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Installation of a High Resolution Potassium Magnetometer in the Coast of Oaxaca, Mexico

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Abstract

In the up-to-date significant investments in earthquake studies and especially in detection of earthquake precursors there is a lot of emotional and in general non-critical measurements of precursors. We are trying to establish some kind of reference conditions for detection of precursors. A brief analysis of the number of measurements and especially Loma Prieta precursor is given. Based on Loma Prieta precursor and in general confirmed by a series of other precursors, a spatial distribution of expected magnetic anomalies for a given magnitude of earthquake was calculated. Different methods of measurement are assessed and a short base gradient method explained. Supersensitive (50 fT) potassium 3 sensor gradiometer is described and some initial field data presented.

1. Introduction and General Overview

Attempts to foresee earthquakes, and to measure or assess precursors goes far back in history and includes such impractical things as unusual behavior of animals etc. Magnetic measurements started more than 100 years ago and reported anomalies of several hundred nT were common (Fig. 1). However, after discovery of proton magnetometer when measurements could be done more accurately, the “anomalies” suddenly decreased close to few nT or even fractions of nT. Obviously, previously reported hundreds of nT anomalies could be assigned to anything but earthquakes. This kind of approach to measurement (“better to measure something than not to measure at all”) finally discredited the method entirely.

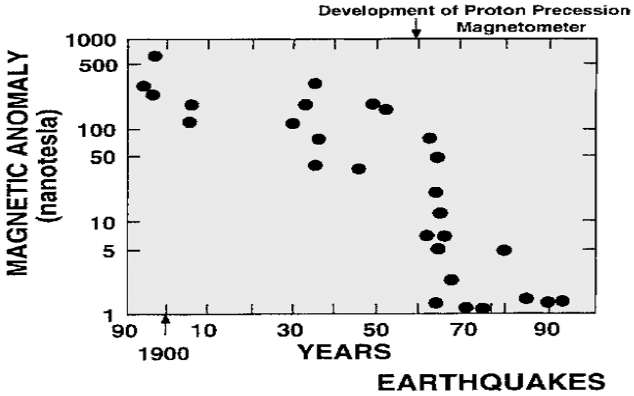

Fig. 1. Reported tectonomagnetic anomalies as a function of time. Sufficient drop of anomaly intensities happened when absolute proton precession magnetometers and noise reduction techniques were introduced (Johnston 1997).

Magnetic precursors to seismic activity can be expected as a result of gradual build up of strain in the rocks (confirmed in the laboratory tests) that induce a temporal change in its magnetic properties, i.e., create small magnetic anomalies. A number of other phenomena, such as (ionized) water flow, or microcracks with charge separation may exist and cause magnetic precursors.

Natural disasters caused by earthquakes can be better mitigated if these emotional/romantic and non-critical approaches were replaced by a rigorous engineering approach. So far there are quite few reported precursors that could be used to establish a reference, a background for detection of precursors for given earthquake magnitude.

Most spectacular Loma Prieta precursor (Ms 7.1 Central California earthquake happened on Oct. 17, 1989, near Loma Prieta), shown in Fig. 2 (Fraser-Smith 1990, disputed by some) offers us a possibility to calculate spatial distribution of magnetic field anomalies due to earthquakes so we can assess what can be expected in future earthquakes.

Loma Prieta 1989 Precursor

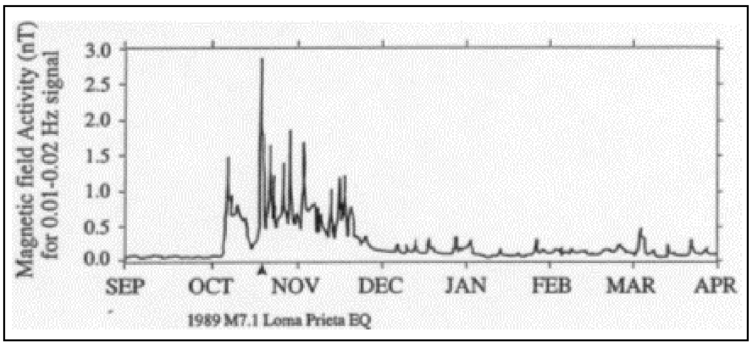

Fig. 2. Loma Prieta (M7.1) → B = 5 nT anomaly at 17 km distance to hypocenter and 1.7×10^{11} Am^2 magnetic moment (Fraser-Smith 1990).

Assuming the “anomaly” is dipolar and knowing geometry of measurement and magnitude of the earthquake we can calculate total fields and gradients produced by the dipole. Also, assuming the anomalies are proportional to earthquake energy we can calculate expected magnetic fields for all earthquake magnitudes. Dipolar fields decrease with a cube of distance, gradients of magnetic field with a fourth potential of distance.

