Sinkholes along the Dead Sea Coast and Their Development

Boris SHIRMAN and Michael RYBAKOV, Israel

Key words: sinkholes, sea level decline, aerial photographs, shallow voids, magnetic susceptibilities.

SUMMARY

Sinkholes are large open holes (the largest is as much as 30 m in diameter and 15 m in deep) that result from the earth simply collapsing. In the last decade hundreds of sinkholes have formed along the Dead Sea coastlines in Israel and Jordan causing severe damage to the regional infrastructure. Sinkholes occur along the sea shore within a narrow strip of 60 km long and about 1 km wide. The formation of sinkholes accelerated in the past few years to a growth rate of about 150-200 per year. They spread parallel to the general direction of the Dead Sea fault system. The formation of these sinkholes is connected to the dramatic drop of the Dead Sea water level and associated groundwater levels.

The most alarming cases are sinkholes that have occurred in resort areas, in and around Highway 90, and at the Israeli and Jordanian potash plants. Understanding and predicting natural phenomena such as sinkhole collapse around the Dead Sea is very important because of the environmental hazards which it causes.

In our work we discuss several geophysics methods that have been employed to investigate and predict these occurrences: seismic, geoelectric, microgravity. We have given special consideration to the magnetic method which was developed at the Survey of Israel together with the Geophysical Institute of Israel. The magnetic method indicates that prediction of sinkholes is possible.

> *"And the vale of Siddim was full of slimepits; and the kings of Sodom and Gomorrah fled, and fell there; and they that remained fled to the mountain."*
> (Genesis, Abram and Lot part: 14-10)

Sinkholes along the Dead Sea Coast and Their Development

Boris SHIRMAN and Michael RYBAKOV, Israel

1. INTRODUCTION

Are the slime pits described in the Old Testament analogous to the unique phenomenon called "sinkholes along the Dead Sea shore"?
Sinkholes started appearing in the Dead Sea region in the early 1980s. Highly dynamic, sinkhole development accelerated with a rate of about 150-200 per year.
Collapse-sinkholes are an environmental hazard. An alarming case occurred recently in the resort area, on Highway 90, and at the Israeli and Jordanian potash plants.
Sinkholes are scattered within a narrow strip of 60 km long and about 1 km wide (Fig.1) and are clustered in parallel to the general direction of the Dead Sea Transform fault system. (Arkin,1993, Arkin and Gilat, 2000, Abelson, 2003). A single sinkhole can reach a diameter of 25 m and extend to a depth of 20 m. The sinkholes have evolved due to the dramatic decline of the Dead Sea level, which exceed 25 m since the early 1930's (Fig.2). The contributor factor for this decline in succeeding years was the interception of the freshwater flow to the Dead Sea upstream by agricultural, industrial etc. needs of surrounding countries.

