SuperGradiometer
Earthquake Prediction Instrumentation

Our World is **Magnetic.**

The SuperGradiometer designed for specialized stationary applications that require the most demanding survey specifications.

Key benefits include:

- Integrated system that replaces combined fluxgate / total field installations

- Long term stability for accuracy and reliability of measurements

- Unsurpassed immunity to temperature changes and aging of materials

- High sensitivity, high speed vector measurements using Potassium technology
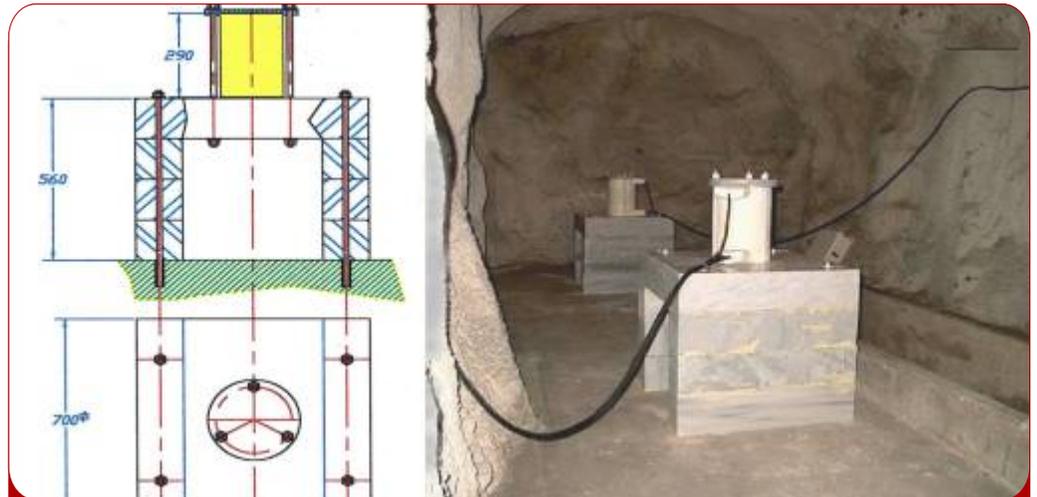
- Optimized signal to noise ratio through advanced Potassium design

- Rapid data output using custom Windows-based display software

- Efficient remote control operation / interrogation using RS-232 and USB

- Flexibility to enable real-time transmission via RS-232 and modem to satellite and phone links

- Internet-based upgrades (from the office or field)

SuperGradiometer installed near Eilat, Israel within the framework of a joint Canada-Israel research project. Sensors and mounting platforms are shown.

Magnetics has played a significant role in Earthquake studies for several decades. Based on the theory of piezomagnetism and / or piezokinetics, it offers a possibility of detection of precursors to earthquakes due to gradual pressure build-up. Three typical limiting factors include sensitivity, long-term stability and a need to eliminate environmental noise (diurnals, man made noise).

Early monitoring systems with sensitivities in the nT range and long base differential measurement produced in a few cases, startling precursors that could, however, be neither confirmed nor repeated. Some of the more recent work has employed induction coils with an improved sensitivity (25pT) but limited long term features (bandwidth down to 0.01Hz) and the results have been somewhat better. When detected, corresponding anomalies varied from few nT to few tens of pT (close to instrument's background noise).

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, their fields vary with the cube of distance (i.e. their detectability will be limited to a proximity to epicenters - or better, to hypocenters).

More systematic results can only be obtained if the measurements can be done with substantially increased sensitivity; long-term stability; and by taking into consideration the very local character of dipolar magnetic field, large time variations of magnetic field (diurnals), noise and man-made noise.

Both magnetometers, and to a lesser extent, induction coils, need to work in differential mode to reach the best sensitivity - free of diurnals and man-made 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 man-made noise.

Earthquake research studies show large amplitude magnetic responses weeks and hours before events. Smaller events appear to exhibit less coherent patterns; likely due to the lack of sensitivity of traditional magnetic instruments.

SuperGrad - GEM's Latest Technology

GEM's new SuperGradiometer is designed to improve detection of subtle responses and potentially lower the threshold of detectable earthquakes.

The GSMP-20GS3 was developed with the Russian research group of Dr. E. Alexandrov in response to the United State Geolo-gical Survey's (USGS) requirement for an ultra-high sensitivity magnetic gradiome-ter. It is the highest sensitivity total field measuring device ever developed with a 0.05 pT root-mean-square (rms) sensitivity at a sampling rate of 20 Hz (averaged over a 1 sec. interval). This ultra-high sensitivity is well over an order-of-magnitude more sensitive than any other system.

