PN-ACR-342

FINAL SCIENTIFIC REPORT
July 20, 2001

Submitted to:
The Middle Eastern Regional Cooperation Program (MERC)
U.S. Agency for International Development

GEOPHYSICAL FRAMEWORK STUDIES OF THE DEAD SEA RIFT AND JORDAN AND ISRAEL

Grant No. TA-MOU-96-C15-165

US-AID project officer
William H. Crane
U.S. Embassy, Tel Aviv

Project duration: October 1996 - September 2000

Prepared on behalf of the participants by:
Dr. Uri S. ten Brink, Scientific coordinator of the project
U.S. Geological Survey, Woods Hole, MA 02543, USA
Tel: 1-508-457-2396; Fax: 1-508-457-2310; E-mail: utenbrink@usgs.gov

A

Executive summary

The project *Geophysical framework studies of the Dead Sea rift and Jordan and Israel* had several objectives: (1) To create a unified gravity data base and maps of the Dead Sea Rift and its surrounding territory of Jordan and Israel. (2) To delineate subsurface sedimentary basins and faults along the Dead Sea Rift to be used in exploration of groundwater, oil, earthquake hazard assessment, and infrastructure projects, such as the Dead Sea-Red Sea Canal. (4) To transfer technology among the project participants. (5) To promote peace in the Middle East through scientific and economic cooperation.

The work plan for this project was aimed at fulfilling these objectives. During the project we achieved the following:

1. Jordanian, Israeli, and American scientists met each other 8 times. The scientists toured each other facilities, exchanged technical skills, and worked together on data compilation and analysis.

2. The working relationships, which developed among the participants also led to increased cooperation in other areas and with other parties:

(a) An impromptu joint study was initiated to calibrate ground penetrating radar equipment between the GII and the NRA.

(b) GII provided training in reflection and refraction seismic methods to NRA technicians and scientists.

(c) Existing magnetic data were exchanged between the NRA and GII.

(d) The scientists were granted access to each other's archive of seismic reflection profiles, which helped considerably in the interpretation of the gravity data.

(e) A meeting of the general director of GII and his personnel with Palestinian scientists from An-Najah University was facilitated by the NRA.

(f) A meeting between the general director of GII and his personnel and the president of An-Najah University, Prof. Rami Hamdallah, took place at the president's office in Nablus during February 1999.

(g) Drs. Radwan Kelani, An-Najah University, and Dr. Michael Rybakov, GII, jointly measured the gravity field in the Palestinian Autonomy area of Jericho in February 1999 using funding from the American participant in the project. They co-authored a report on their findings.

(h) A new proposal to the US-AID MERC program was submitted. This proposal builds on the knowledge gained during this project and includes Palestinian scientists.

3. Jordanian and Israeli scientists carried out joint fieldwork to measure common gravity points across their International border. These points were used to accurately merge the gravity data sets of Jordan and Israel.
4. Jordanian, Israeli, and U.S. scientists made joint field trips to verify some measurements and look for surface geological and topographical features that could be effected in the gravity data.
5. Over 2500 additional gravity stations were measured in Jordan and over 1400 in Israel during the duration of the projects. The measurements were made in places where data did not exist to better delineate the location of faults and the aerial extent of basins.
6. A combined data set for Jordan and Israel was established and is residing in the national archives of both Jordan and Israel. This data set continues to be updated beyond the life of the grant by direct data exchange between NRA and GII as new measurements are being gathered by Jordan and Israel.
7. Seven publications resulted from this study including large-scale maps, reports, an abstract and a formal publication in a leading international scientific magazine reported the results of the project. All publications acknowledge the support of US-AID grant TA-MOU-96-C15-165.
8. Talks were presented at an international conference and at seminars in American and German universities.