From Table 1 it is evident that smaller magnitude earthquakes (M4 or M5) are virtually undetectable except for immediate vicinity of the hypocenter. Detectable anomalies even for magnitude 6 are situated very close to the hypocenter.

Table 1

Dipolar magnetic fields/gradients as per Loma Prieta

Estimated Magnetic Moment Am^2	Earthquake Magnitude	Magnetic Fields & Gradients Distance from Hypocenter							
		10km	20km	40km	80km	160km	320km	640km	1280km
2.26×10^{14}	9	22.6μT 6.78nT/m	2.82μT 420pT/m	350nT 26.5pT/m	44nT 1.7pT/m	5.5nT 0.1pT/m	0.69nT 6.5fT/m	86pT 0.4fT/m	11pT 25aT/m
7.15×10^{12}	8	714nT 214pT/m	89nT 13.4pT/m	11.2nT 0.84pT/m	1.4nT 52fT/m	0.17nT 3.3fT/m	22pT 0.2fT/m	2.75pT 12.5aT/m	
2.26×10^{11}	7	22.6nT 6.78pT/m	2.82nT 0.42pT/m	0.35nT 26.5fT/m	44pT 1.7fT/m	5.5pT 0.1fT/m	0.69pT 6.5aT/m		
7.15×10^{9}	6	0.714nT 214fT/m	89pT 13.4fT/m	11.2pT 0.84fT/m	1.4pT 52aT/m	0.17pT 3.3aT/m	22fT 0.2aT/m		
2.26×10^{8}	5	22.6pT 6.78fT/m	2.82pT 0.4fT/m	0.35pT 26.5aT/m	44fT 1.7aT/m	5.5fT 0.1aT/m	0.7fT 0.006aT/m		
7.15×10^{6}	4	0.714pT 0.2fT/m	89fT 13aT/m	11fT 0.8aT/m	1.4fT	0.17fT	22aT		

Now it is clear why we have so few precursors detected. Smaller, more common earthquakes may be undetectable, larger are very rare. Few precursors in the past were detected by shear luck only when sensors happened to be very close to epicenter/hypocenter.

For example, according to Table 1 to ensure detectability of say M7 in certain area we would have to have a network of gradiometers sensitive better than 1.7 fT/m spaced at less than 2×80 km. More realistic is 2×40 km = 80 km so the anomaly can be detected with relatively high signal to noise ratio. By the same token, M6 event could only be detected at one half of this distance with good S/N ratio.

On top of the above dipolar limitations, deep anomalies will be further attenuated due to skin-effect caused by conductivity of soil. Practically, measurements should be done at frequencies below 10 mHz to avoid severe attenuation due to skin-effect.

However there is a general fair agreement of reported precursors with the calculated fields according to the Loma Prieta precursor (Table 2).

Table 2

Case histories

Place and Reporter	Magnitudes	Sensor Distance / Sensitivity at Frequency	Signal Reported	Signal as per Loma Prieta
Hector Mines Klemperer et all 1999	7.1	132km / 25 – 50pT/0.01Hz	No signal	14pT without Skin effect 0.3fT/m
San Juan Bautista Karakelian et all 2000	5.1	9.4km / 20pT/0.01Hz	20pT	20pT 6fT/m
Spitak Molchanov et all 1992	6.9	129 / 20pT / 0.1 – 1.0Hz	50 – 200pT	7pT 0.17fT/m
Italy, a swarm Villante et all 1997	< 5.8	65 – 85km / ?	No signal	1.3pT 0.06fT/m
Loma Prieta Park et all 1993	7.1	30km / ? / 10Hz	No signal	No signal; skin effect attention over 1,000 times
GUAM Hayakawa 1996	7.1	88km	0.1nT	47pT without skin effect $\Delta = 2.9$km @ 0.01Hz at sea $2\Delta \rightarrow 6.5$pT/0.17fT/m
GUAM Hayakawa 1999	8.2	88km	Positive Fractal analysis	2.1nT / 71fT/m without skin effect $2\Delta = 7.4$ times attenuation 0.28nT / 9.6fT/m

2. Magnetic Methods of Measurement

Sensitivity of magnetometer/gradiometer must not be compromised by other non-earthquake sources of magnetic anomalies.

Traditionally, magnetic measurements must be done in gradiometric form to avoid daily (diurnal) variations of the magnetic field. Long base differential measurement with the reference magnetometer far away allows for only partial reduction of diurnal influences and final sensitivities are of nT range. Short base allows for better elimination of diurnal and other far-away influences but it requires much more sensitive magnetometers.

