Short Base Magnetic Measurements for Earthquake Research

Magnetics has played a significant role in Earthquake studies over decades. Based on the theory of piezomagnetism and / or piezokinetics, it has occasionally produced startling results that could not, however, be either confirmed or repeated.

Some of the more recent work has employed both induction coils and ULF magnetic field component measurement, and results have been very similar. The detected anomalies varied from a few nT down to few tens of pT, close to instrument's background noise.

Figure 1: Location of Earthquake Studies in Progress / Planned in Dead Sea Rift area, Israel.

Need for Increased Sensitivity

Other tests were less positive and the main reason appears to be poor sensitivity of the instruments employed in the research. The magnetometers in use managed 1 – 4 nT overall noise (References 1 and 2), and induction coils improved this to some 0.025 nT or 25 pT.

While sensitivities are better with induction coils, their main problem is that they cannot measure the slow build-ups of magnetic moments that are related to the piezomagnetic effect and pressure build-up. Their bandwidth is 0.01 Hz to 10 Hz and 1/f noise (where f is the source frequency) severely limits detection of more slowly evolving events.

Piezomagnetic anomalies vary substantially with the earthquake intensity, composition of rocks that come under pressure, geometry of pressure etc. Assuming that they are of dipolar character (3), their fields vary with the cube of distance (i.e. their detectability will be limited to a proximity to epicenters on better hypocenters).

More systematic results can only be achieved if the measurements can be done with substantially increased sensitivity. This is not easy to achieve due to large time variations of magnetic field (diurnals) and "cultural" noise due to human activities.

Both magnetometers, and to a lesser extent, induction coils need to work in differential mode to reach the best sensitivity - free of diurnals and cultural noise. Reference instruments that measure only temporal variations of the magnetic field are usually placed away from active zones, (long base), resulting often in imperfect elimination of diurnals and cultural noise.

Short Base Measurements

True gradiometric (i.e. Short Base) measurements place stiffer requirements on the instrument sensitivity (or placement of sensors close to hypocenter of the earthquake) in comparison to electromagnetic measurements.

This effect is due to the fast decay of dipolar magnetic gradients with distance:

$$\frac{dH}{dr} = \frac{-3H}{r}$$

where dh / dr is a measured gradient, H is the magnetic field produced by earthquake at the measurement site and r is the distance to the hypocenter.

The advantage of Short Base Measurements is a possibility of deep suppression (if not complete elimination) of the influence of diurnals and "cultural" noise. For this to occur, it is important to ensure that the two gradient sensors record strictly synchronous readings.

Potassium SuperGradiometer

The extreme sensitivity required for the Short Base method of Earthquake Research is delivered by the Potassium SuperGradiometer from GEM Systems. SuperGrad was developed in cooperation with the United States Geological Survey and Professor E.A. Alexandrov and his research group.

The background noise of the magnetic gradient of GEM's SuperGrad is 0.05pT or 50fT for 1 reading per second. Spacing of sensors 50m to 100m from each other produces a gradient sensitivity of 0.5fT/m to 1fT/m.

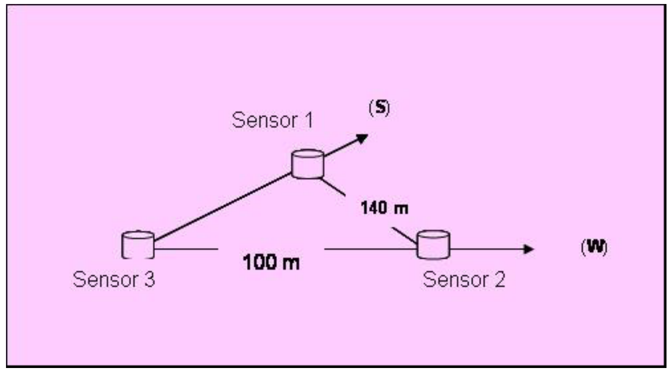


Figure 2: Sample SuperGrad Array showing two horizontal sensors (W, S) referenced to sensor (3) for horizontal gradient measurement.

For a 10km distance between sensors and the earthquake hypocenter, this is equivalent to detecting some 1.6pT to 3.3pT of its magnetic field at 1 reading per second (or magnetic moment of 16 – 33.10^{6} Am^{2}). At 100km distance to hypocenter the detectability becomes 16 – 33pT.