The results of this project led to the discovery of several new subsurface basins, where aquifers are ususally found, such as the Timna-Qa-Taba and Gharandal in the southern Araba (Arava) Valley and the Damia Basin in the Jordan Valley, and to the exact determination of the shape of most of the other basins. The locations and arrangements of faults were mostly unknown previously. One particular surprising result is the fact that the Dead Sea plate boundary is composed of relatively short (several 10s of km) and discontinuous segments. This result implies that only moderate size earthquakes (less than magnitude 7.5) are expected because the magnitude of earthquakes is almost linearly related to the length of each fault segments.

List of Attachments

Attachement 1. Copy of an article in the leading international scientific journal *Geology* summarizing the scientific results. Published in 1999.

Attachement 2. U.S. Geological Survey *Open-File Report 00-0341*, reporting the results of an impromptu joint Palestinian-Israeli gravity survey in Jericho. Published in 2000.

Attachement 3. Updated gravity map of the Dead Sea rift and its vicinity. Scale 1:200,000. Published in 2001.

Attachement 4. Gravity map of the Dead Sea rift and its vicinity with interpretation. Scale 1:250,000. Published in 1998.

Preface and research objectives

The populated areas of Israel and Jordan comprise a single geological unit of the Dead Sea rift and its uplifted surrounding highlands. The different tectonic, geomorphic, and climatic factors, which shaped the land in this region, have operated without regard to political boundaries. The two countries acknowledged the need to cooperate and as a result, this project was one of the five cooperative projects in Earth Sciences, which were approved as part of the peace agreement between Israel and Jordan. The socio-economic benefits to this project are:

1. To cover the Dead Sea rift by gravity survey and to complete the Bouguer gravity map.
2. To map the subsurface faults to assist in earthquake hazard assessment and development programs along the rift valley, such as the Dead Sea-Red Sea Canal.
3. To map basins or sub-basins that could be assist to the estimation of potential oil and water reservoirs.
5. To use the results as a basis for future cooperation in geophysical and geological work.

The work was completed according to the work plan in the proposal.

Regional Tectonic Framework

The Dead Sea fault system is a north-south striking left-lateral shear zone extending from the incipient oceanic ridge (Red Sea) in the south to the Taurus upthrust collision in the north (insets of Figure 1 and 2). About 105 km of left-lateral displacement between the African and Arabian tectonic plate took place along this fault system during the last 15 million years. The average rate of motion during the last 5 million years is probably 6 millimeter per year. In the section between Jordan and Israel, the Dead Sea fault system is located within the Dead Sea rift valley. Subsurface sedimentary basins developed within the rift valley between parallel and overlapping faults segments and sometimes along single faults. Some faults splay from the main faults toward the Mediterranean Sea in northern Israel (Karmel-Fari'a) and Lebanon (Roum) and may accommodate some of the relative plate motion.

Accomplishments

Herein we are pleased to report that all the project goals were accomplished. The accomplishments are as follows:

<u>Collection of common gravity stations</u>

Jordanian and Israeli national gravity base stations were twice occupied using two gravity meters of Lacoste & Romberg (model G880 and D20) and one Autograv Scintrex. Bet

She'an and Sheik Hussein Bridge stations were tied on March 25, 1996. Aqaba Airport and Elat stations were measured on March 26, 1996. The difference between the Jordanian and Israeli reference gravity values is 14.93 ± 0.03 mGal.

Collection of gravity data

More than 40000 points were collected over the years by the NRA and GII along the Dead Sea Rift and its surrounding areas. This number includes 800 gravity stations, which were collected by NRA in the first year, 1400 gravity stations which were collected in the second year, and 300 gravity stations in the third year. GII collected over 300 gravity stations in the first year, 800 gravity stations in the second year, and 300 gravity stations in the third year. The new measurements were collected in areas of sparse measurements in order to better delineate the subsurface structure and faults. Lately, the NRA started collecting gravity data on the rugged rift shoulders using a surveying GPS instrument, which was purchased with project funds in March 1998.

Reduction and editing of gravity data

All the new gravity data stations were checked and reduced according to conventional procedures. These include calculation of instrument drift and tidal attraction, the conversion of field measurements to gravity values, the subtraction of the International Gravity Formula, free-air and Bouguer corrections, and Terrain correction. The Israel gravity database was recalculated using a similar formula to the one used for the Jordanian database and its reference value was shifted to the Jordanian data base. Finally, both databases were merged.

