GEM SYSTEMS
ADVANCED MAGNETOMETERS

Potassium Magnetics Technology for Earthquake Research

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Our World is Magnetic

Overview

- Introduction to Past and Current Methods
- Detectability of Earthquakes
- Short Base (Gradient) Measurements
- Potassium SuperGradiometer
- Instrumentation
- Summary

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Introduction to Magnetics

- Several decades of investigation
- Based on theory of piezomagnetism and / or electrokinetics
- Possibility of detection is related to gradual pressure build-up prior to earthquakes or “events”

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Monitoring Systems (1)

- Traditional Methods
  - Magnetic sensors (0.1 nT sensitivity)
  - Long base measurements
    - Some startling results
    - No duplication of results
- Recent Work
  - Induction coils
    - Improved sensitivity to 25 pT
    - But, limited bandwidth (0.01 Hz)

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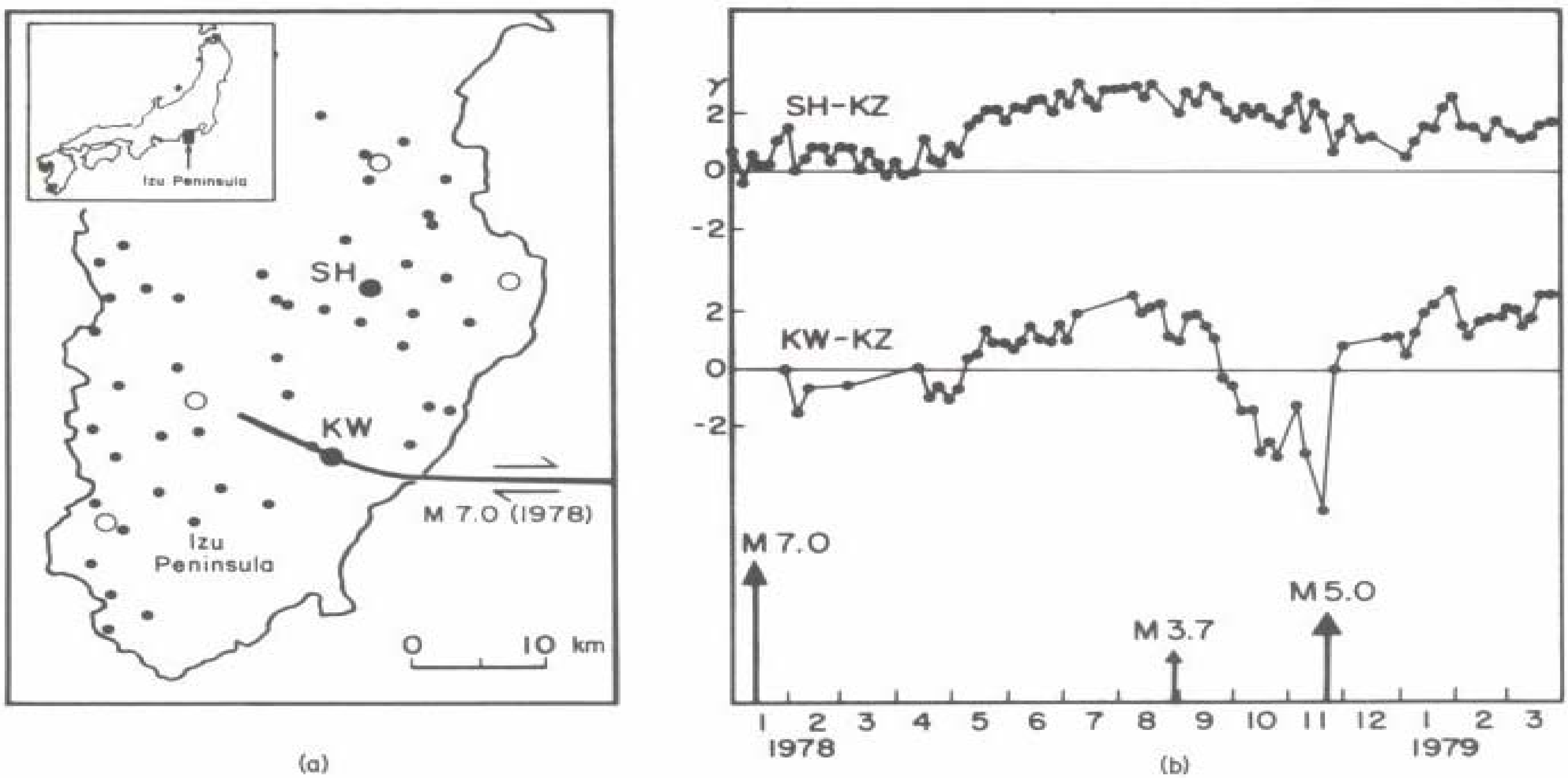
Changes in Magnetic Field



Magnetic field precursor for the M5.0 earthquake at Kawazu, 1978.