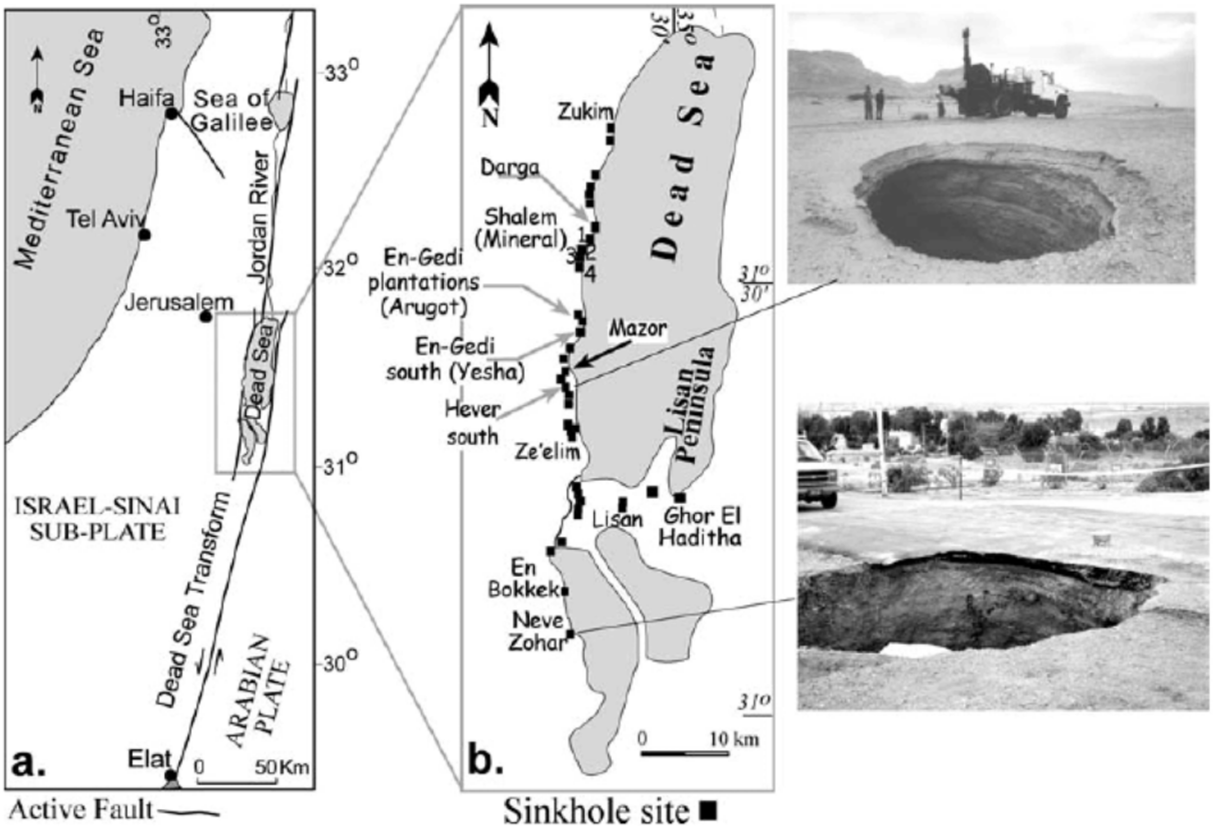

Fig1. (a) Location map showing the Dead Sea basin along the Dead Sea Fault Transform system;
(b) Distribution of sinkhole sites along the Israeli Dead Sea coast and two examples of sinkholes (Abelson, 2003)

