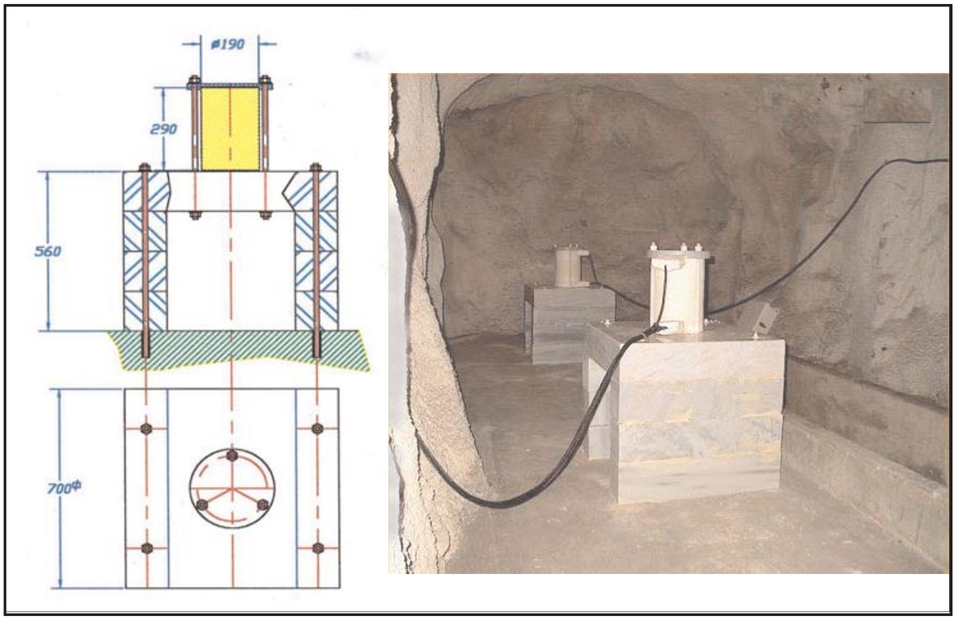
SuperGradiometer

Earthquake Prediction Instrumentation

The SuperGradiometer system is designed for earthquake prediction applications that require the most demanding survey specifications.

Key benefits include:

- **Most sensitive gradiometer available (1 fT/m) for detection of subtle signatures**
- **Most sensitive magnetometer available**
- **Elimination of cultural effects**
- **Elimination of diurnal effects**
- **Minimal 1/f noise (in contrast to electromagnetic methods)**
- **Complementary gradiometer and total field magnetic data for integration with radon data**
- **Standalone or Integrated SuperGrad / Radon System (ISGR) options**
- **Efficient remote control operation / interrogation using RS-232**
- **Flexibility to enable real-time transmission via RS-232 and modem to satellite and phone links**



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.

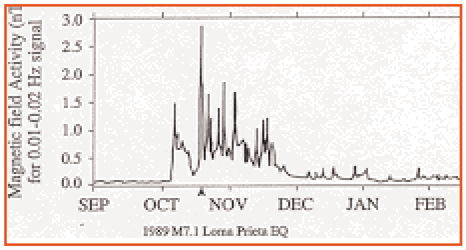
The GSMP-20GS3 was developed with the Russian research group of Dr. E. Alexandrov in response to the United State Geological Survey's (USGS) requirement for an ultra-high sensitivity magnetic gradiometer. It is the highest sensitivity total field measuring device ever developed with a 0.05 pT root-mean-square (rms) sensitivity at a sampling rate of 20 Hz (averaged over a 1 second 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 cultural noise (i.e. from nearby infrastructure), and minimization of 1 / f noise that typically degrades results from other types of measurements (ex. Electromagnetic). Note that f is the frequency of the piezomagnetic signal from the event.

Detectability of Earthquakes by Gradiometers

Assuming that earthquakes create a dipolar magnetic anomaly, we can calculate the detectability of earthquakes of given magnitude. The magnetic induction B of a magnetic moment M is a clearly defined quantity that relates the radius, magnetic field and susceptibility (details are provided in a paper entitled, “Development of a Potassium Super Gradiometer for Earthquake Research and Other (Exploration) 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:

$$\text{Moment} = 1.74 \times 10^{11}\ \text{Am}^2$$

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

Magnitude	Mag Moment Am^2	Detectable Distance [km]				
		Magnetometer 1nT	Magnetometer 0.1nT	Induction coils 25pT	Super Grad 1 fT/m	Super Grad 0.1 fT/m
8	2.2×10^{12}	60	130	205	160	285
7	7×10^{10}	18	39	61.5	67.5	120
6	2.2×10^{9}	6	13	20.5	28.5	50.7
5	7×10^{7}	1.8	3.9	6.15	12	21.3
4	2.2×10^{6}	0.6	1.3	2	5.1	9
3	7×10^{4}				2.1	3.8

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

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

GEM is currently recording data at a site in the middle East 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.

SuperGrad Specifications

Performance

Resolution: 0.001 pT for up to 20 readings per second

Intrinsic Noise Density: 0.05 pT / Hz $^{1/2}$

Absolute Accuracy: 0.2 nT.

Time Base Stability: 0.01 ppm over -40°C to + 55°C

Long Term Stability: Better than 1 pT / day.

Dynamic Range: 10,000 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. No tuning.

Sensor Orientation: 45 +/- 3 5 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 µT.

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

Lamp Assembly: 17 cm x 9 cm dia.

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.

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