One limitation of short base gradiometers is the difference in inclination/declination between the sensor points. This difference will result in reduced diurnal variations invading gradient measurements. The effect was discovered by B. Ginzburg and B. Shirman of Soreq and Survey of Israel, respectively, when analyzing data from the supergradiometer installation in Amram tunnel near Eilat in Israel. The effect can be compensated by addition/subtraction of reduced amplitude of diurnal variations.

Another source of unwanted interference comes from the ionosphere that generates its own gradients at the place of measurement.

3. Supergrad in Mexico

Potassium SuperGradiometer developed by GEM Systems in cooperation with Acad. E. Alexandrov and his group and Dr. A. Green of USGS shows extraordinary sensitivity of 50 fT for one reading per second. This sensitivity opens the door to short base gradiometric measurement in earthquake studies. At 50 m spacing of sensors the gradient sensitivity of this instrument reaches 1 fT/m. From Table 1 one can see this sensitivity to be better (detectability reaches farther) than a fraction of nT sensitivity achieved in long base measurement.

The SuperGradiometer consists of three large potassium sensors operating at a single, very narrow (0.15 nT) potassium valence electron spin resonance spectral line. Sensors are attached to 100 m long cables to avoid magnetic influence of a console. Mutual sensor spacing can be selected from 1-200 m.

The installation location on the Pacific coast in Oaxaca, Mexico, was carefully selected considering several site characteristics that include relatively flat topography away from local villages and large main roads. The selected installation site was surveyed using an Overhauser vertical gradiometer to produce magnetic and gradiometric maps (Figs. 3 and 4). This survey allowed us to select three orthogonal locations for the three sensors in low gradient areas with a baseline of 140 m (NS) and “height” of 70 m (West). Gradients $S_3 - S_2$ and $S_2 - S_1$ are routinely recorded and $S_3 - S_1$ is of course also available as well as all 3 total fields. Directions of magnetic fields at the 3 sensors have been measured as shown on Table 3.

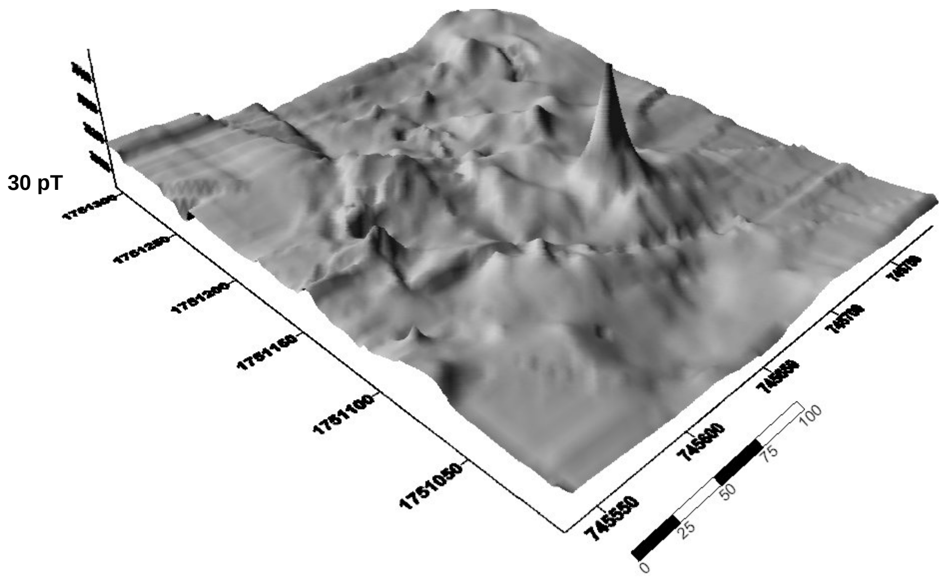

Fig. 3. Site selection: data.

Due to the above differences in magnetic field directions we can expect diurnal changes nominally of some 20 nTpp to show up in the SuperGrad gradients in 10-30 pTpp range. This can be reduced/eliminated by applying both inclination and declination corrections obtained from potassium dIdD. At this point the dIdD has not yet been deployed in El Trapiche Cozoaltepec in Oaxaca, Mexico.