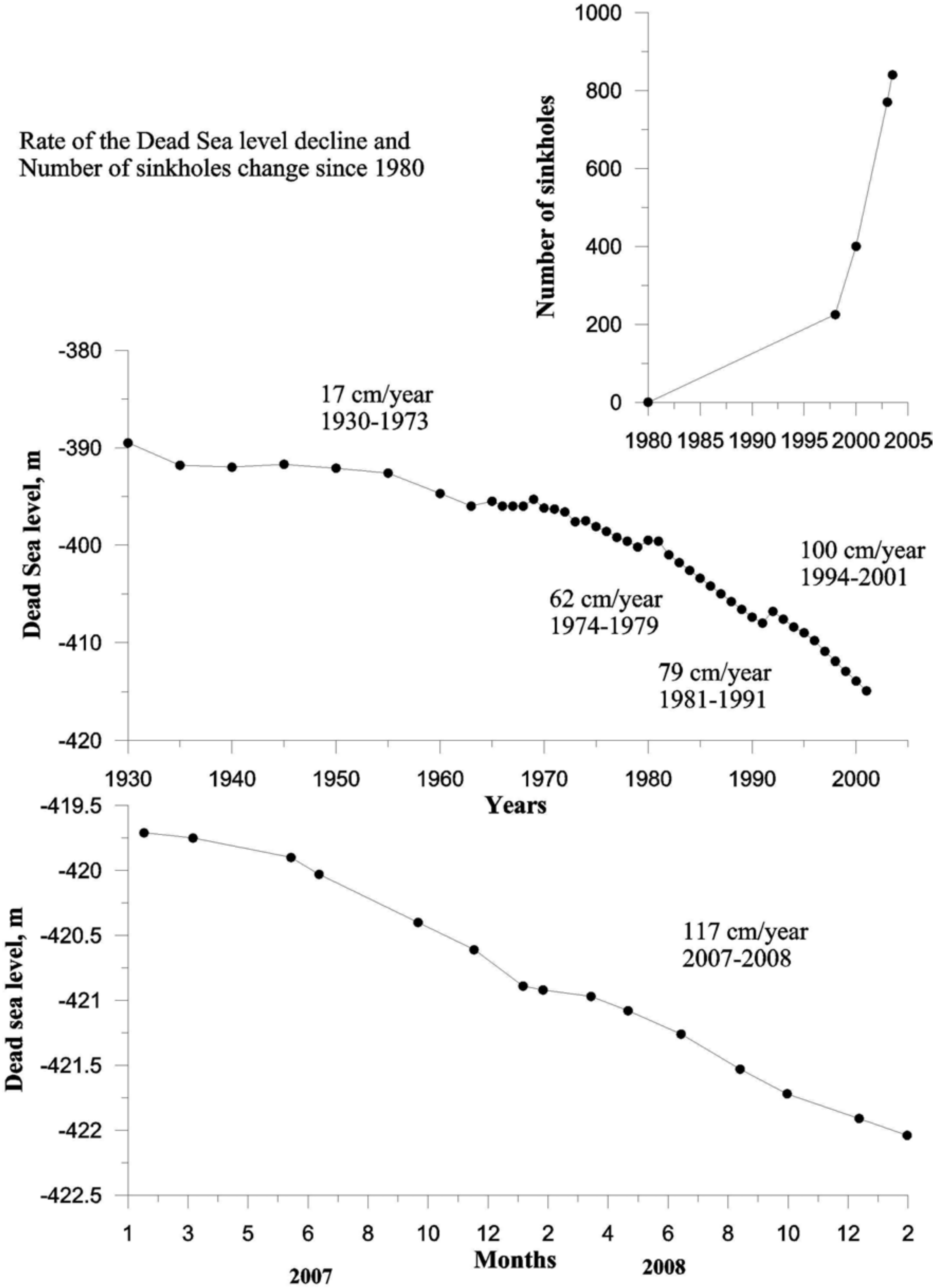

Fig.2 (Top) Number of sinkholes appearing since 1980 and rate of Dead Sea level decline since 1930 (Abelson, 2003)
(Bottom) Dead Sea level decline in recent years (Original measurements by the SOI team)

Three main types of sinkholes have been observed: gravel holes occurring in alluvial fans, mud holes occurring in clay deposits, and a combination of the two. The diameter/depth ratio of sinkholes tends to be small at the alluvial fans and much higher in the wet mud flats.
One popular assumption for the cause of sinkhole generation is the formation of cavities by ground water dissolution within layers of soluble rock (Neal and Johnson, 2002). Therefore, the investigation techniques are directed at searching for layers of soluble rock and ground water for potential dissolution. Among these are seismic refraction, boreholes and sampling of groundwater from the boreholes in order to predict locations of sinkhole development. Other techniques such as gravimetric or micromagnetic methods are directed at searching hollow cavities. The Geological Survey of Israel and Geophysical Institute of Israel employed a variety of tools such as seismic reflection and refraction, electrical methods, drilling, groundwater sampling and others (Shtivelman et al., 1999; Yechieli et al., 2002).
Also, the Survey of Israel made a contribution to sinkhole investigation in aerial photograph interpretation (Itamar and Raizman, 2000), micromagnetic techniques development (Rybakov et al., 2005; Rybakov et al., 2006) and following the Dead Sea level decrease in recent years.
We shall touch briefly on the sinkhole phenomenon and center our attention on micromagnetic techniques in which the authors were involved.

2. GEOPHYSICAL METHODS TO INVESTIGATE AND PREDICT SINKHOLES

2.1 Aerial photograph investigation

Mapping was carried out using ortho-rectified aerial photographs from the archive of the Survey of Israel from: 1990, 1992, 1993, 1995 and 1997. It was shown (Itamar and Raizman, 2000), that sinkholes are not distributed randomly but concentrated in clusters along the Dead Sea shore. About twenty such clusters were identified. Cluster orientation and their temporal evolution do not necessarily coincide with the direction of the main fault but probably depend on the local geological condition at each site (Raz, 2000).

2.2 Seismic refraction and boreholes

Seismic refraction and boreholes were conducted in the vicinity of sinkhole sites. The next results were obtained (Abelson et.al., 2004). A salt layer with a thickness of several meters exists within the upper part of the sediment. The seismic refraction displays three layers; the upper two layers consist of alluvial and fluvial sediments. The lower layer is the salt layer. The depth of the top layer ranges between 20 to 50 m and the thickness of salt may exceed 20 m.
Geochemical analysis of groundwater from various boreholes proves that groundwater is far below saturation and therefore has the potential to dissolve salt.

2.3 Micromagnetic technique

The technique is based on revealing 'inverse' anomalies using magnetic mapping at a bounded region of space (Rybakov et al., 2005). The guide for sinkhole detection before their collapse gave susceptibility measurements in outcrops measured in the range from 10 to 70 micro sgs.