From Kiyoo Mogi: Earthquake Prediction, Academic Press, Japan, 1985.

Monitoring Systems (2)

- <u>Induction Coils</u>
  - Detect first derivative of magnetic field
  - Detect all 3 components
  - Skin Effect Problems
    - 50 km @ 0.01 Hz
    - 1.6 km @ 10 Hz

Detectability of Earthquakes

- Assuming earthquakes create dipolar anomalies, can calculate detectability of earthquakes of given magnitude:

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

- Where μo is magnetic permeability, M is magnetic moment, and α is the angle between radius vector, **r**, and dipole direction.
- r is distance from hypocenter to the observation point

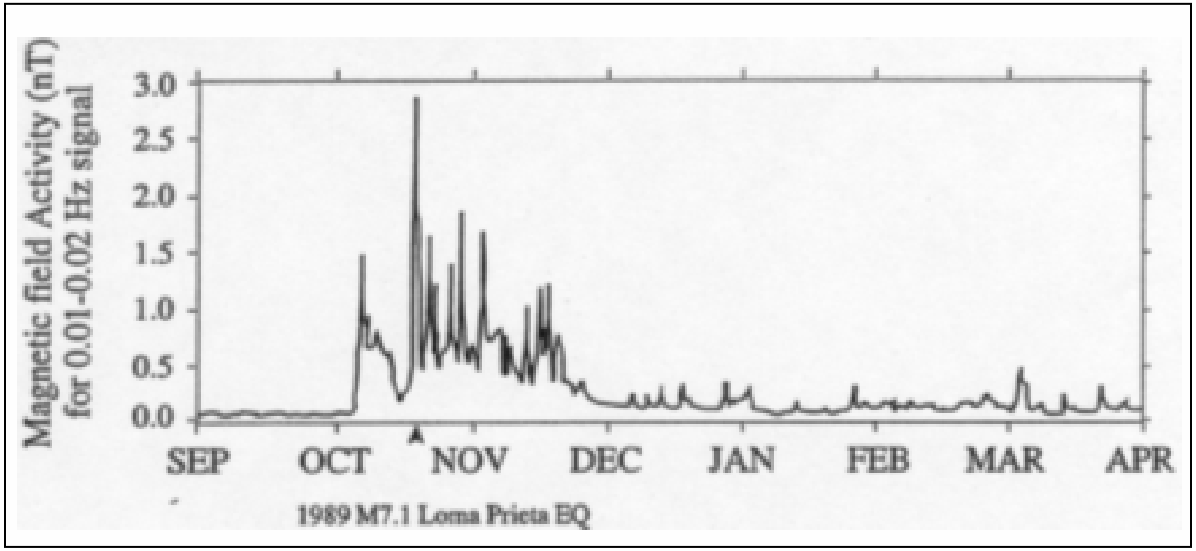
Magnetic Moment (1)

- Assuming $\cos^2 = 0$ for simplicity, the previous equation can be solved for M, Magnetic Moment, as follows:

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

- Results are extended to look at data from the Loma Prieta earthquake of 1989 which clearly shows magnetic precursors.