Compilation of all available gravity data into a unified digital database

The gravity data along the Dead Sea Rift is now in a unified database. The database continues to be upgraded by periodic data exchange as more gravity stations are collected. Bouguer gravity anomaly maps with shaded relief have been produced in scales of 1:250,000 and 1:200,000 (see attached map). The Bouguer gravity anomaly maps of Jordan and Israel have also been produced in different scales.

Digitization of topography data base

Digital terrain elevation database for Israel and the western slopes of the Jordanian highlands exists at a 25 meters grid interval (Hall, 1993). For the rest of Jordan we obtained a newly released Defense Mapping Agency grid at ~900 meters grid interval. The two data sets were compared where they overlap.

Generation of gravity maps for various parts of the Dead Sea rift

Bouguer gravity maps with a scale of 1:250,000, 1:200,000 and 1 :100,000 (not included) were generated for the Dead Sea rift. The gravity map was overlain on a shaded relief topography map of the area to aid in the interpretation.

Geological interpretation

The results of the joint geological interpretation of the gravity data by NRA, GII, and USGS scientists are detailed in Attachment 1, 3 and 4. The data set collected and assembled during this project allows for the first time a regional geophysical interpretation of the Dead Sea Rift. The qualitative analysis of the Bouguer gravity map, overlain on a shaded relief topography provides a wealth of structural information of the Dead Sea. The maps show that the Dead Sea fault system is broken into many fault segments. Some segments parallel each other, others are arranged en-echelon and others are simply aligned. Some of these faults are still active, and some are buried and are presumably inactive.

The maps also show the aerial extent of subsurface basins. The rift along the Jordan - Israel border is typically divided into the following basins: Gulf of Aqaba, Wadi Araba (Arava Valley), Dead Sea, Jordan Valley, Sea of Galilee and Hula. The gravity map indicates that we are dealing with more than the above mentioned basins. These basins are the following: Aqaba-Elat, Timna-Qa-At-Taba, Gharandal, Dead Sea, Jericho, Damia, Bet-Shean, Baqura-Kinarot, Sea Of Galilee (southern and northern basins)and Hula basins. Several of these basins do not occupy the entire width of the rift valley. Some of these basins, especially in the Arava/Araba Valley, probably contain groundwater aquifers.

Our interpretation of fault locations based on the gravity and on seismic reflection data indicates that the motion along the 420-km long Dead Sea tectonic plate boundary is accommodated by at least 15 separate fault segments with segment lengths varying between 25 and 55 km. More fault segments are shown buried on seismic reflection profiles and do not offset or perturb the upper sedimentary section, indicating that they are no longer active. Strike-slip faults tend to smooth themselves as they mature, in other words, the geometrical complexity of strike-slip faults should decrease with increasing cumulative strike-slip offset (Wesnousky, 1988). By comparison with other plate boundaries worldwide, the cumulative offset of 105 km along the Dead Sea plate boundary is expected to be accommodated by a single smoothed 420-km-long fault segment (Stirling et al., 1996; Wesnousky, 1988). The observations of a large number of basins and of numerous and overlapping fault segments along the Dead Sea plate boundary suggest a continuous adjustment to changes in the

relative plate motion. A continuous adjustment of the plate boundary is to be expected considering that the pole of rotation between Arabia and Africa is close to the Dead Sea plate boundary and may have been getting closer with time (Chu and Gordon, 1998).

