anomalies caused by several targets and random noise. When linear structures with different strikes are intersected, the field components caused by these structures are superimposed. It is especially difficult to detect the NI against a background of geophysical anomalies superposited at a node. Besides, one has the problem of discriminating between the DFZ and NI with different size, strike, and inclination. To reveal the NI of hidden faults, an informational method was suggested [33, 10]. The method is based on the logical-statistical processing and integrated interpretation of magnetic and gravity fields, and elevations of observation points as well. It is possible to reveal the NI by the calculation of information on linear peculiarities along crossing directions and then calculation of informational parameters reflecting the presence of intersection of different structural directions.

The amount of information obtained by measurement of a geophysical field U [1, 25] is approximately

$$J_u \approx \log(L_u/\Delta U), \tag{1}$$

where L_u is the magnitude of U anomaly, ΔU is the error of its determination.

It is convenient to explain the essence of this technique using apparent cruciform graticule that is composed of two mutually perpendicular rectangles. Each rectangle is made up of three elementary squares. The central

square, being common for both rectangles, falls directly within the hypothetical area of intersection and is not involved in computation. For each direction, field isolines, which cross the external line of outer squares and the internal line parallel to it, are counted (μ and ν). The isolines are plotted with the interval close to that of the ΔU error. Also, from [34], the amount of information obtained as result of a physical measurement is:

$$J_u = \log(L_u/\Delta U), \tag{2}$$

where L_u is the span of the measured U value, ΔU is the measurement error.

Relationships (1) and (2) are similar, but they were obtained in different ways [25]. Consequently, if μ or ν isolines are present on a portion of the map, then their numbers correspond to the $L_u/\Delta U$ value in Eq. (2). The amount of information J_p on the NI presence is determined by the ratio of the amounts of information on the presence of anomalies with different strikes $J_1 = \log_2\mu$ and $J_2 = \log_2\nu$. In order to reduce the effect of high-gradient zones with a common strike, J_p is calculated by the expression

$$J_p = (J_1 + J_2)J_1/J_2, \tag{3}$$

where $J_1 \leq J_2$.

The variations in the size and direction of the rectangles would make it possible to distinguish NI of different types. In actuality, a digital model and software substitute for the isolines map and the cruciform graticule, respectively.

The testing of the technique on a model magnetic field related to meridian and latitudinal faults ("magnetic lineaments") showed the efficiency of algorithms described above (Fig. 3). There has been successful testing under natural conditions as well (e.g., [35]).

2.3 Quantitative integrated interpretation

Target detection is usually impossible using a single geophysical method, since identical geophysical anomalies may be related to an anomaly source with different physical properties, mode of occurrence, pattern, and nature. Thus, integration of geophysical methods is necessary in order to reveal and characterize hidden targets. From the theoretical point of view, the development of integrated studies is more rational than attempts to improve the precision of separate methods; two (sometimes three) geophysical methods are usually required for the detection of a desired target [36].

The measurement, processing, and interpretation of the natural (magnetic, gravity, thermal, some electric/electromagnetic and other) fields and/or

artificial (seismic, acoustic, electric and other) fields may solve this problem. However, target signals are commonly weak and almost indistinguishable from the background because of natural and/or artificial noise, whereas non-interesting (undesirable) signals may be stronger. In some cases, the conventional processing methods may be insufficient, particularly for the revealing of small geo-ecological targets against the background of very variable near-surface environments.
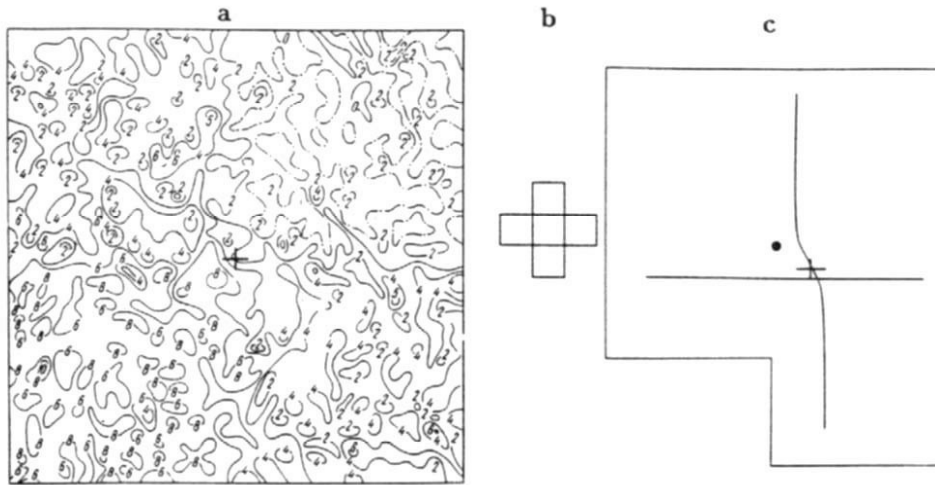

Figure 3: Detection of hidden model faults and their intersection node. Fig. 3a shows synthetic magnetic field of mutually perpendicular, intersecting linear structures, plus random noise. Broken lines in Fig. 3a mark zero contours. Fig. 3b shows a sliding cruciform graticule used for computing the number of isolines per area. The results of computations are presented in Fig. 3c. A small cross marks the location of the intersection of the pre-set structures. The solid lines are anomaly axes determined with the rectangular graticule. The small disk is the point of the NI defined according to the maximum value of the J_p index.

An informational technique allows one to detect a hidden target using an integrated index [10, 32]. Such index calculation accumulates signals of different magnitude from different geophysical fields and eliminates effects of noise and irrelevant objects. The target-indicator U (i.e. geophysical, geochemical or other anomaly) can be expressed by informational units ac-

cording to Eq. (1) or Eq. (4):

$$J_u = -\log P_j, \tag{4}$$

where P_j is the frequency rate of the j-th interval on the histogram of indicator frequency distribution.

The J_u value may be replaced by the relative amount of information (coefficient of informativity):

$$K_u = J_u/\log R, \tag{5}$$

where log R value determines the information obtained when the observation result falls into j-th interval of histogram, whereas the probability of falling into any of R intervals is identical.

This coefficient is an average (complete) information, contained in the results obtained by measuring with one method. The K_u index application enables one to take into account the range of different fields.

The summation of these units for N measurement methods and obtained informational indices emphasize the presence of a desired target and suppress extraneous effects. The complex index J_{compl} eliminates the effects of a strong anomaly recorded by a single geophysical method and accumulates the anomalies recorded by all the methods:

$$J_{\text{compl}} = \sum_{i=1}^{N(N-1)/2} [(K_p)_i/(K_p)_{\text{max}}], \tag{6}$$

where $K_p = (K_i + K_k)K_i/K_k$, $K_i \leq K_k$; K_i and K_k are information values obtained by i-th and k-th measurement method, respectively.