This is still comparable to induction coil sensitivity, although induction coils, measuring relatively high frequencies suffer from severe skin depth effect at comparable distances. SuperGrad sensitivity is about an order or magnitude better than reported sensitivities of induction coils.

In contrast to induction coils, the SuperGradiometer has no 1/f noise i.e. for slower frequency band the gradient sensitivity increases further in sub fT/m area - opening possibilities of measurement not available before. Potentially, magnetic moments weaker than 10^6 Am^2 could be detectable at 10km distance to a hypocenter of the earthquake.

The final limiting factor is possibly the long-term drift of the magnetometer / gradiometer – a factor which is currently being evaluated. Elimination of "cultural" noise is also promising. At the distance of 1km and the sensitivity of 1fT/m, a large anomaly of $1000Am^2$ related to cultural effects becomes undetectable.

Experimental Results

A three-sensor SuperGradiometer has been developed for a joint project of Earthquake studies with the Israeli Institutes SOREQ, Survey of Israel and Geological Survey of Israel. The Canadian-Israeli Industrial Research and Development Foundation (CIIRDF) supports the development.

Figure 3: SuperGrad console with three sensors in background. The large-volume sensors are heated to 45^0 C by electronics contained within the console.

The SuperGradiometer was installed in mid 2002 in Amram tunnel near Eilat in Israel. This site is in the vicinity of numerous weak earthquakes and the goal is to learn more about the earthquakes and possibly detect precursors. Radon monitoring supplements magnetic measurement (References 11 - 17).

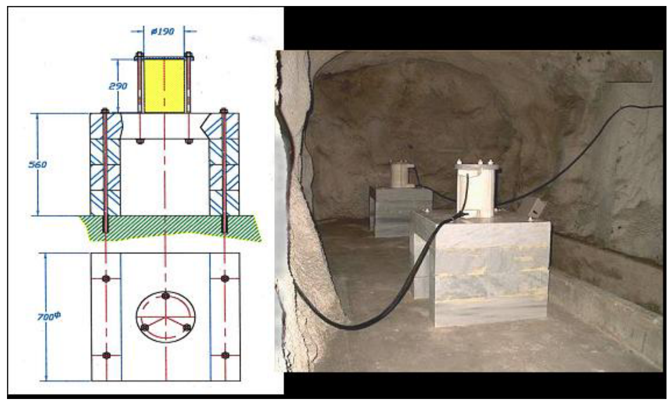


Figure 4: 2 SuperGrad sensors installed in Amram tunnel with a sketch of a marble sensor mounting platform.

The SuperGrad measures magnetic fields at 3 sensors 20 times per second with 50msec (10Hz Nyquist bandwidth) and 1 sec integration times. Six channels of data measured to 1fT resolution (11 digits) are transferred to Survey of Israel automatically on an hourly basis for analysis. A GPS receiver provides precise Universal Time. Noise background of the data is about 0.1pT for 1second integration giving about 2fT/m sensitivity at 50m-sensor spacing.

The gradiometer has now been in operation for more than a year and more than 4.35 billion individual readings – likely the largest volume magnetic dataset of this type ever collected – have been acquired. Based on these results, the system shows excellent long-term reliability.

Unfortunately, due to slight magnetization of surrounding rocks the directions of magnetic field are slightly different at the three sensors. As a consequence a minute part of diurnal variations invades the gradient readings. This imperfection can be corrected at the expense of increase in noise to some 0.25pT rms (~ 1pTpp) as shown in Figure 5.

A second 3 sensor SuperGradiometer has been built and will be deployed on magnetically quiet new site near the same rift within a year.

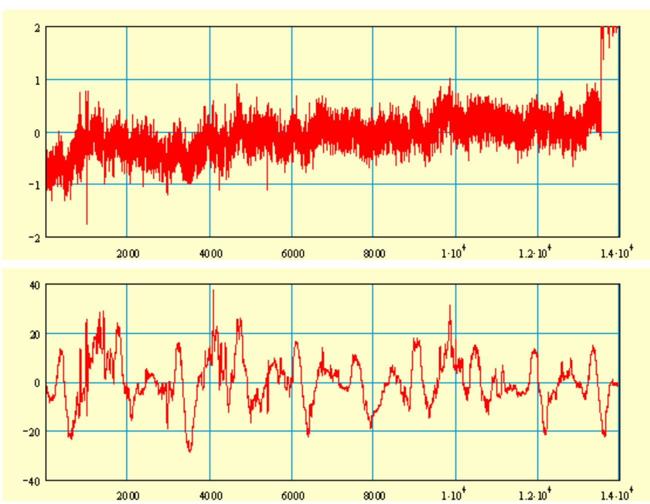


Figure 5. Some of the records from Amram tunnel. Lower trace is the original gradient record with about 40 pT of diurnals present. Upper trace is a corrected gradient with increased noise to about 1 pT.

