GEM Advanced Maqnetometers
52 West Beaver Creek Road West, Suite 14
Richmond Hill, ON Canada L4B 1L9
Ph. 905-764-8008 Fax. 905-764-2949
info@gemsys.ca www.gemsys.ca

Earthquake Detectability

By Ivan Hrvoic, GEM Advanced Magnetometers*

If we assume that earthquakes create dipolar type of magnetic anomaly, we can calculate certain regularity and detectability of earthquakes of given magnitude. Magnetic induction B of a magnetic moment M is defined as:

$$\boldsymbol{B} = \frac{\mu o\, M\sqrt{1 + 3cos^2\alpha}}{\boldsymbol{4}\pi\, \boldsymbol{r}^3}$$

Where μo is magnetic permeability $\mu o = 4\pi\, 10^{-7}\frac{Vs}{Am}$ and α is the angle between radius vector r and dipole directon,

$$1 \leq \sqrt{1 + 3cos^2\alpha} \leq 2$$

We can assume $cos^2 = 0$ for simplicity
Then:

$$\boldsymbol{M} = \frac{4\,\pi\, r^3 B}{\boldsymbol{\mu o}}$$

From reports[1,2] on Loma Prieta M7.1 earthquake (maximum magnetic anomaly B = 2.8nT at 7km distance to epicenter and 17km depth of hypocenter) and San Juan Bautista M5.1 earthquake (20pT anomaly at 2km distance to epicenter and 9km depth of hypocenter) one can calculate the magnetic moments:

For Loma Prieta $B_{max} = 2.8nT$ r = 17km

$$M_{LP} = 1.37\ 10^{11}\ Am^2$$

For San Juan Batista B=20 pT r = 9.22km

$$M_{SJB} = 1.56\ 10^{8}\ Am^2$$

Considering uncertainty of M_{SJB} measurement one can conclude that the moments of earthquake magnitudes follow energy dependence i.e. $10^{1.5}$ for a unit difference of the Richter scale. Nominal magnetic moments and the maximum distances they can be detected by various sensitivity magnetometers and gradiometers are then shown in Table 1.

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Magnitude	Magnetic Moment $[Am^2]$	Detectable Distance [km] Magnetometers, nT		Induction coils	SuperGrad	SuperGrad
		1nT	0.1nT	25pT	1fT/m	0.1fT/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
2	$2.2\ 10^{3}$					

Table 1

Gradients of magnetic moment are:

$$\frac{dB}{dr} = \frac{3\mu o\ M}{4\pi\ r^4}$$

and

$$r = \left[\frac{3\mu o\ M}{4\ \pi\ \frac{dB}{dr}} \right]^{1/4}$$

Potassium Supergradiometer is capable of 1fT/m gradients sensitivity in "fast" (1 second) mode of operation and very likely considerably better than 0.1fT/m for "slow" modes (over minutes or hours).

From Table 1 we can conclude that the magnetometers of 1nT sensitivity can detect only the strongest earthquakes (7 and 8), magnetometers of better sensitivity of 0.1nT and induction coils earthquakes of magnitude 6 or more, and the Supergradiometer in "fast" mode 5 and higher magnitude while "slow" Supergrad can possibly detect magnitude 4 and up.

Of course, the above analysis is very coarse as it does not take into account geometrical factors.

(1) Fraser-Smith, A.C., A. Bernardi, P.R. McGill, M.E. Ladd, R.A. Helliwell, and O.G. Villard, Jr. (1990). ***Low-frequency magnetic measurements near the epicenter of the M_s 7.1 Loma Prieta earthquake***, Geophys. Res. Lett. 17, 1465-1468.

(2) Darcy Karakelian, Simon L. Klemperer, George A. Thompson, Anthony C. Fraser-Smith Department of Geophysics, Stanford University, Stanford, CA 94305-2215. ***Results from electromagnetic monitoring of the Mw 5.1 San Juan Bautista, California earthquake of 12th August, 1998.*** Proc. of the 3rd Conference on Tectonics Problems of the San Andreas Fault System, Eds. G. Bokelmann and R.L. Kovach, Stanford University Publication, Geological Sciences, vol XXI.