This approach differs from other ones (pattern recognition, automatic classification, etc.) in that the investigator gives indicators of a target. Hence, the problem is solved promptly; previous "training" or subsequent analysis of the meaning of separate defined classes are not required. The application of this simple technique provides an approximate but stable solution of the problem. At the same time, it provides the clear quantitative criterion. Such informational processing will significantly improve the resolution and time required to reveal a desired target from a complex data set.

Algorithms have been developed as software in the former USSR and have been successfully tested on models and in real complicated environments on known ore bodies and deep faults (e.g., [10, 37]). The example
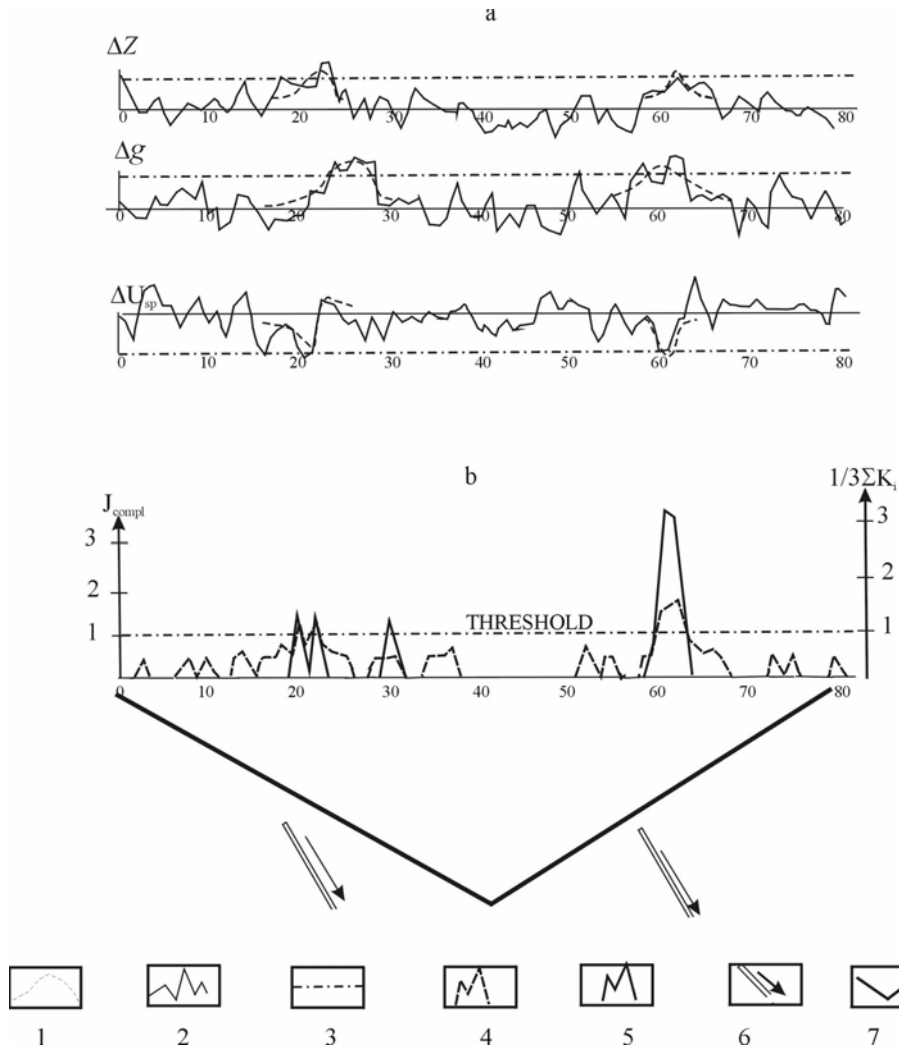
Figure 4: Integrated quantitative interpretation of model geophysical fields over model faults: a - magnetic (ΔZ), gravity (Δg), and electric self-potential (ΔU_{sp}) fields; b - computation of complex indices J_{compl} and ΣK_i. (1) geophysical field of model body; (2) summarizing field of model body and noise; (3) doubled standard deviation of the noise; (4) value and graph of information sum; (5) single value and graph of J_{compl}; (6) model body, the arrows show the direction of magnetization vector and polarization axis of electric field; (7) terrain relief.

of the detection of model faults is shown in Fig. 4. Thin plate approximation is relevant for a series of bodies including fault zones. Fig. 4 shows the detection of such inclined faults according to informational complex indices intensifying week anomalies of separate geophysical fields (it is clear that J_{compl} index is more effective for revealing a hidden target).

2.4 Induced polarization method

The induced polarization (IP) method differs from other geophysical methods by combining measurements of different electrical parameters and, therefore, has integration advantages. IP equipment registers at the same observation point the data provided by the three electric methods: IP, direct current (DC)/resistivity and SP methods [38–40].

The effect of IP in a real two-phase medium is a consequence of the interaction of rock-forming minerals with electrolytes, which behave as an accumulator of outside electrical field energy. Rectangular pulses of current directed through steel electrodes stimulate the electric processes in the ground. Voltage and electric current are measured not only between electric pulses, but also when a current is switched on. This permits measurement of an apparent resistivity ρ_a. When an electric current in the ground is interrupted, the voltage does not drop to zero instantaneously. Its relaxation time, the voltage value, and drop character are parameters of the ground-induced polarization. These parameters in parallel to resistivity data can be correlated with lithology and granular character of the geological medium, water content, and water salinity in layers. For the receiving of correct IP-signal, SP anomalies have to be compensated. Non-polarizing potential electrodes (signal receivers) ensure self-potential measuring. Obtained SP data provide the means to reveal the existence and direction of water filtration.

It is possible to move the IP array along the profile for the detection of near-surface sub-vertical targets (electric profiling), or to increase the separation of current electrodes for the increase of depth penetration and mapping of gently sloping discontinuities at depth (electric sounding).

3 Main geo-ecological problems for geophysical prospecting

3.1 Seismic hazard

Besides the history of seismic events, seismic danger for each area is determined by the following: a) location within a specific geo-tectonic block, b) nearness to faults and fault peculiarities, and c) location with reference to a geological section and ground physical properties of the area. Israel is situated at the confluence of lithosphere plates, i.e. in a seismic-active zone (Fig. 5). Regional mapping of main faults has predicted great seismic hazard for pipelines within the Eastern Mediterranean [41]. It is evident from Fig. 5 that the first version of the planned Baku (Azerbaijan) – Ceychan (Turkey) pipeline was located within the active East Anatolian Fault (EAF) zone. Subsequently the pipeline has been relocated to a longer route that avoids the fault.