Magnetic Moment (2)



- Loma Prieta (M7.1) → B=5 nT anomaly at 17 km distance to hypocenter and 1.7 x 10^{11} Am^2 magnetic moment
- San Juan Bautista (M5.1) → 20 pT anomaly at 9.4 km distance to hypocenter and 1.7 x 10^{8} Am^2 magnetic moment
- Spitak (M6.9) → 0.2 nT anomaly at 129 km distance to hypocenter and 4.3 x 10^{12} Am^2 magnetic moment

Field / Grad Distribution

Loma Prieta 1989

Earthquake Magnitude	Estimated Magnetic Moment Am^2	Magnetic Fields & Gradients				
		Distance from Hypocenter				
		50km	100km	200km	400km	
8	3.6×10^{13}	28.8 nT	3.6 nT	0.45 nT	56 pT	Field
		1.728 pT/m	108 fT/m	6.75 fT/m	0.042 fT/m	Gradient
7	1.1×10^{12}	0.91 nT	0.114 nT	14.22 pT	1.77 pT	Field
		54.6 fT/m	3.4 fT/m	0.21 fT/m	0.013 fT/m	Gradient
6	3.6×10^{10}	28.8 pT	3.6 pT	0.45 pT	56 fT	Field
		1.73 fT/m	0.108 fT/m	6.75 aT/m	0.042 aT/m	Gradient
5	1.1×10^{9}	0.91 pT	0.114 pT	14.22 fT	1.77 fT	Field
		0.0546 fT/m	3.4 aT/m	0.21 aT/m	0.013 aT/m	Gradient
4	3.6×10^{7}	28.8 fT	3.6 fT	0.45 fT	56 aT	Field
		1.73 aT/m	0.108 aT/m	0.007 aT/m		Gradient

Potassium SuperGradiometer

- Delivers sensitivity needed for Short Base work
- Background noise is 50 fT for 1 reading / second
- Can increase sensitivity further by placing sensors at specific distances, say 50 to 100m, which gives 1 fT/m gradient sensitivity
  - An order of magnitude better than induction coil sensitivity
  - No skin effect
- Evaluating SuperGrad for long-term drift and elimination of man-made noise

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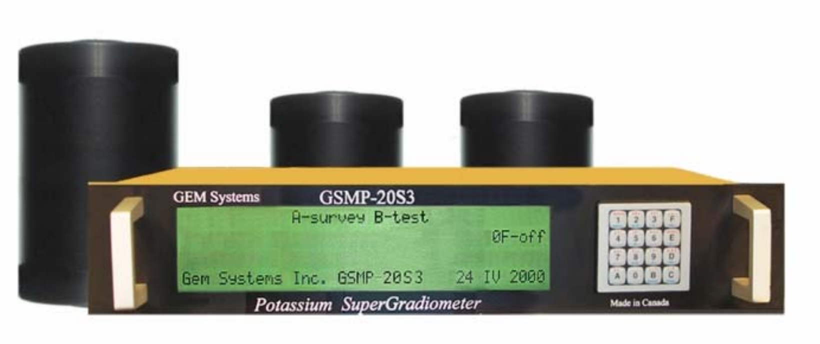
Instrumentation

- Based on optically pumped Potassium method
- Very high sampling (up to 20 samples / second)



- Also designed for minimal heading error, high absolute accuracy and reliability

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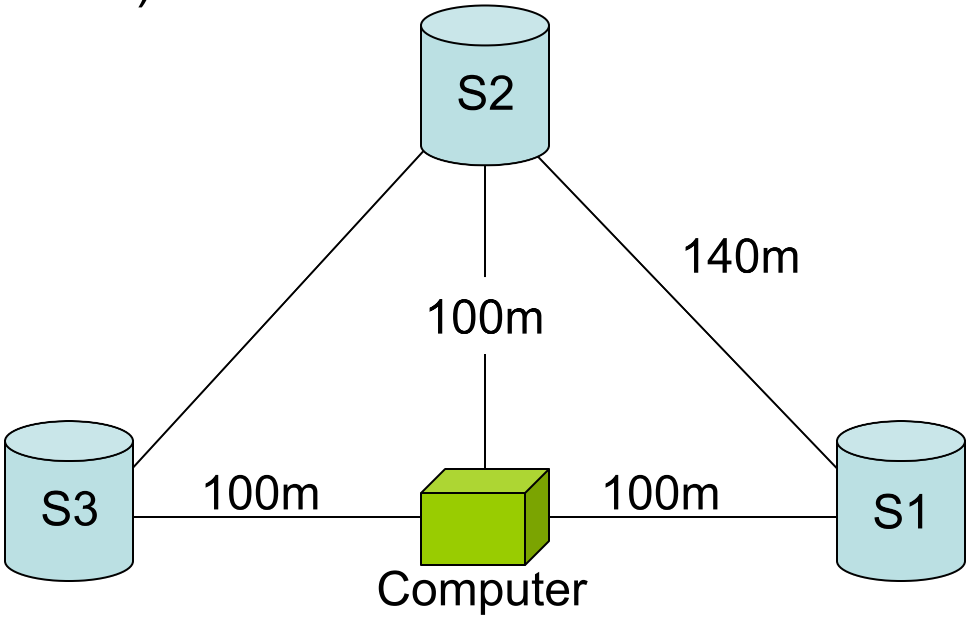
SuperGrad Array