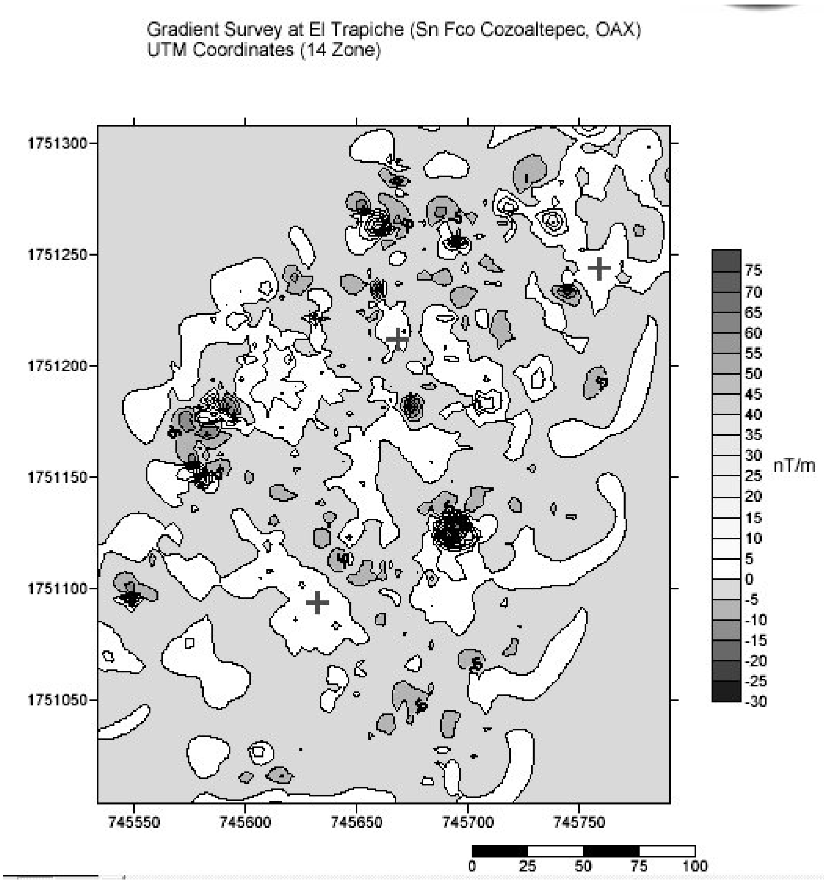

Fig. 4. Site selection: sensor location.

Table 3

Inclinations and declinations at sensor positions

	Inclination	Inclination difference	Declination	Declination difference
Sensor 1:	43.16°		5.11°	
		2.4′		2.4′
Sensor 2:	43.12°		5.05°	
		4.2′		1.2′
Sensor 3:	43.19°		5.27°	

The system is away from power lines so the energy for the instrument is derived from a solar panel array and lead-acid. Data is organized in hourly files in a local computer and transmitted via an Internet satellite link for further archiving and processing at Instituto de Geofisica-UNAM in Mexico City. Several graphs of total field and gradients are shown in Figs. 5, 6 and 7.

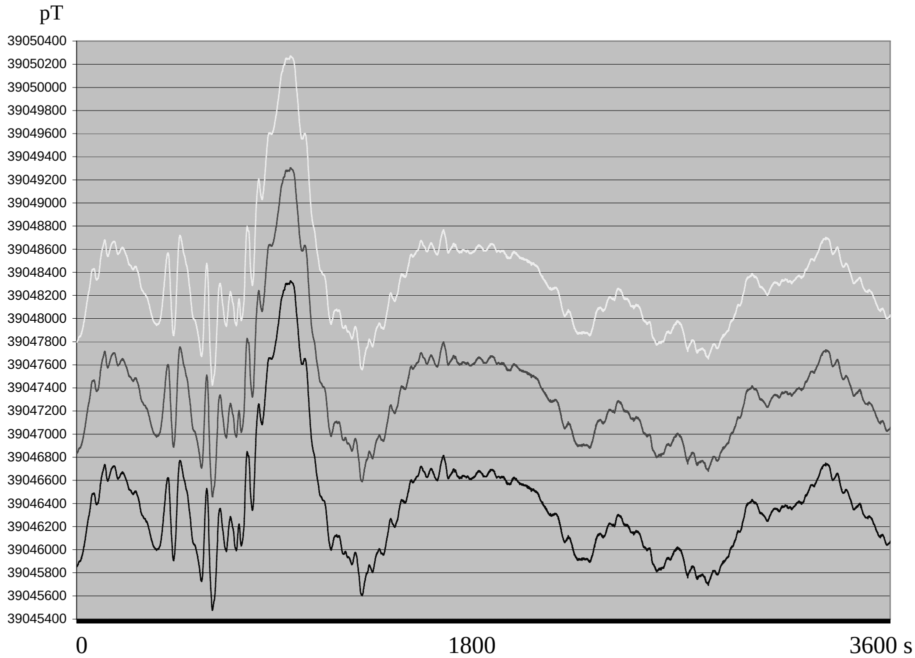

Fig. 5. Sample of SuperGrad total field record.