The importance of taking into consideration a seismic hazard during a major construction project concerns enormous expenditures. An anti-seismic program in Israel requires billions of dollars, but can save many thousands of human lives. Note that seismic hazards within different Israeli regions are different because of considerable heterogeneity in regional geology. Thus, reliable zoning of Israel according to possible seismic hazard is very important. The seismicity map of Israel was developed by the Geophysical Institute of Israel (GII) at a small scale (1:750,000) and was based on earthquake records at a few tens of seismological stations. The corresponding map of seismic hazard for Building Code 413 is even more generalized (Fig. 6). The separation of the country into quasi-linear zones contradicts abundant geological-geophysical data (published geological maps, deep wells, seismic profiles, and measurements of magnetic and gravity fields) that suggest a dominant block structure of Israel (Fig. 7).

Moreover, seismological data alone are insufficient for the prognosis of long-term seismic activity. For example, according to Probabilistic Predictional Map of Greece predicting strong shallow earthquakes for the period of 1986-2006, three strong and damaging earthquakes in 1995-1996 occurred within regions characterized respectively by low, medium and high probability [44]. Therefore, a seismotectonic map covering the territory of 125,000 km^2 and adjacent marine areas was composed for Greece at a scale of 1:500,000, and now a new 1:100,000 map is planned. For Iran (with territory of 1,630,000 km^2) 1:250,000 seismotectonic map was composed. A similar map does not exist for Israel, which has much less territory.
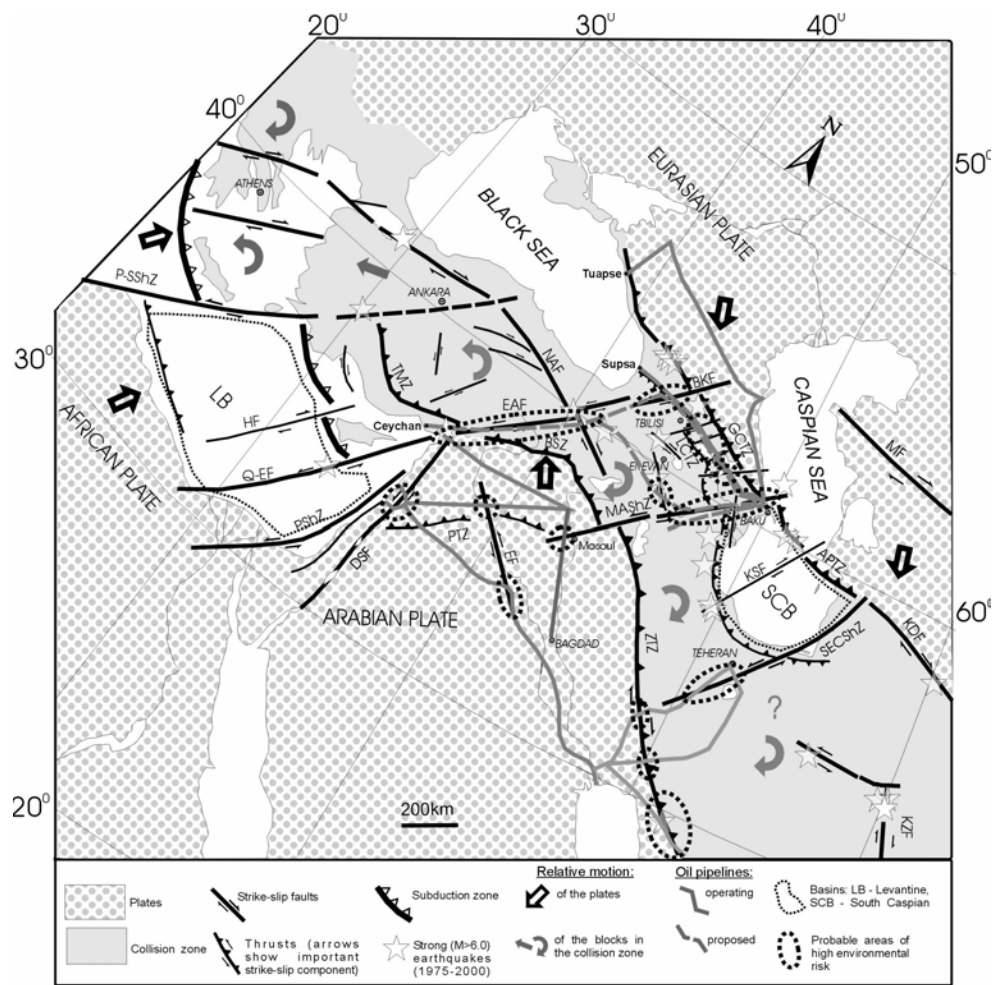
Figure 5: Major fault zones and pipelines within the Eastern Mediterranean
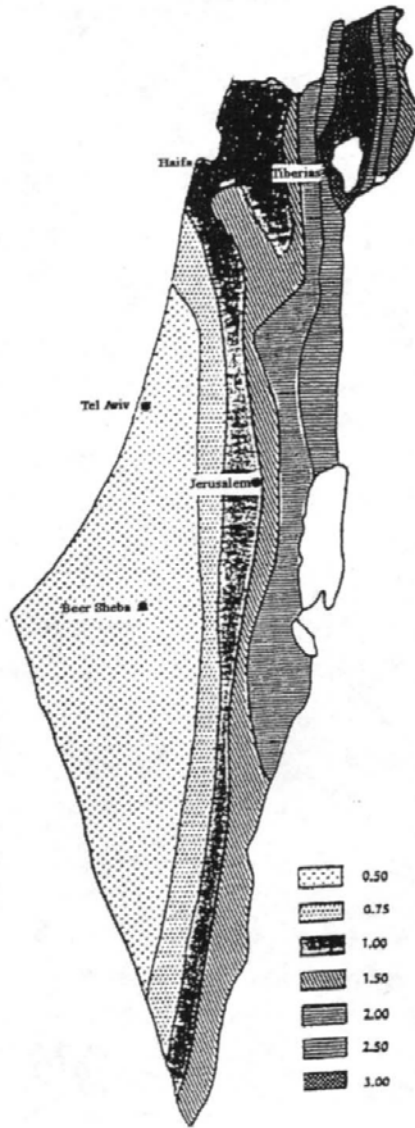and adjacent regions.