For earthquake research, the GSMP-20S3 can achieve gradient sensitivities of 1fT/m (10-15 T/m) with a sensor spacing of 50m - a major advantage over traditional long-baseline measurements (i.e. total field with reference station for removal of diurnals) which have sensitivities on the order of 1nT. The GSMP-20S3 also minimizes cultu-ral noise (i.e. from nearby infrastructure), and minimization of 1 / f noise that typical-ly degrades results from other types of me-asurements (ex. Electromagnetic). Note that f is the frequency of the piezomag-netic signal from the event.

Detectability of Earthquakes by Gradiometers

Assuming that earthquakes create a dipo-lar magnetic anomaly, we can calculate the detectability of earthquakes of given mag-nitude. The magnetic induction B of a mag-netic moment M is a clearly defined quan-tity that relates the radius, magnetic field and susceptibility (details are provided in a paper entitled, "Development of a Potas-sium SuperGradiometer for Earthquake Re-search and Other Applications").

These results can be applied to data from the Loma Prieta earthquake of 1989. As shown, this earthquake clearly illustrates precursor phenomena. Measurements

were made with a nearby induction coil that had been set up fortuitously.
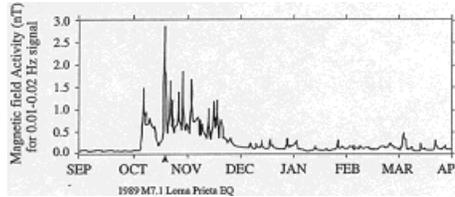
Magnetic data before & after the Loma Prieta earthquake in California, 1989.

From reports on the M7.1 earthquake (maximum magnetic anomaly B = 2.8nT at 7km distance to epicenter and 17km depth of hypocenter), one can calculate the magnetic moment. Using Bmax = 2.8nT and r = 18.38km, gives:

$$\text{Moment} = 1.74 \times 10^{11} \text{ Am2}$$

This type of analysis can be used to assess expected magnetic moments for various magnitudes and the distances to hypocen-ters at which they will produce anomalies equaling noise levels of magnetometers and induction coils.

Magnit ude	Mag. Moment Am ^{2}	Detectable Distance (km)			
		Magnet ometer 1n T	Magnet ometer 0.1n T	SuperGrad 0.1fT/m	SuperGrad 0.1fT/m
8	2.2 x 10^{12}	60	130	160	285
7	7 x 10^{10}	18	39	67.5	120
6	2.2 x 10^9	6	13	28.5	50.7
5	7 x 10^7	1.8	3.9	12	21.3
4	2.2 x 10^6	0.6	1.3	5.1	9
3	7 x 10^4			2.1	3.8

Comparison of different types of sensors, nominal moments and the maximum dis-tances (km) they can be detected.

This analysis re-inforces the ability of the SuperGradiometer (and Short Base Mea-surements) to detect extremely subtle phenomena.

GEM is currently recording data at a site in the middle East, Mexico and is seeking to expand its installed base in tectonicaly active regions for earthquake prediction. These measurements are complementary to other methods, such as seismics, GPS, radon, etc. that are now in use, and can provide essential data for data integration.

Specifications

Performance / Sensor

Resolution: 0.001 pT for up to 20 readings per sec.
Intrinsic Noise Density: 0.05 pT / Hz 1/2
Absolute Accuracy: 0.1 nT
Time Base Stability: 0.01 ppm over -40°C to +55°C
Long Term Stability: better than 1 pT / day
Dynamic Range: 20,000 to 100,000 nT
Operating Temperature: -40°C to +55°C
Power Consumption: 22 to 32 V
                    12 W average
                    40 W maximum
Tuning: wideband system
                    auto tuning
Sensor Orientation: 45 +/- 35 degrees off the magnetic field direction

Rate of Reading
0.01 to 1000 samples / second

Output
Analog: 1 channel of magnetic field and
            1 channel of gradient data.
            1, 10 & 100 pT
            1, 100, 100 nT
            1 mT

Digital: serial RS232C with programmable parameters
Visual: alphanumeric LCD
            11 digit magnetic field
            7 digit magnetic gradient

Dimensions & Weights

Console: 483 x 89 x 406mm / 6.6 kg
Sensor: 26.3 cm dia. x 23 cm / 6.0 kg
Electronics: 100 x 50 x 100 mm / 1.0 kg
Cable Lengths: User-specified, 1 - 300m

Standard Components
GSMP-20S3 console, Potassium sensor with cable, GSMP-20S3 software, RS-232 cable and instruction manual. Optional GPS for precise time values. GEM also provides a Radon option for SuperGrad.

GEM SYSTEMS
ADVANCED MAGNETOMETERS