Future Initiatives

While results continue to arrive from the Israeli site at Amram tunnel, another has been deployed at the Geological Survey of Canada's observatory in Ottawa. It will also be deployed at the Kakioka Observatory in Japan in mid-2004 in preparation for an IAGA workshop on magnetic observatory instrumentation.

References

1. Y. Sasai, Y. Ishikawa, Bulletin of the Earthquake Research Institute, Vol. 55 p 895-911.

2. Y. Honkura, S. Koyama, Bulletin of Earthquake Research Institute, 55 (1980) p 449–481.

3. Y. Sasai, Bulletin of the Earthquake Research Institute, Vol. 54 (1979) p 1-29.

4. Alexandrov, E. B. and Bonch-Bruevich, V. A., 1992. Optically Pumped Atomic Magnetometers after Three Decades. Optical Engineering. April, Vol. 31 No. 4.

5. Chyi, L. L. et al., 2001. Radon Monitoring for Earthquake Prediction in South Central Taiwan.

   gsa.confex.com/gsa/2001AM/finalprogram/abstract_25440.htm

6. Ginzburg, H., Zafrir, H. et al. 2002. New Ultrasensitive Magnetic Gradiometer for Long Term Monitoring, Isolation and Identification of Different Phenomena in the Geomagnetic Field.

   www.gemsys.ca/PDFDocs/Soreq%20Ultrasensitive%20Gradiometer.pdf

7. Ginzburg, H., Zafrir, H. et al. 2002. New System for Highly Sensitive Magnetic and

Radon Monitoring of the Active Fault in the Dead Sea Rift Region.

www.gemsys.ca/PDFDocs/Soreq%20Earthquake%20Monitoring.pdf

8. Hrvoic, I., Hollyer, G.M., et al., 2003. Development of a High Sensitivity Potassium Gradiometer for Near Surface Applications. SAGEEP Conference Proceedings, San Antonio, TX.

9. Morrison, H.R., and Romanowitz, B. A., 1997. Monitoring of Electromagnetic Fields and Electrical Conductivity at Observatories in California.

erp-web.er.usgs.gov/reports/annsum/vol37/nc/g2517.htm

10. Park, S.K., Johnston, M.J.S., Madden, T.R., Morgan F.D., Morrison, H. F.,1993, Electromagnetic precursors to earthquakes in the ULF band: A review of observations and mechanisms, Review Geophysics, vol. 31, 117-132.

11. Steinitz, G. et al., 2003. A Statistically Significant Relation between Rn Flux and Weak Earthquakes in the Dead Sea Rift Valley. The Geological Survey of Israel.

12. Steele, S.R.: 1984/85, "Anomalous radon emanation at local and regional distances preceding earthquakes in the New Madrid seismic zone and adjacent areas of the Central Mid-Continent of North America, 1981 – 84", Pure Appl. Geophys. 122, 353-368.

13. Steinitz, G. Vulkan, U., Lang, B., Gilat, A. and Zafrir, H.:1991, "Radon emanation along border faults of the Rift in the Dead Sea Area", Isr. Geol. Surv. Rep. GSI/35/91, and SNRC Rep ZD/161/91, 44p.

14. Steinitz, G., Vulkan, U., Lang. B., Gilat, A., Zafrir H.: 1992, "Rn enamation along border faults of the Rift in the Dead Sea area", Isr J. Earth Sci., 41, 9-20

15. Steinitz, G. Vulkan, U., Lang, B.: 1994, "The radon flux at the northwestern segment of the Dead Sea – progress report", Isr. Geol. Surv. Rep. TR-GSI/28/94, and SNRC Rep. ZD/177/94, 37p.

16. Vulkan., U., Assael, Y., Yaffe, Y., Lang, B. and Steinitz, G.: 1995, "Radon measurement techniques used in tectonically related projects", Isr. Geol. Surv. Rep. GSI/39/95, and SNRC Rep. ZD/179/95, 21p.

17. Vulkan., U., Lang, B. and Steinitz, G.: 1997 "Earthquake related Radon monitoring in the Dead Sea area", IV Int Conf. On Rare Gas Geochem., University of Rome TRE, Rome, 51.