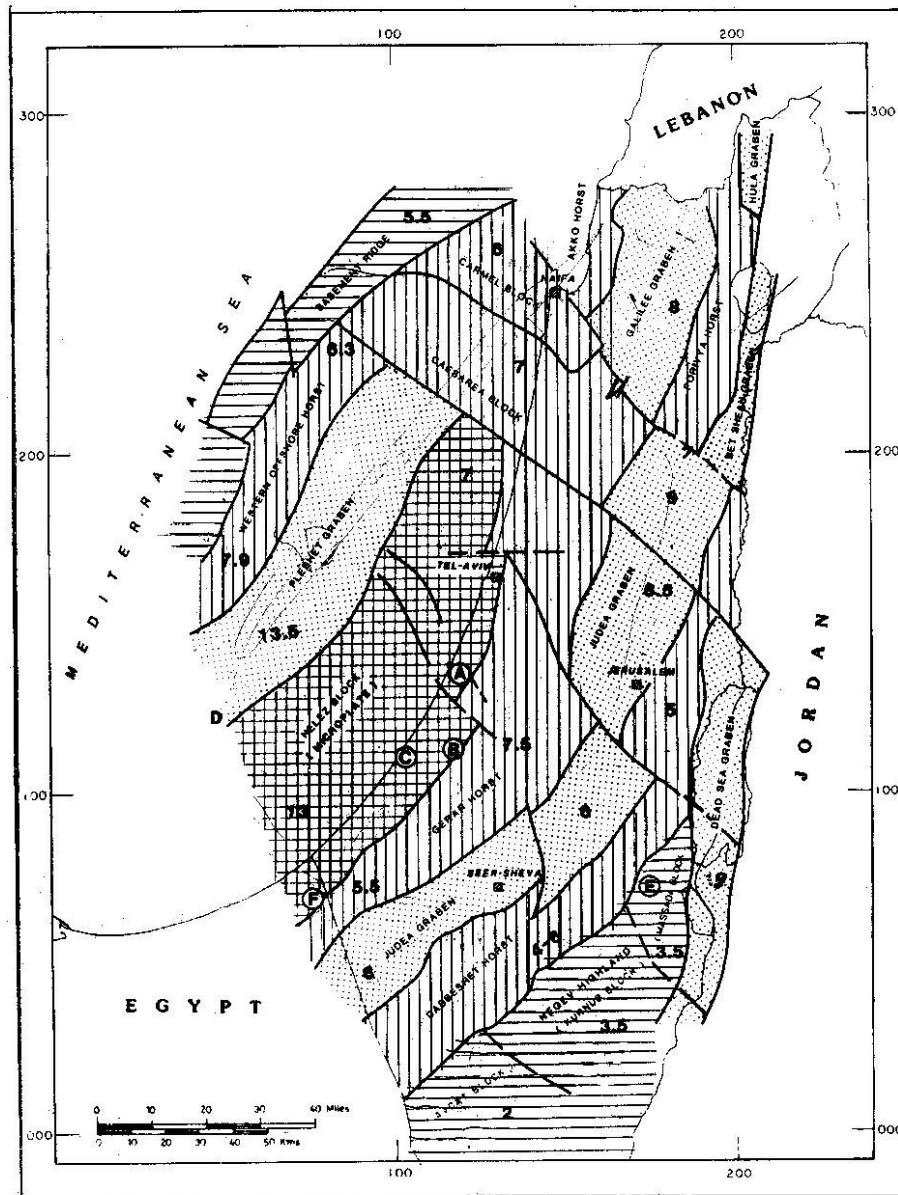Figure 6: Map of Israel with seismic coefficients for the building of seismic-stable construction [42].

Figure 7: Tectonic pattern of Israel [43]. A: Ashdod oil-and gasfield.
B: Helez oilfield. C: Shiqma gasfield. D: Mango oil discovery. E: Zohar
gasfield. F: Sadot gasfield. Figures indicate depth to the basement (in kms)
based on the present geophysical and well data.

The development of a reliable seismotectonic (seismogeological) map of Israel using integration of all the available data is possible now, because 1) a basic geological-geophysical data-set is available for our region (e.g. [45–48]); 2) a methodological base for the additional processing and interpretation of geophysical fields, for the construction of the map and its regional insertions has been elaborated [10, 35]. The conventional seismotectonic maps (widely prepared abroad) have to be completed by the data on peculiarities of deep structure including hidden faults and their intersections (such nodes are particularly dangerous), as well as by the results of direct correlation between long-term seismicity and geophysical fields of our region. The possibilities and required peculiarities of such correlations have been studied in a similar region [49].

Seismic risk zoning will determine the requirements for seismic-stable buildings and constructions for each specific area. The project will save unnecessary expenditures for building strengthening within non-hazard regions and will concentrate required efforts in localized hazard areas only. Thereby, the cost of the project will be many times compensated. Suggested integrated work can be performed in three years with the planned financial support of $400,000.

Regional zoning [35] must be supplemented by detailed study of grounds for most important sites. Study of ground acceleration has a crucial significance. The GII performs such expensive microseismic mapping for several Israeli towns (e.g., [50, 51]). Another direction is an attempt to predict the precise time of a shock. The GII, Geological Survey and Survey of Israel, Soreq Nyclear Center performed such studies, mainly, by monitoring of magnetic field and radon emission (e.g., [22, 23]).

3.2 Gas-hydrate problem

In the last years dual aspect of gas-hydrate (clathrate) substances has become very real. Methane-hydrate is a subject of great hope as a huge energy source and great fear as an environmental hazard.

Hydrates consist of water molecule cages that surround and trap hydrocarbon molecules in a lattice network. With a structure and appearance similar to ice, 1 ft^3 of solid hydrate contains between 150 and 180 ft^3 of gas at standard conditions [52]. Methane-hydrates exist as stable solids at depths below the seafloor ranging from about 100 to 1100 m. Despite higher pressure, elevated temperature at depth destabilizes methane clathrate. As the result of gas-hydrate decomposition, a lot of drinking water might be obtained.

There are some advantages for gas-hydrate prospecting comparatively with conventional oil-and-gas exploration. First, gas-hydrate areas are usually much bigger. Second, depth of its occurrence is usually shallower. Third, physical properties of hydrates are clearly distinguished from those for host medium, which makes for exploration efficiency in well logging and seismic prospecting. Similarities between some forms of hydrates and ores open fresh opportunities for application of other geophysical methods as well.

The potential energy resources of gas-hydrates exceed the resources of coal, oil and conventional gas in the world by at least a factor of two [52]. Other estimations of gas-hydrate reserves are often much higher (e.g., [53]). The data of the US Geological Survey testify to the presence of gas-hydrates under the floor of the eastern Mediterranean Sea as well [54]. The study and use of gas-hydrates in Israel can provide additional energy and water resources. Unlike coal and fuel oil for power-stations, industry, and life, gas sources are environment-friendly. New traditional gas pools have already been revealed on Israel' shelf (e.g., [55, 56]).

At the same time, the plan to built an island chain along Israeli coast and to transfer of Pi-Glilot oil-and-gas storage to an island opposite Tel-Aviv requires further knowledge of the gas-hydrate layer as well. Non-controlled change of temperature and/or pressure at the marine floor may cause decomposition of gas-hydrate deposits, following by underwater landslide, earthquake, tsunami and destruction of offshore constructions. Thus, it is urgent to study the gas-hydrate problem in Israel. Otherwise, the negative experience of building without sufficient preliminary surveys at the Ramat-Hovav industrial area (e.g., [57]) will be repeated.