Modeling shows that such susceptibility of sediments allows us to detect hollowness at a depth of about 10-15 m. by means of magnetic survey. In order to design a magnetic survey, we simulated observed anomalies over a buried and opened voids inside low magnetization media. A normally magnetized body produces a standard dipole anomaly, a positive/negative pair with the low to the north and the location of the source at the inflection point of the anomaly. In the case of a nonmagnetic cavern, we look for the opposite effect. The method was checked near the open sinkholes. The 'inverse' magnetic anomalies caused by the hollowness of 10 m diameter in the media with magnetization of 50 micro sgs at the Hever site comprise a few nanoTesla (Fig.3). Observed results confirmed model calculations. These anomalies can easily be isolated by means of modern magnetometers.

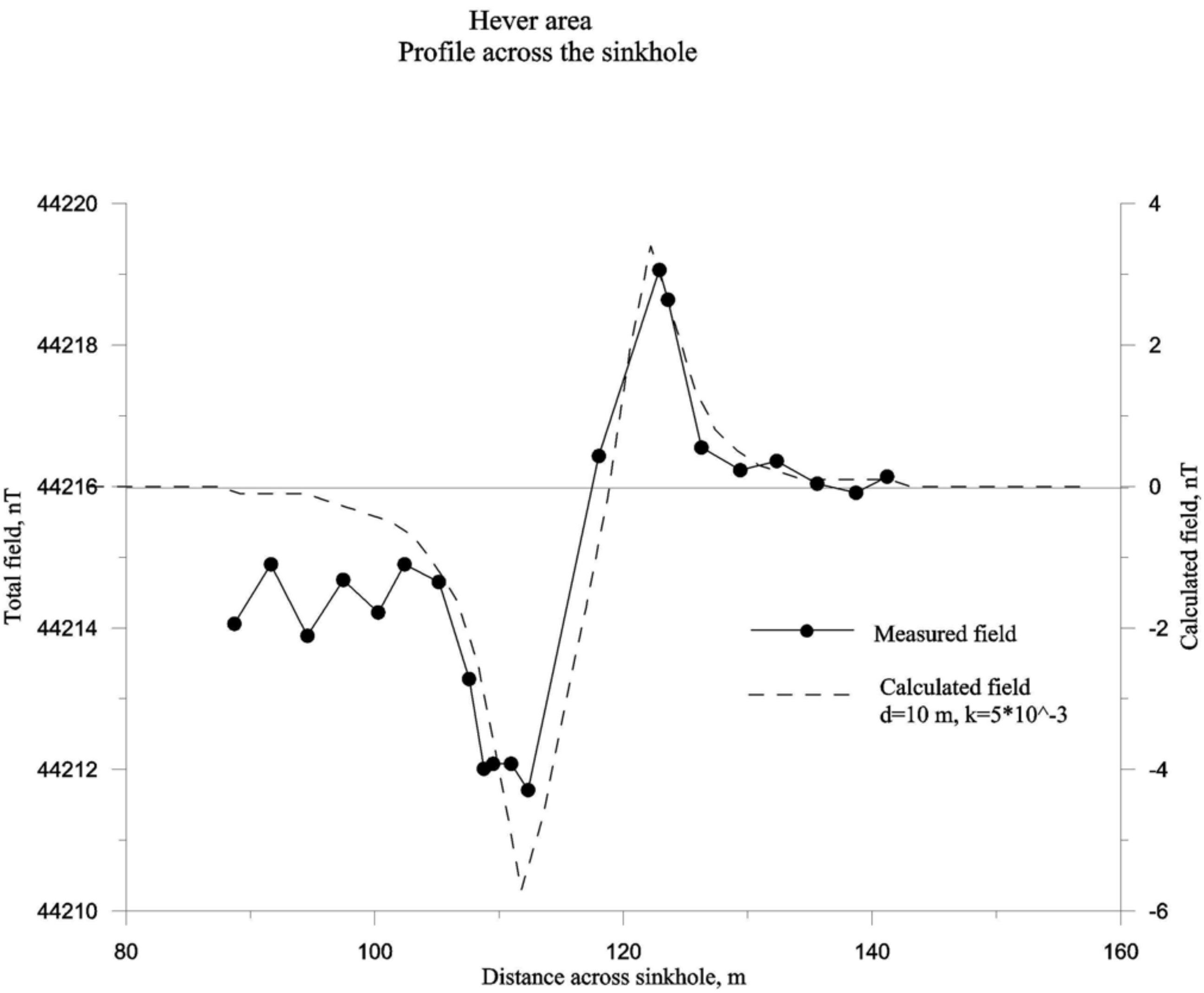

Fig. 3 Measured and calculated magnetic field changes produced by sinkhole at the Hever site.