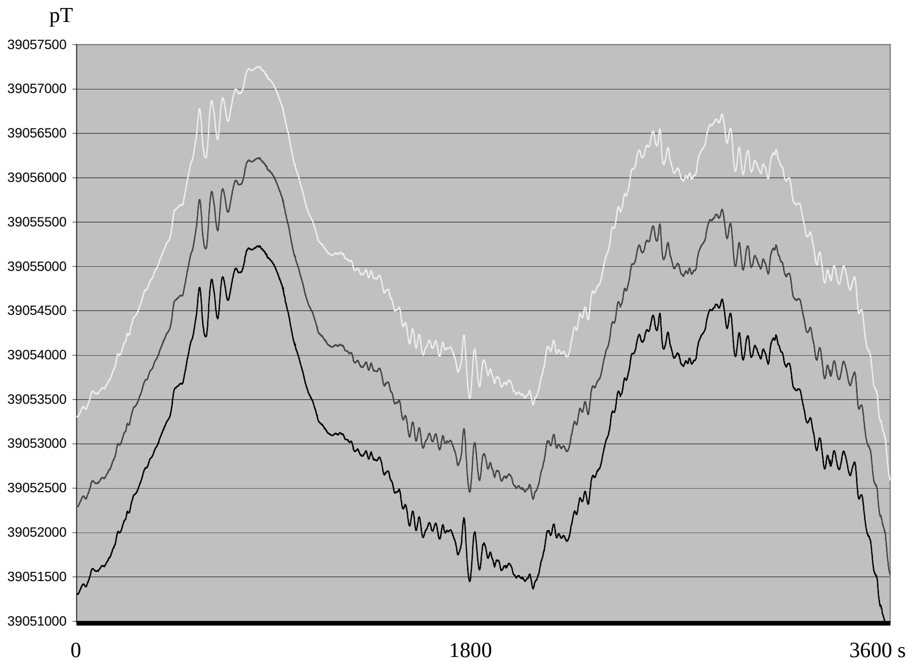

Fig. 6. Sample of SuperGrad total field record.

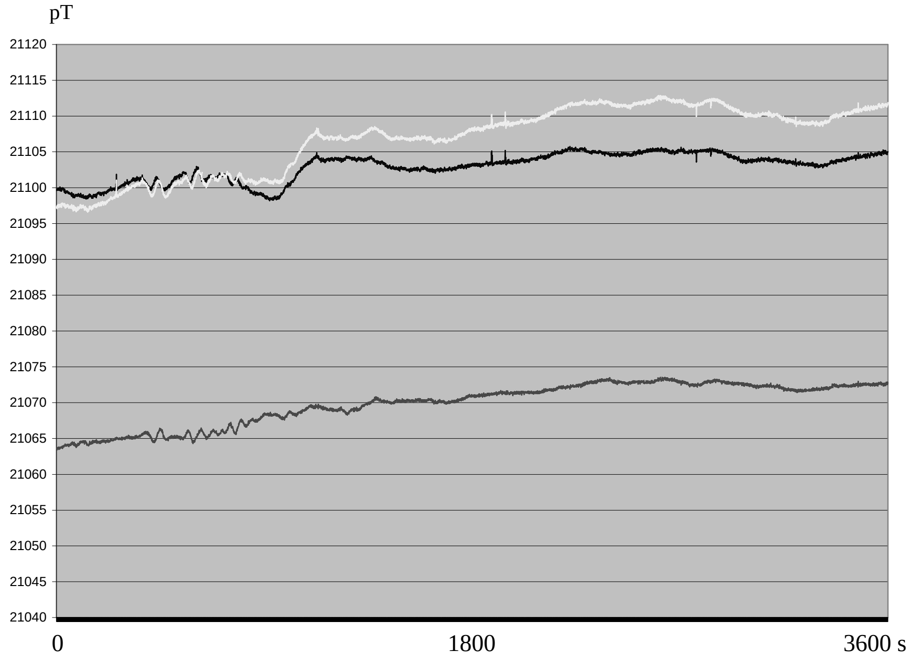

Fig. 7. Sample of SuperGrad total field record.

4. Conclusion

Installation of a SuperGradiometer in the Oaxaca, Mexico segment of the Middle America trench, in close proximity to the seismogenic zone, besides performing as a supersensitive magnetic observatory (once the installation of Potassium dIdD magnetometer is completed) offers an excellent possibility to detect precursors from large earthquakes. The field deployment of a SuperGradiometer under harsh conditions has gained sufficient ruggedness to operate reliably in a tropical environment.

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