It is advisable to follow the modern experience of the USA. In May 2000 the US Congress passed the Methane Hydrate Research and Development Act. The research program involves 13 government labs or agencies, 10 universities and at least seven exploration and production companies [52]. Japan and India followed the USA in rapid sequence of gas-hydrate research. My proposal for the first stage of gas-hydrate mapping on the Eastern Mediterranean seafloor must confirm potential of Israeli shelf for gas-hydrate prospecting and possible exploitation [58]. On the other hand, this proposal will permit evaluation of the risk of methane-hydrate decomposition. The GII and other institutions must cooperate in this study, which is planned for 4 years duration with expenditure of about $ 120,000 per year. Financing of the study requires a special integrated budget of several organizations, such as the Ministries of the Infrastructure and Building, Environment and Science.

3.3 Local destructive phenomena

This group of problems is close to the gas-hydrate problem and related to the study of landslides and collapses, karst and other sinkholes (e.g. along Dead Sea onshore). The GII, other government institutions, and some universities perform integrated geophysical study of these problems, which have mainly an engineering-geological character (e.g. [13, 14]).

A multitude of artificial underground constructions is located in the uppermost part of the geological sequence of Israel. For example, ancient underground water-storages not marked at the maps of Jerusalem. Remote detection of such targets before their excavation is necessary in order to save them and for emergency situations. Such problems could be solved by electric and/or seismic methods, and sometimes by magnetic prospecting (e.g., [59]).

The electric prospecting (firstly, SP method) and thermal prospecting can be useful to reveal hidden leakage of fluids from reservoirs and pipeline corrosion. These installations are fraught with consequences in the form of reservoir destruction or gas-pipeline burning. Similar processes are possible at landfills. Thus, a geophysical monitoring of potentially dangerous sites is necessary.

3.4 Water and ground pollutions

Israel is provided by 70 % of fresh water from underground aquifers in shore and mountain areas. Protection of underground waters from different pollutions is of great importance. An encroachment of salt water into a freshwater aquifer is dangerous for the ecosystem, agriculture, and the population. The Hydrological Service of Israel, the GII, and some universities are actively researching this problem. Borehole drilling is expensive and is an invasive method, and besides it characterizes a geological section at separate points only. According to the GII data (e.g., [7]), a combination of drilling with a denser grid of electric soundings allowed detection of the seawater/freshwater interface within a sand aquifer by specific electric resistivity (ρ) measurements of seawater (low ρ) and freshwater (high ρ). However, in the Mediterranean coastal plain of Israel the geological section contains clays of low resistivity, which cannot be distinguished from conductive seawater-bearing sands. Another electric property of clays - polarizability (or chargeability) - has to be higher than the polarizability of sands containing salt water. Thus, the induced polarization method (which permits the simultaneous registration of the polarization parameters, ρ and
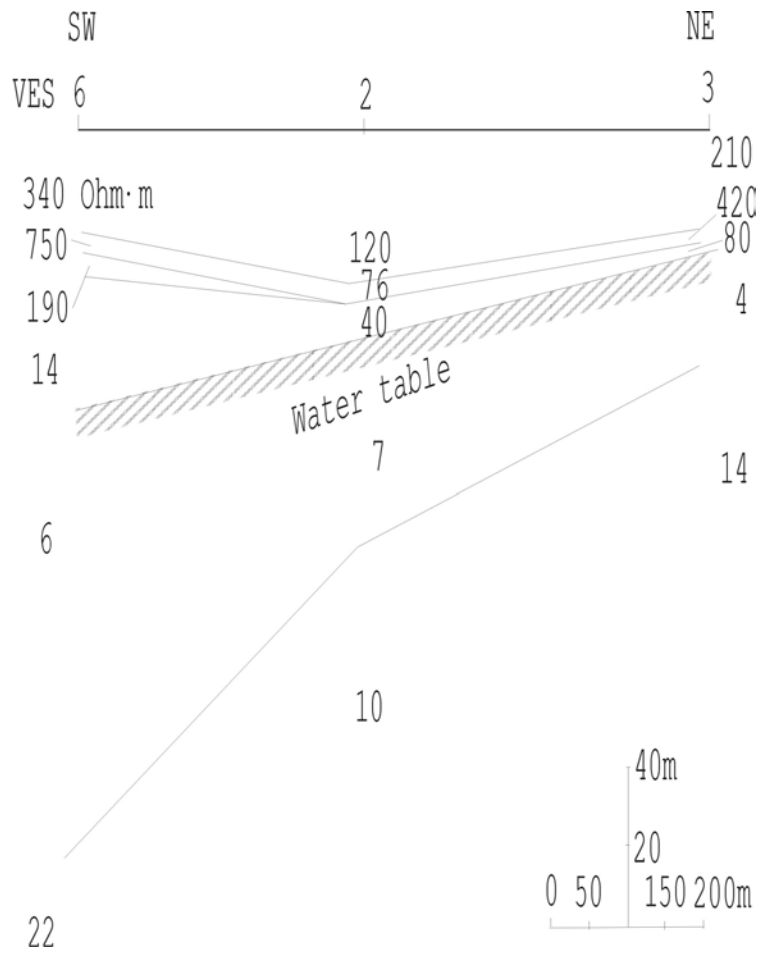
Figure 8: Geoelectrical cross-section within Ramat Hovav area.

SP at the same observation point) is suggested for the separation between saltwater-bearing sands and clays of low resistivity [60].
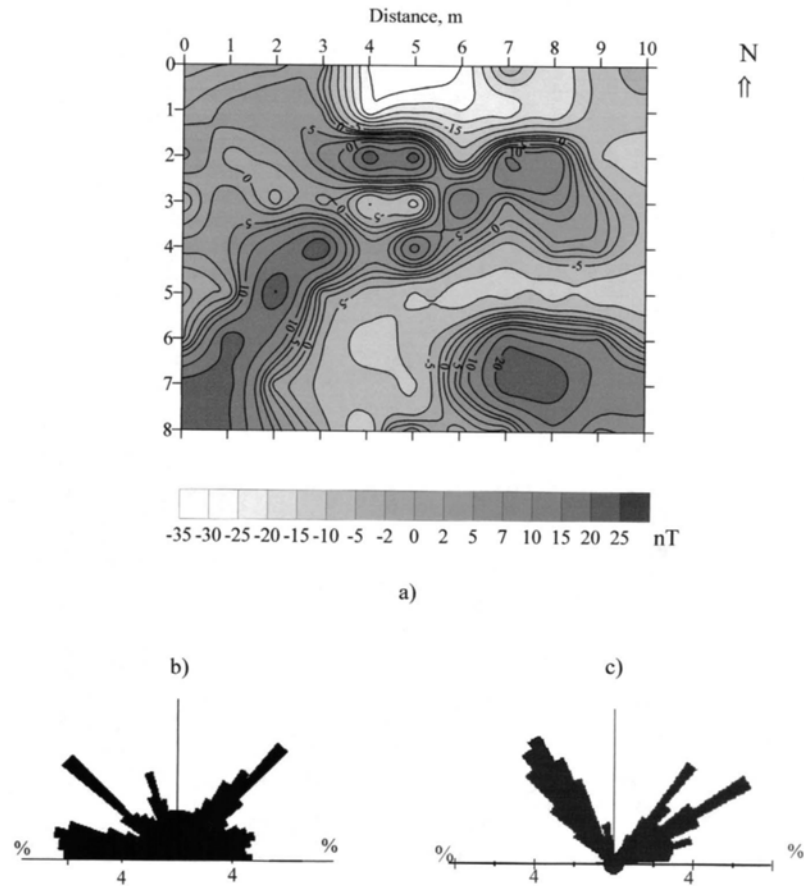