18. USGS, 2003. Real-Time Fault / Volcano Monitoring and Research Results:

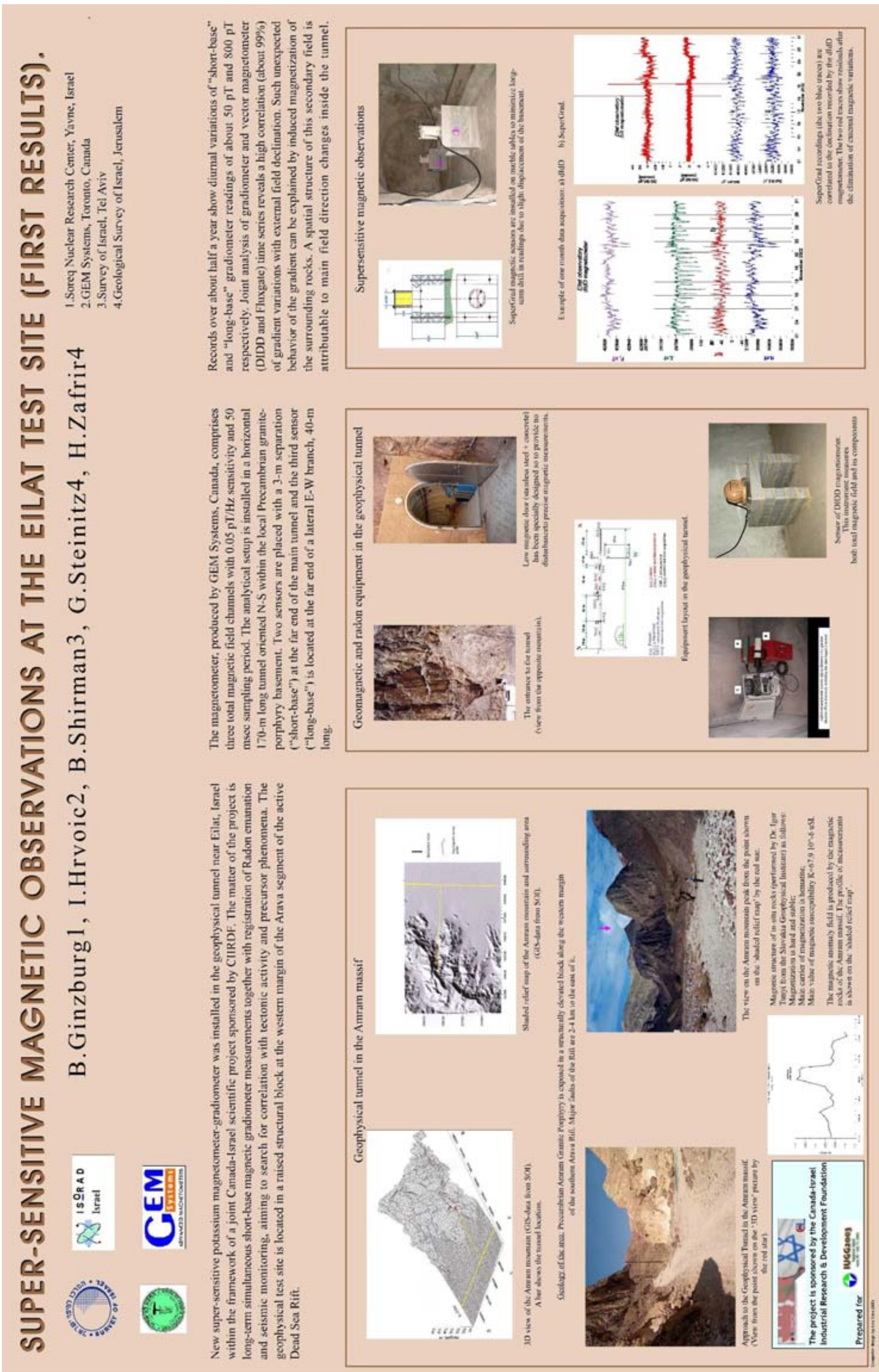
quake.wr.usgs.gov/research/deformation/monitoring/index.html

quake.wr.usgs.gov/research/deformation/monitoring/pk.html

quake.wr.usgs.gov/research/deformation/monitoring/lv.html

GEM SYSTEMS ADVANCED MAGNETOMETERS

Advanced Magnetometers



Our World is Magnetic.