- 3 sensors arranged according to terrain (horizontal or vertical)



- Sensor spacing up to 140m
- Long term integration is promising

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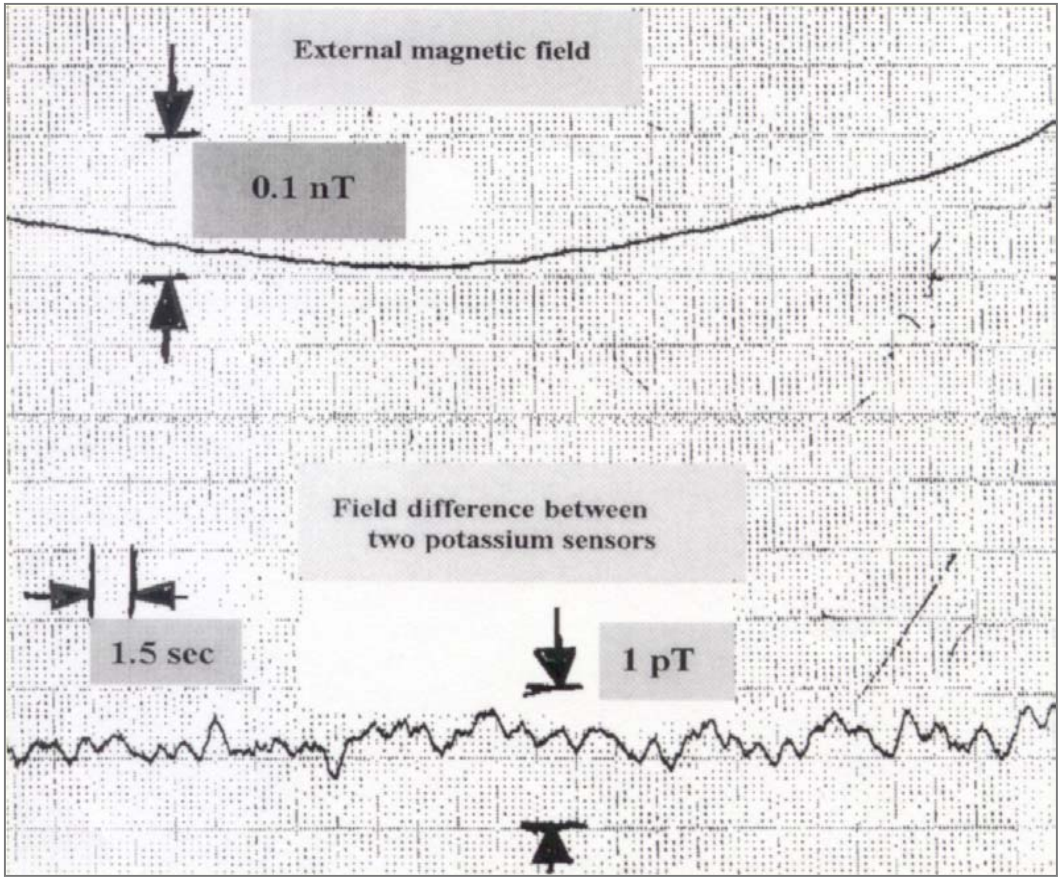
Data (1)