Figure 9: Micromagnetic survey within Ramat-Hovav site: a) map of ΔZ isogams (nanoTesla), b) rose-diagram of isogams strike, c) strike orientation histograms of some 1330 burial joints in Lower Eocene chalks around Beer-Sheva [62].

Electric prospecting is an important tool for the characterization of underground water and its possible directions of flow. For example, a water-bearing layer is distinguished according to vertical electric sounding (VES) data of Klang and Levanon [61] in the area of Ramat-Hovav industrial zone. Here both water table and top of the Judea Group are electrical discontinu-
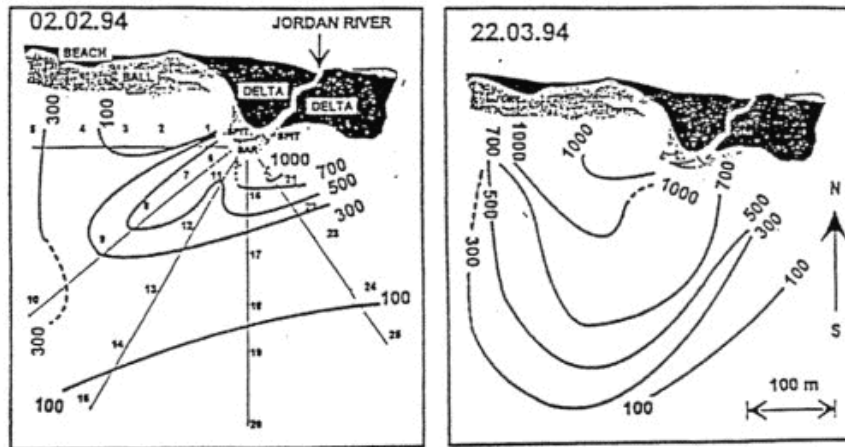
Figure 10: Dynamic study of bottom sediments, Jordan River mouth, using isolines of magnetic susceptibility (of 10^{-5} SI units). 1,2,...,25 are numbers of bottom probe points on radial profiles in lake Kinneret.

ities and, therefore, the inclination of local and regional aquicludes can be determined. It is evident from Fig. 8, where S. Bagdasarov plotted resistivity section along the line of VES Nos. 6, 2 and 3 that made possible the detection of the water table [57].

For the study of possible fluid, pathways micromagnetic survey is also applicable in some cases. Non-magnetic Lower Eocene chalks in Ramat Hovav are intersected by fractures with slight ferruginization. Micromagnetic survey within the area (Fig. 9a) resulted in a rose-diagram of the magnetic anomalies strike distribution (Fig. 9b), which shows NW and NE oriented anomalies on the background of a sub-latitudinal regional trend. The local component of the magnetic strikes obtained (Fig. 9b) corresponds to the rock fracture strikes observed in the field (Fig. 9c). Thus, micromagnetic study can be used for mapping of fracture distribution in favorable conditions, where there is distinctive contrast between host medium and investigated features. Such surveys can substitute for the conventional methods where rock exposure at the surface is insufficient for direct measurements.

Water flows in industrial areas (e.g. Ramat-Hovav) may lead to a significant accumulation of the environmentally hazardous heavy metals in bottom sediments and surrounding soils. Detection of these metal concentrations by conventional methods is labor consuming and costly. Alternatively, it is possible to detect a presence of heavy metals by rapid and easy measurements
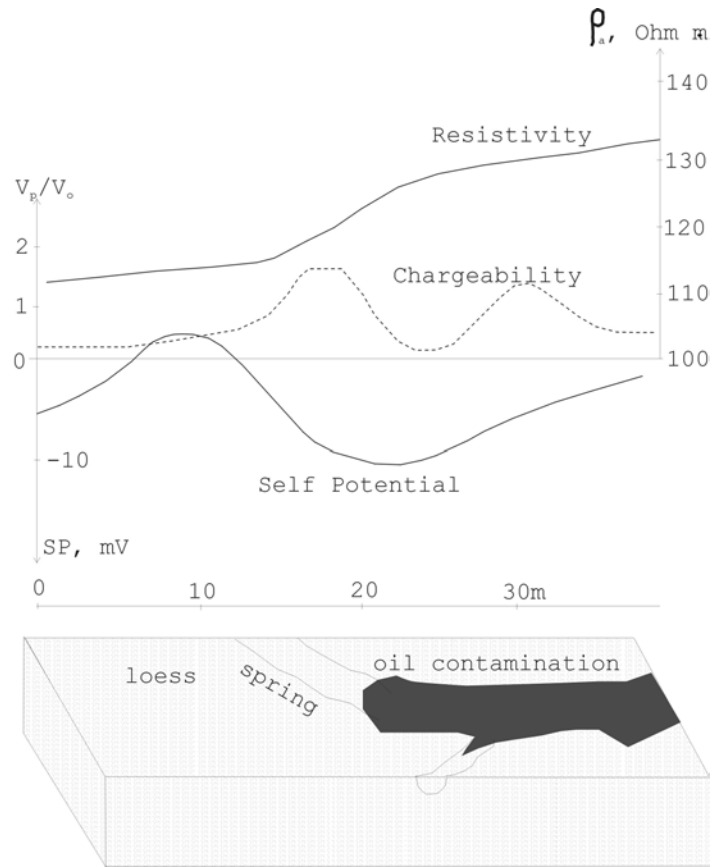
Figure 11: Detailed electric profiling of resistivity (ρ_a), chargeability (V_P/V_0) and self potential (SP) at the site of oil pollution in loess soil near Beer-Sheva.

of magnetic susceptibility (κ) of water-born sediments containing magnetic metals and minerals. The heavy fraction will be rich in heavy metals and magnetic minerals. Therefore, κ measurements would permit the monitoring of the distribution of these environmentally hostile components. A similar approach was used for the investigation of the movement of bottom sediments in lake Kinneret [10, 63]. Magnetic susceptibility measurements performed at the inlet of the Jordan river showed changes in localization of magnetic basaltic particles in the bottom sediments of lake Kinneret before and after storm, reflecting the change in distribution of heavy fraction in the bottom sediments (Fig. 10). Such approach for the study of industrial pollution of stream sediments was successfully tested latter in southern France [64].