Analysis of historical earthquake records suggests a maximum Local magnitude, M_L=7.3, for earthquakes along the Dead Sea plate boundary, which using the local relationship, LogL=0.5 M_L-1.6, corresponds to a maximum rupture length of 115 km (Ben-Menahem, 1991). The corresponding moment magnitude, Mw=7.3, is larger than expected from the rupture of a single fault (Stirling et al., 1996). Hence, few fault segments were likely moving simultaneously during a single earthquake, possibly in a manner similar to that observed during the Landers earthquake in California (Hauksson et al., 1993). A section of 115 km corresponds to the distance from the southern end of the Dead Sea Basin (Lat. 30°28') to the northern end of the Lisan peninsula (Lat. 31°28'), where there is a possible jog from the eastern to the western side of the Dead Sea. Another possible section stretches from the northern end of the Dead Sea to the northern end of the Sea of Galilee.

Publications resulting from this grant

ten Brink, U.S., M. Rybakov, A. Batayneh, M. Hassouneh, U. Freislander, A. Al-Zoubi, and V. Goldshmidt, 1997, Basins and fault segments along the Dead Sea Transform, *EOS*-American Geophysical Union, v. 78 (46-Suppl.), p. F654.

ten Brink, U., Rybakov, M., Al-Zoubi, A., Hassouneh, M., Batayneh, A., Frieslander, U., Goldschmidt, V., Daoud, M., and Rotstein, Y., Bouguer gravity anomaly map of the Dead Sea transform plate boundary in Israel and Jordan, scale 1:250,000, *USGS open-file report*, 98-516, 1998.

ten Brink, U., Rybakov, M., Al-Zoubi, A., Hassouneh, M., Batayneh, A., Frieslander, U., Goldschmidt, V., Daoud, M., Rotstein, Y., and Hall, J.K., The anatomy of the Dead Sea plate boundary: Does it reflect continuous changes in plate motion? *Geology*, v. 27, 887-980, 1999.

Rybakov, M., Goldshmidt, V., Segev, A., and El-Kelani, R., Interpertation of gravity and magnetic data from Israel and adjacent areas- Data acquisition in the Jericho area, A gravity survey, *GII report 840/63/99*, 2000.

Rybakov, M., El-Kelani, R., and ten Brink, U., Joint Israeli-Palestinian gravity survey in the Dead Sea Rift valley, *USGS open-file report*, 00-362, 2000.

Segev, A., Goldshmidt, V., and Rybakov, M., Late Precambrian-Cambrian tectonic setting of the crystalline basement in the northern Arabian-Nubian shield as derived from gravity and magnetic data Basin and Range characteristic, *Isr. J. Earth Sci.*, v. 48, 78-85, 2000.

ten Brink, U., Al-Zoubi, A., and Rybakov, M., Bouguer gravity anomaly map of the Dead Sea fault system, Israel and Jordan, scale 1:200,000, *USGS open-file report*, 01-0216, 2001.

Transfer of Technology

One of the stated purposes of this joint project is the share of technology and expertise. The following technology transfers have been achieved during the project time.

Dr. A. Batayneh and Mr. M. Hassouneh learned to use SURFER and GRAPHER, commercial GIS software on Windows95, which allows manipulation of data, gridding, and contouring and the overlay of different data sets such as topography and gravity.

Dr. Michael Rybakov familiarized himself with GMT, a Unix-based free software for geophysical data manipulation, gridding, and contouring.

Several PC computers Gateway 2000 installed with Windows95 and applicable GIS software were purchased by NRA.

A differential GPS system was purchased by NRA and is being used to determine the exact elevation of gravity stations.

A printer and a scanner were purchased by NRA.

Outreach

- Dr. Abdallah Al-Zoubi, NRA presented the results at invited seminars at Columbia University, Woods Hole Oceanographic Institution, Northwestern University, and the University of Missouri.
- Dr. Uri ten Brink presented the results at international conferences in San Francisco and at Sharm-Al-Sheikh.
- Dr. Michael Rybakov presented the results at a seminar in Potsdam, Germany.

Scientific Cooperation

Project scientists met several times during the times of the project in Jordan, Israel, and U.S.A. and twice in the field for joint measurements of gravity stations.