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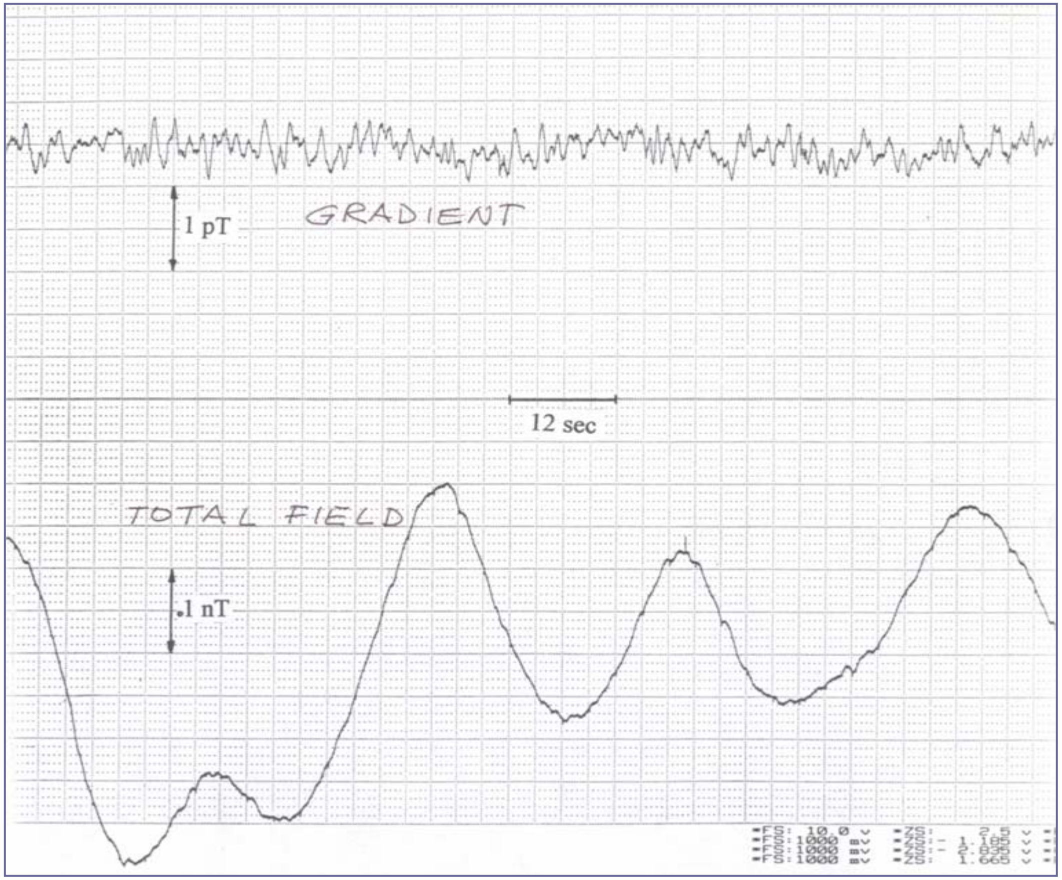
Data (2)



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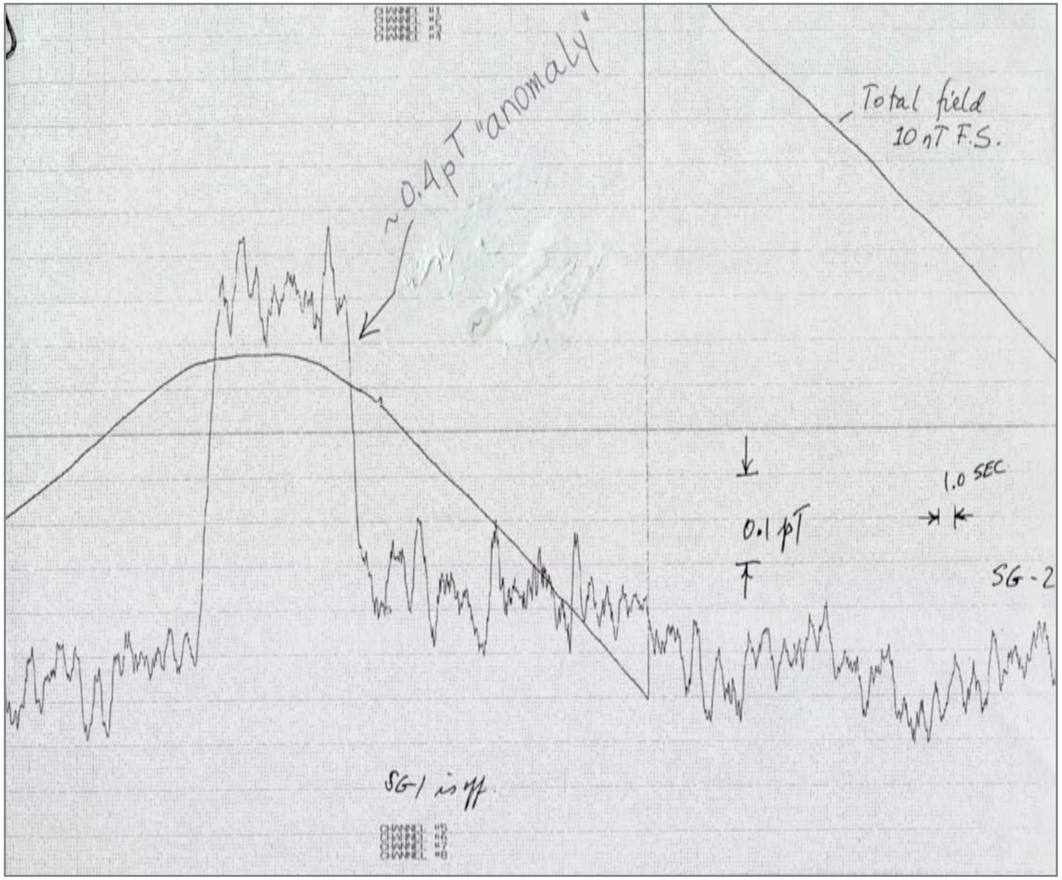
Data (3)