Oil contamination of water results in ρ values growing, whereas heavy metals contamination is reflected in ρ decrease. Thus, ρ measurements can provide important information on water composition and sources of pollution. Ground oil pollution may be detected by electric prospecting as well [57]. The IP method was tested for the study of oil contamination in loess soil near an oil storage tanks farm at the HaEshel terminal in the vicinity of Beer-Sheva town. Oil product flowing out from damaged pipeline is detected by clear increase of the resistivity and chargeability, and by characteristic SP anomaly (Fig. 11).

3.5   Physical-biological effects

It is known that sites dangerous for human's health are localized along active faults (e.g., [65]). Weakened fault zones may provide pathways for rising radioactive emanations and other fluids flow that may cause chronic illness. They may also be sites of pollution.

Variations of geophysical fields in space and time have an affect on population. It was noted that endemic diseases in some countries (e.g. goitre in Azerbaijan) were correlated with the characteristic combination of magnetic and gravity anomalies. Therefore, it is worthwhile to perform comparative analysis of the geophysical maps and areas of endemic diseases in Israel. On the other hand, the "magnetic storm" influences speed and quality of reactions of pilots, drivers, and complex system operators; chronic heart and other diseases become aggravated. Thus, monitoring of geophysical fields for prognosis of chronic disease intensification and of weakening of human reaction is not less important than the weather forecast.

Problems	Geophysical methods	Main goals
Detection of *regional seismic activity zones* and the *precursors of earthquakes*	Integration of seismological observations with almost all other geophysical methods	1. Estimation of regional deep structure and seismotectonic zoning. 2. Distinguishing of earthquake precursors on forecast polygons
Mapping of *gas-hydrate* deposits in East Mediterranean shelf	Seismic prospecting, well logging and possibly electric and gravity/magnetic prospecting	Revealing and contouring of methane-hydrate layers
Prognosis of *landslides and collapses*	Electric and seismic prospecting, the GPR (ground penetrating radar)	Characteristics of geological section of dangerous zones and their monitoring
Detection of *karst and similar sinkholes*	Electric, gravity and seismic prospecting, the GPR; sometimes, magnetic prospecting	Localization of bodies with low density, distinctive electrical and other properties
Inspection of *saline or another pollution of waters*	Induced polarization method, water resistivity and surrounding soil magnetic susceptibility measurements	Detection of layers and sites with different physical properties

Problems	Geophysical methods	Main goals
Inspection of *ground contamination* and *bottom sediments moving*	Electric prospecting, magnetic susceptibility measurements, magnetic and radioactive surveys	Detection and monitoring of geophysical peculiarities
Detection of *pipe-lines corrosion* and *leakage from reservoirs*	Self-potential method, thermal prospecting	Localization and monitoring of geophysical anomalies
Inspection of *landfills*	Electric, magnetic and thermal prospecting, radioactive survey	Basement characteristics, distinguishing of materials with different properties and processes of chemical alteration and burning
Detection of *fluid and charged particle flows*	Emanation and other radioactive surveys, electric prospecting	Revealing of active fault zones that focus fluid flows
Study of the areas of *endemic diseases*	Analysis of magnetic, electromagnetic, gravity and radioactive data	Comparative analysis of the peculiarities of geophysical maps and medical data

Table 2: Geo-ecological application of geophysical prospecting.

4   Conclusion

Reported short review of the problem shows that geo-ecology scope is very spacious (Table 2). At the same time, it is clear that geo-ecology is in its starting stage of development. The subject of geo-ecological studies is located on intersection of different fields and interests. Thus, integration of relative funds and budgets is required for the solution of actual geo-ecological problem.

References

[1] B.E. Khesin, *Prognosis and Localization of Hidden Mineralization in Mountainous Regions on the Basis of Geophysical Data*, (in Russian) (Nedra, Moscow, 1976).

[2] B. Khesin, Scientific Israel – Technological Advantages **4**, 103 (2002).

[3] *Geotechnical and Environmental Geophysics*, Ed.: S.H. Ward, Society of Exploration Geophysicists, Tulsa, v. **1-3** (1990).

[4] D.K. Butler, K.J. Sjostrom, and J.L. Llopis, The Leading Edge **16**, 1593 (1997).

[5] M. Meju, The Leading Edge **21**, 460 (2002).

[6] J.E. Nyquist and C.E. Corry, The Leading Edge **21**, 446 (2002).

[7] M. Goldman, D. Gilad, A. Ronen, and A. Melloul, Geoexploration **28**, 153 (1991).

[8] M. Goldman, B. Rabinovich, M. Rabinovich, D. Gilad, I. Gev, and M. Shirov, J. Appl. Geophys. **31**, 27 (1994).

[9] M. Goldman, Y. Yechieli, U. Kafri, C.I. Voss, The Israel Mineral Science and Engineering Association, The Fifteenth Conference, Haifa, p. E-44 (2000).

[10] B. Khesin, V. Alexeyev, and L. Eppelbaum, *Interpretation of Geophysical Fields in Complicated Environments*, Series: Modern Approaches in Geophysics, v. **14** (Kluwer Academic Publishers, Dordrecht-Boston-London, 1996).

[11] B. Khesin, S. Feinstein, V. Frid, Ye. Vapnik, and G. Ben-Noon, In: *Ecological Problems of Beer-Sheva and Negev*, p. 40 (Beer-Sheva, 1999).

[12] V. Frid, D. Bahat, J. Goldbaum, and A. Rabinovich, Israel J. Earth Sci. **49**, 9 (2000).

[13] M. Rybakov, V. Goldshmidt, L. Fleisher, and Y. Rotstein, The Israel Mineral Science and Engineering Association, The Fifteenth Conference, Haifa, p. E-102 (2000).

[14] V. Shtivelman, M. Goldman, D. Wachs, and Y. Yechieli, The Israel Mineral Science and Engineering Association, The Fifteenth Conference, Haifa, p. E-115 (2000).

[15] L. Eppelbaum and Z. Ben-Avraham, Israel Geological Society, Annual Meeting, Abstracts, p. 22 (2002).

[16] M. Ezersky, Israel J. Earth Sci. **51**, p. 29 (2002).

[17] A. Zureili, G. Tibor, Z. Ben-Avraham, B. Herut, and A. Nishri, Israel Geological Society, Annual Meeting, Abstracts, p. 138 (2002).

[18] *Seismicity of Israel and Adjacent Areas*, Map on the scale of 750,000. Prepared by the Seismological Division of the Institute for Petroleum Research and Geophysics (Survey of Israel, Jerusalem, 1994).