U. ten Brink (USGS) visited GII during February 22-March 1, 1997. Y. Rotstein, M. Rybakov (GII), and U. ten Brink (USGS) visited NRA during February 25-26. They met with K. Sheyyab, the General Director of NRA and his deputy, K. El-Kaysi and were shown the NRA facilities. The work plan for the first year and the location of new measurements were discussed with M. Jaradat, Director of Geophysics and Technical Services Directorate, who was responsible for gravity measurements in Jordan and with M. Daoud, the former Head of the Geophysics Division. A. Al-Zoubi and A. Batayneh showed the visitors the computer facilities and software used at NRA and Al-Zoubi introduced the visitors to the Petroleum Club of Jordan and to M. Abu-Ajamieh, a noted Jordanian geophysicist.

U. ten Brink (USGS) visited GII during April 2 - April 27, 1997. M. Hassouneh (NRA) visited GII during April 11-17, 1997. Together they examined carefully the data quality of the two countries and edited out erroneous measurements. They also proceeded to plot preliminary joint maps from parts of the data set. M. Hassouneh was trained in the use of Surfer and Radian software. Together with Y. Rotstein they set goals for the continuation of Year 1 work.

A. Batayneh (NRA) and M. Rybakov (GII) visited U.S. Geological Survey office in Woods Hole, MA during August 10 - September 7, 1997, and Y. Rotstein (GII) visited Woods Hole during (August 15-19, 1997). Together they completed the compilation of the data and the preparation of the annual report for Year 1. A. Batayneh was trained in the use of Surfer software and Rybakov was introduced to GMT software.

In the second project year U. ten-Brink (USGS), M. Dauod and M. Hassouneh (NRA) visited GII during march 15-22, 1998. Together they exchanged the gravity data, discussed future work, and examined seismic data in the archives of GII.

U. ten-Brink (USGS) and M. Rybakov visited NRA during march 23-31, 1998. Together they trained the staff of the Geophysics Division in the use of software and GPS, and examined seismic data in the archives of NRA.

U. ten-Brink, M. Rybakov and M. Hassouneh made a field trip to the Jordan Valley and Wadi Araba. They checked several gravity stations and made susceptibility measurement in selected places.

U. ten-Brink, M. Rybakov and A. Al-Zoubi made a field trip to Jarash area to see the Zarqa River fault.

A. Al-Zoubi, M. Hassouneh, and M., Rybakov visited USGS office in Woods Hole, during July, 19 to the August 2, 1998. Together they completed the compilation of the gravity data set for the Dead Sea rift, prepared maps at 1:250,000 scale, and wrote this report. ten-Brink and Al-Zoubi completed the qualitative interpretation of fault and basin locations along the rift.

Dr. Al-Zoubi, NRA, spent the period between September 2000 and June 2001 at the Woods Hole Oceanographic Institution as a Fulbright post-doctoral scholar, working on derivatives from this grant. During the tenure of his scholarship he wrote and submitted two papers to scientific journals, one of which has been accepted for publication and the other is in review.

Acknowledgments

Matching funds and encouragement by the USGS (U.S.A.), NRA (Jordan) and GII (Israel) are gratefully acknowledged. We thank USGS administration, Directors General of NRA, Engineers Suleiman Abu- Aliem and Kays El-Kaysi, and the Director General of GII, Dr. Yair Rotstein. We thank the technicians and field crew of the NRA and GII for their field support.

References cited

Hall, J.K., 1993, The GSI terrain model (DTM) project completed, Israel Geological Survey Current Research, vol. 8, pp. 47-60.

Hollett, K.J., McGaffrey, W.F. and Walti, C.L., 1991, Geology and water resources of Owens Valley, California: U.S. Geological Survey Water-Supply paper 2370-B, 77 p.

Stirling, M.W., Wesnousky, S.G. and Shimazaki, K., 1996, Fault trace complexity, cumulative slip, and the shape of the magnitude-frequency distribution for strike-slip faults: A global survey: Geophysical Journal International, v. 124, p. 833-868.

Wesnousky, S., 1988, Seismological and structural evolution of strike-slip faults: Nature, v. 335, p. 340-343.