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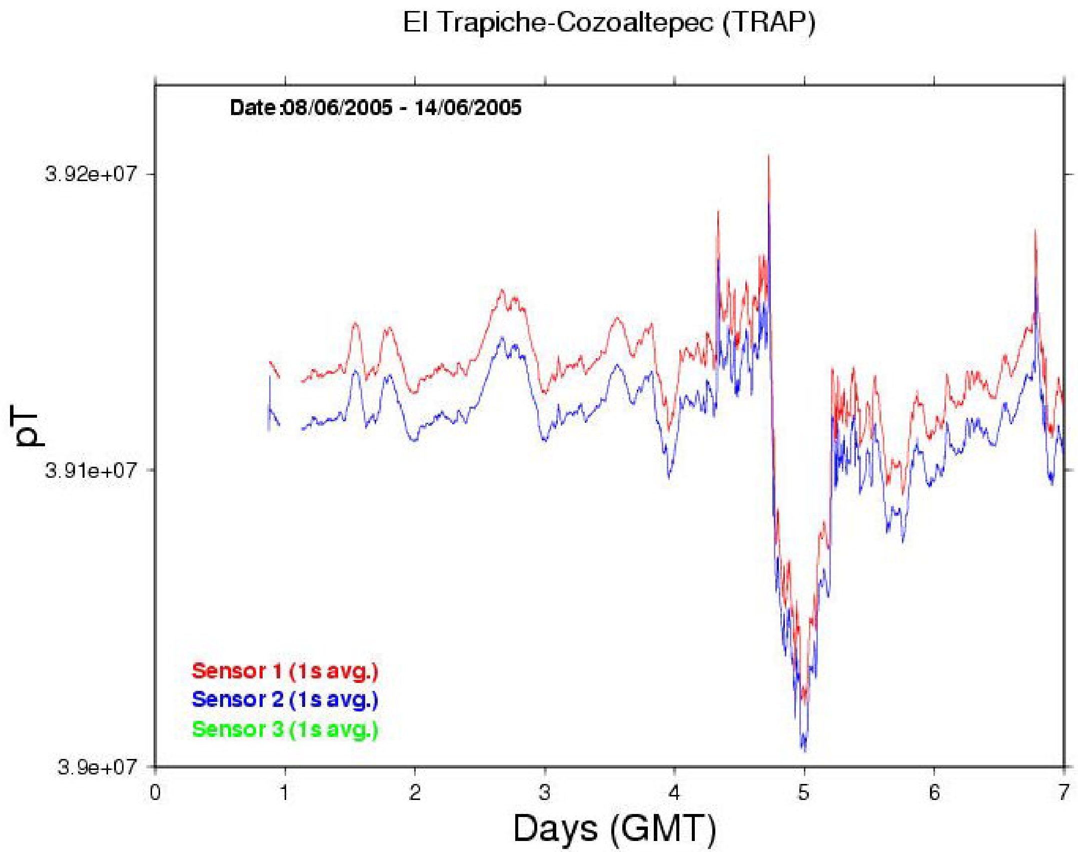
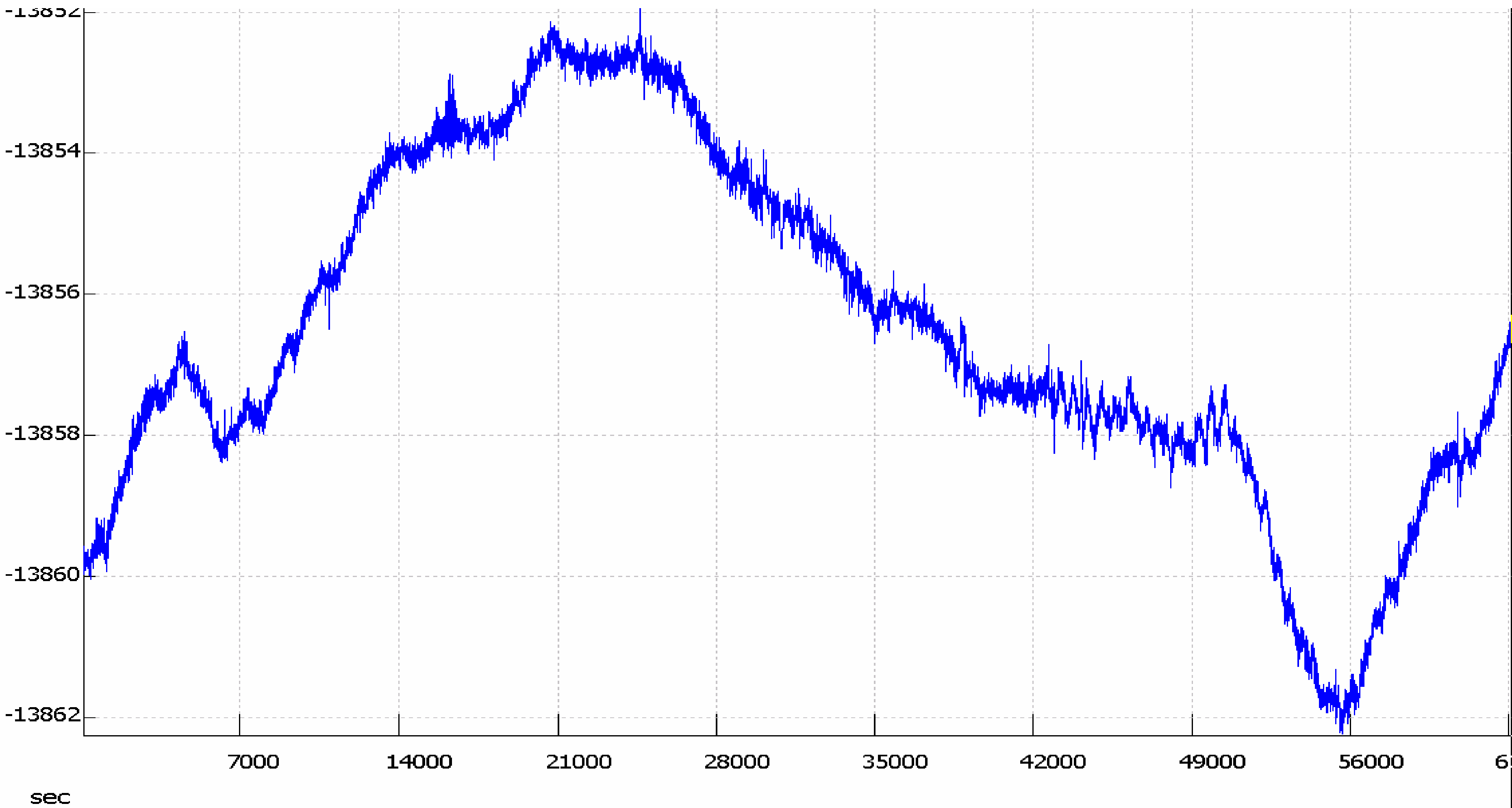
Mexico Data - Magnetics



Mexico Data - Gradient



Conclusion

- Very limited success detecting magnetic precursors:
  - Limited sensitivity of instruments
  - Difficulties in suppressing non-earthquake sources
- Potassium Supergrad opens new possibilities in suppression of non-earthquake sources and improving detection probabilities

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