Micromagnetic surveys were conducted at five sites with different geological settings (i.e. alluvial fans, mud flats). The results show that this method can detect shallow voids. These voids are reliable precursors of sinkhole development and ground collapse. Predicted and documented in Rybakov et al., 2005 sinkhole collapse in the Assael mud flat were confirmed there later (Rybakov et al., 2006). We hope that such a quick and in expensive method will benefit development of commercial operations along the Dead Sea shore.

3. RESULTS

The formation of sinkholes is attributed to the dissolution of the subsurface salt layer by fresh groundwater due to the drop in Dead Sea level and associated groundwater level. This drop reflects the interception of the freshwater flow to the Dead Sea upstream by agricultural, industrial etc. needs of surrounding countries.

The Dead Sea decline has accelerated significantly since the mid 1970s. Appearance of sinkholes started in the yearly 1980s when the Dead Sea level was about -400 in relation to the Israeli land leveling system.

There is no question that human activity seriously affected the Dead Sea ecosystem. On the other hand, there is evidence (Frumkin, 2002; Bookman-KenTor et al., 2004) that current Dead Sea level and even lower was encountered in the past several thousands years.

In modern times, some effective techniques were developed to better understand sinkhole generation and even to predict their appearance. One such technique is the micromagnetic method cave detection near the Dead Sea.

ACKNOWLEDGMENTS

We thank Bari Shiryon for editing.

REFERENCES

Abelson, M., Baer, G., Shtivelman, V., Wachs, D., Raz, E., Crouvi, O., Kurzon, I., and Yechieli, Y. 2003. Collapse sinkholes and radar interferometry reveal neotectonics concealed within the Dead Sea basin. Geophysical Research Letters, 30, 1545, doi:10.1029/2003GL017103.

Arkin, Y., 1993. "Karstic" sinkholes in alluvial fans. Israel Geological Society,
Annual meeting, Field trip guidebook, 71-80.

Arkin, Y., and Gilat, A., 2000. Dead Sea sinkholes – an ever-developing hazard:
Enviro. Geology, 39, 711-722.

Bookman (Ken-Tor), R., Enzel, Y., Stein, M., 2004. Late Holocene lake level pf the Dead Sea: Geological Society of America Bulltin, 116, 555-571.

Frumkin, A. and Elitzur, Y., 2002. Historic Dead Sea level fluctuations calibrated with geological and archaelogical evidence. Quaternary Research 57, 334-342.

Itamar, A. and Reizmann Yu., 2000. Air photo survey of sinkholes in the Dead Sea area. Israel Geological Survey, Current Research, 12, 21-24.

Raz, E., 2000. Formation of sinkholes in the Dead Sea – a surface survey. Geological Survey Report GSI/31/2000 (in Hebrew).

Rybakov, M., Rotshtein, Ya., Shirman, B., Al-Zoubi, A., 2005. Cave detection near the Dead Sea – a micromagnetic feasibility study. The Leading Edge, 585-590.

Rybakov, M., Meligan, P., Shirman, B., 2006. Predictive environmental geophysics in Israel-an update. The Leading Edge, 426.

Wachs, D., Yechieli, Y., Shtivelman, V., Itamar, A., Bear, G., Goldman, M., Raz, E., Rybakov, M., and Schattner, U., 2000. Formation of sinkholes along the shore of Dead Sea – summary of finding from the first stage of research: Geological Survey of Israel, Report GSI/41/2000 (in Hebrew), 49 p.

BIOGRAPHICAL NOTES

Dr. Boris Shirman is a geophysicist with Survey of Israel (SOI). He earned his M.Sc. in astronomy from the Physics Faculty of the Ural University (Ekaterinburg Russia) in 1973. He obtained his Ph.D in physics & mathematics from Institute of Geophysics (Ekaterinburg, Russia) in 1982. Since the period 1993 he headed a geophysics group in the Research Division of Survey of Israel, Tel – Aviv. His effort mainly concentrated on geomagnetic observatories in Israel and seas tide gages maintenance, on applications development for data processing in geomagnetism, sea leveling and geodesy.

He is engaged in the International Project (Israel-Canada) "Ultrasensitive magnetic gradiometer system for geophysical monitoring of seismic related phenomena".

CONTACTS

Dr. Boris Shirman
Survey of Israel
1, Lincoln st.
Tel-Aviv
ISRAEL
Tel. +972-3-6231816
Fax + 972-3-6231806
Email: bshirman@gmail.com
Web site: www.mapi.gov.il