[19] A. Hofstetter, A. Shapira, and T. van Eck, Tectonophysics **267**, 317 (1996).

[20] A. Shapira, Teva ha-dvarim **51**, 86 (in Hebrew) (2000).

[21] A. Shapira, R. Hofstetter, L. Feldman, Z. Leonov, and Y. Zaslavsky, Israel Geological Society, Annual Meeting, Abstracts, p. 112 (2002).

[22] G. Steinitz, U. Vulkan, and B. Lang, Israel J. Earth Sci. **48**, 283 (1999).

[23] A. Ginzburg, H. Zafrir, N. Gazit-Yaari, G. Steinitz, J. Forrai, Y. Meltzer, B. Shirman, and I. Hrvoic, The First Stephan Mueller Conference of the European Geophysical Society, Dead Sea, Israel, p. 99, 2000.

[24] F. Lloyd, Hart's E&P **77**, 59 (2004).

[25] B. Khesin, V. Alexeyev, and Kh. Metaxa, *Interpretation of Magnetic Anomalies in the Conditions of Oblique Magnetization and Rugged Topography* (in Russian) (Nedra, Moscow, 1983).

[26] B. Khesin and L. Eppelbaum, Geophysics **59**, 744 (1994).

[27] M.S. Field, (U. S. Environment Protection Agency). February 1997. Interpretation of Geophysical Fields in Complicated Environments, by B.E. Khesin et al., 1996. Choice Books, **34**, no. 6. Science and Technology, Earth Sciences. 34-3320. QC808. 96-196 CIP (1996).

[28] B.E. Khesin, *Geophysical Study of the Mountainous Regions*, D. Sc. Theses, Moscow (in Russian), (Geological Prospecting Institute, Moscow, 1981).

[29] B. Khesin, Israel J. Earth Sci. **47**, 47 (1998).

[30] D.W. Simpson and P.G. Richards, *Earthquake Prediction: An International Review*, Maurice Ewing Ser. **4**, (American Geophysical Union, Washington, 1981).

[31] K. Mogi, *Earthquake Prediction* (Academic Press, Tokyo, 1985).

[32] B. Khesin, In: European Union of Geosciences, VII Congress, Strasbourg, France, Terra abstracts, Abstracts supplement No. 1 to Terra Nova, v. **5**, p. 110 (1993).

[33] B. Khesin, Israel Geological Society, Annual Meeting, Ashqelon, p. 79 (1992).

[34] L.N. Brillouin *Science and Information Theory* (Academic Press, N.Y., 2nd ed., 1962).

[35] B. Khesin, Scientific Issues of *Scientists of the South* Association **2**, p. 5 (Beer-Sheva, Israel, 2001).

[36] B. Khesin and L. Eppelbaum, Geoinformatics **8**, 31 (1997).

[37] B. Khesin, V. Alexeyev, and L. Eppelbaum, J. Appl. Geophys. **30**, 187 (1993).

[38] V.A. Komarov, *Electrical Prospecting by Induced Polarization Method* (in Russian) (Nedra, Leningrad, 1972)

[39] V.A. Komarov, In: *Electrical Prospecting. Reference Book for Geophysicist*, p.329 (in Russian) (Nedra, Moscow, 1980).

[40] J.S. Sumner, *Principle of Induced Polarization for Geophysical Exploration* (Elsevier, Amsterdam, 1976).

[41] B. Khesin and Ch. Metaxas, In: 25th General Assembly of the European Geophysical Society, SE1, Nice, France, 2000.

[42] *Report of Seismic Hazard Commission*, Part B, p. 96 (in Hebrew) (2000).

[43] Z. Cohen, V. Kaptsan, and A. Flexer, J. Petroleum Geology **13**, 437 (1990).

[44] D. Papanikolaou, Ch. Metaxas, N. Melis, D. Foundoulis, and I. Parcharides, The Second International Conference on Earthquake Hazard and Seismic Risk Reduction, Yerevan, p. 49 (1998).

[45] Y. Folkman and Z. Yuval, *Aeromagnetic Map* 1:250,000 (Survey of Israel, 1976).

[46] A. Ginzburg, Y. Folkman, M. Rybakov, Y. Rotstein, R. Assael, and Z. Yuval, *Israel - Bouguer Gravity Map*, scale 1:500,000 (Survey of Israel, 1993).

[47] A. Sneh, Y. Bartov, T. Weissbrod, and M. Rosensaft, *Geological Map of Israel*, 1:200,000 (Geological Survey of Israel, 1998).

[48] Y. Bartov, A. Sneh, L. Fleisher, V. Arad, and M. Rosensaft, *Map of Potentially Active Faults in Israel* (Geological Survey, Jerusalem, 2000).

[49] Yu. Riznichenko, B. Khesin, and Kh. Metaxa, Phys. Solid Earth **19**, 1 (1983).

[50] Y. Zaslavsky and A. Shapira, J. Earthquake Engineering **4**, 43 (2000).

[51] Y. Zaslavsky, A. Shapira, and J. Leonov, J. Earthquake Engineering **7**, 1 (2003).

[52] K. Lang, Hart's E&P **75**, 60 (2002).

[53] T. Collett, AAPG Bulletin **86**, 1971 (2002).

[54] R.L. Kleinberg and P.G. Brewer, American Scientist **89**, 244 (2001).

[55] *Hart's Middle East Oil and Gas*, v. **2**, Iss. 10, 16.05.2000, p. 3 (2000).

[56] S. Feinstein, Z. Aizenstat, I. Miloslavsky, P. Gerling, J. Slager, and J. McQuilken, Organic Geochemistry **33**, 1401 (2002).

[57] B. Khesin, Scientific Issues of *Scientists of the South* Association **3**, p. 1 (Beer-Sheva, Israel, 2002).

[58] B. Khesin, Scientific Israel – Technological Advantages **6**, 1-2, 63 (2004).

[59] L.V. Eppelbaum, B.E. Khesin, and S.E. Itkis, J. Archaeol. Prospection **8**, 163 (2001).

[60] B. Khesin, Scientific Israel – Technological Advantages **3**, 12 (2001).

[61] A. Klang and A. Levanon, *Electric Resistivity Survey in Ramat Hovav Area* (Holon, Inst. Petr. Res. Geophysics, Rep. GE/320/77, 1977).

[62] D. Bahat, *Tectonofractography* (Springer, Berlin-Heidelberg-N.Y., 1991).

[63] B. Khesin and B. Shteinman, In: 2nd International Symposium on the Geology of the Eastern Mediterranean Region, Jerusalem, p. 22 (1995).

[64] F. Desenfant, E. Petrovský, and P. Roshette, Water, Air and Soil Pollution **152**, 297 (2004).

[65] V.P. Rudakov, Science and Technology in Russia **1-2** (38-39), p.19 (in Russian) (2000).